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TESTING OF SMALL HOUSEHOLD BIOMASS BOILERS FROM THE ASPECT OF WASTE GAS EMISSIONS

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ABSTRACT

The use of biomass for energetic purposes is actual issue from different aspect of views, such as economy, used technologies, combustion specifications, environmental issues, etc. Different types of biomass are available on the market today. During the combustion process in furnaces, these types of biomass behave differently due to their specific physicochemical properties. In this research, used biomass types were wood biomass, soybean straw and chamomile waste from medicinal herbs processing. Pellet combustion was performed in a commercial furnace that was designed to heat the living space by burning wood pellets. Furnace was installed with measurement system for emissions of combustion products. The current law regulation of the Republic of Srpska in the field of environmental protection does not include testing of emissions of combustion products for plants with power less than 100 kW. In this research, the influence of pellet type on concentrations of carbon monoxide and nitrogen oxides was investigated, as well as the volume content of oxygen in the waste gas for plants with power less than 100 kW. Also, it was investigated whether the addition of additives (clay, kaolinite, bentonite), used to improve the melting characteristics of ash, has an effect on reducing the emission of combustion products. The results obtained by measuring the gas emissions are compared with the standard EN 14785 which is related to the emission of carbon monoxide and nitrogen oxides.

During this research, characteristic of ash left after combustion of tested pellets was examined. According to these examinations, it can be pointed out that potential problems can occur when burning these types of pellets in small household heating furnaces.

Keywords: biomass combustion, pellet, gas emission, ash melting

INTRODUCTION

The use of various forms of bioenergy has been on a constant upward trend in recent decades, both in Europe and in other parts of the world. One of the most claimed types of biomass used for energy production is wood pellet. Wood pellet became an important energy source for furnaces and boilers for household heating, industrial boilers and energy plants for the production of electricity and heat, but it also became an important factor in international trade. The role of wood pellets in international trade in bioenergy products was insignificant (10% in 2004), but its share rose to 36% in 2015 (Schipfer, Kranzl, Olsson, & Lamers, 2020). Due to the limited availability of wood as a material for pellet production, as well as high standards for pellets on the European and international market and efforts to meet the growing needs for bioenergy in a sustainable way, were the reasons that increased use of lignocellulosic biomass of poor quality, agricultural and industrial waste, herbaceous plants and more. The great potential of using biomass lies in the fact that it is a renewable energy source and is considered a "CO_2 neutral" fuel with low nitrogen and sulfur content. However, there are some limitations to the use of raw biomass such as low energy density, so biomass is processed to obtain a more convenient form for transport and storage (Chen, et al., 2021). Biomass processing can be based on the thermal treatment of biomass, such as processes of carbonization, hydrothermal carbonization and torrefaction, or more simple technological processes of pelleting and briquetting, which are much simpler and more common in practice (Ljubojević, 2016).

The most important category of pellet consumers are households that use furnaces or boilers on solid fuel with lower thermal power. This category of combustion plants is not covered by the law regulations of the Republic of Srpska in the field of environmental protection and air quality. The conversion of the chemical energy of biomass into thermal energy is always followed by the formation of combustion products, which leave the process in the form of flue gases. Some of them, such as carbon monoxide (CO) and nitrogen oxides (NO_x) are harmful to the environment. Therefore, it is very important to know the specific physicochemical characteristics of different types of biomass pellets and their behavior in the combustion process in boilers for domestic use.

According to the data of the Republic Bureau of Statistics, emissions of photochemically active gases in the Republic of Srpska, such as carbon monoxide and nitrogen oxides, have grown constantly, in the period from 2002 to 2018, which indirectly contributed to the greenhouse effect. In the period, a drop in emissions of 1.29% was recorded for nitrogen oxides, and an increase in emissions of 2.19% for carbon monoxide (Zavod za statistiku Republike Srpske [ZSRS], 2021). However, these measurements did not take into account the emissions from numerous individual domestic fireplaces, whose share in the total emissions of flue gases is not negligible. Therefore, special importance should be given to monitoring and controlling the emission of flue gases and particles from small plants that burn solid fuels such as pellets, and which have less developed purification systems.

The complex chemical structure of the biomass from which the pellet is made has a significant impact on the thermal value of the pellet, its behavior during combustion, as well as the amount and properties of the ash produced. It is known in general that elements that form the biomass ash are Al, Ca, Cl, Fe, K, Mg, P, Na, S, Mn, Si and Ti, and they contribute to various technological and environmental aspects of biomass combustion (Vassilev, 2017; Bostroom, et al., 2012). Some types of biomass, such as agricultural and herbaceous residues, as well as some parts of wood such as bark, have a high content of alkaline oxides and salts. Alkali metals form fewer stable oxides than Ca, Mg, Si and P, so it can be said that these elements are mainly responsible for the formation of ash (Davidsson, Korsgren, Pettersson, & Jäglid, 2002). Their presence in the ash affects unwanted processes, such as lowering the melting temperature, agglomeration, and sintering, which can lead to various problems during combustion (Werther, Saengar, Hartge, Ogada, & Siagi, 2000;

Mlonka-Mędrala, Magdziarz, Gajek, & Nowińska, 2020).

Some of the most interesting and challenging problems are related to the characteristics of sintering and melting ash, which is directly related to operational problems in the combustion process, as well as process efficiency, emission problems, and especially particle emissions. The paper points out the potential problems that can occur during the combustion of wood pellets, soybean straw and chamomile waste in small household heating boilers, due to the complexity of the chemical composition of these types of biomass. The chemical structure of the fuel is responsible for the emission of gases, aerosols and solid pollutants into the environment, as well as the corrosion of the walls of the combustion furnace (Obernberger, Brunner, & Bärnthaler, 2006). It is a known fact that modifying the chemical composition of biomass can affect the way of combustion and the properties of residual ash. Modification of the biomass composition can be performed by chemical pretreatment with acids, which reduces the concentration of alkali metals and alleviates the adhesion of ash and the tendency to form slag (Yu, et al., 2014, Namkung, et al., 2019). The second method is based on the idea of using cheap, safe and available additives, such as different types of clay, which can affect alkali metals in biomass ash during combustion (Wang, Husteda, Skreiberg, Skjervraka, & Grønlia, 2012; Mack, Kuptz, Schön, & Hartmann, 2019). Numerous experimental studies have been conducted on this topic, however, due to the variability of biomass types and combustion conditions, solutions that have proven effective under certain conditions may not be effective for other fuels or other combustion conditions. In addition to the effect on ash melting temperatures, the addition of inorganic additives to the wood mass before pelleting makes the process of pelleting much easier to perform (Holm, Henriksen, Hustad & Sørensen, 2006).

The aim of this study was to examine how the type of biomass, from which the pellet is made, affects the emission of CO and NO_x during combustion in low-power boilers up to 18 kW and whether the use of additives, used for improving the melting characteristics of ash, has the effect of reducing emissions.

MATERIALS AND METHODS

Three types of pellets prepared from different types of biomass, without the addition of additives, were used in pellet combustion experiments:

- Pellet made of wood, with ENplus certificate. The producer is the company ENSA BH - Srbac, and this pellet is available on the market of Bosnia and Herzegovina, as well as the EU market;
- Pellet made of soybean straw (CRO Pellet);
- Pellet made of chamomile waste from medical herbs processing plant *Prirodno bilje* – Banja Luka. Pellet was produced in the company ENSA BH – Srbac for the purposes of these experiments, and it is not available on the market.

Table 1 gives basic data on the types of biomass from which the tested pellets were made.

Table 1 Biomass composition of selected pellet types

Type of pellet	Producer	Biomass specific
Industrial pellet	ENSA BH	spruce 80% (wood pieces with bark), 20% oak
Pellet made of soybean straw	CRO Pellet	soybean straw, dust < 2%
Pellets made of the chamomile waste	ENSA BH	chamomile waste

Locally available additives were used to improve the melting characteristics of the ash:

- Kaolinite,
- Clay for making refractory bricks,
- Natural zeolite (bentonite).

Additives are mixed into the finished pellet in the amount of 1% w/w in relation to the dry matter of the pellet.

Determination of moisture content in pellet samples was performed according to the procedure described in the standard method for determination of moisture in solid biofuels EN ISO 18134. Determination of ash was performed according to the procedure described in the standard method ISO 18122. Measurement of the high heating value of the pellet was performed using an adiabatic calorimeter *Parr*, Model 6200, in accordance with the procedure described in standard EN 14918.

Pellet combustion experiments were performed on the experimental setup shown in Figure 1. The experimental installation consists of:

- A furnace designed for heating households on wood pellets, manufacturer "*Termoflux*" Jajce;
- Flue gas exhaust system, which consists of two exhaust channels and a flue gas fan;
- Flue gas composition measurement system.

According to the manufacturer, the furnace is designed to meet the requirements of EU standards that are relevant to this type of equipment, without specifying parameters related to the environmental characteristics of its operation. The basic characteristics of the furnace are given in Table 2.

Table 2. Characteristics of pellet combustion furnaces

Manufacturer	***Thermoflux***
Model	Interio 20
Dimensions (LxWxH)	650 x 630 x 1080 mm
Weight	214 kg
Thermal power	4 – 18 kW
Fuel consumption	1 – 4 kg/h
Fuel tank capacity	30 kg

Measurements of mass concentrations of oxygen (O_2), carbon monoxide (CO) and nitrogen oxides (NO_x) in flue gases were performed using a *Horiba VA 5000* gas analyzer, with thermocouples placed in positions where the measures of flue gas temperature and temperature inside the furnace were performed. The measuring device consists of two systems: a flue gas sampling system and a system for analyzing the concentration of individual gases. Gas sampling is performed through a joint system, after which the samples are led to measuring cells for the detection of individual gases. The operating principle of measuring cells is in accordance with the standards and methods prescribed for measuring stationary sources emissions:

- EN 14792 – Determination of mass concentration of NO_x – Chemiluminescence method,
- EN 15058 – Determination of mass concentration of CO – Non-dispersive infrared spectrometry (ND-IR) method,
- EN 12039 – Determination of CO, CO_2 and O_2 - Electrochemical cell method.

The duration of each experiment, in stationary conditions, was 10 minutes, for each sample.

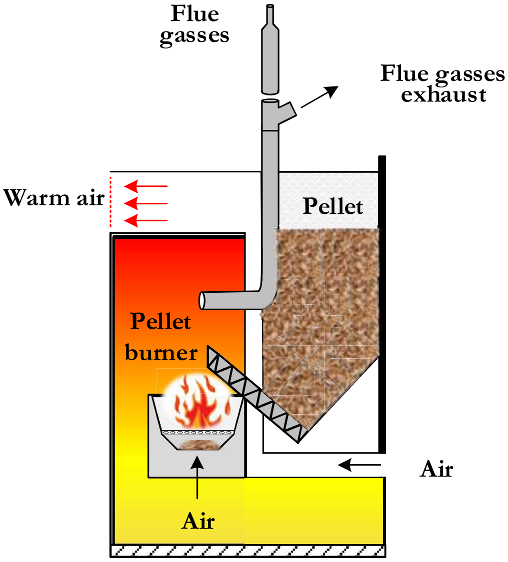

Figure 1. Scheme of experimental setup

RESULTS AND DISCUSSION

The quality of the pellets indisputably affects combustion. Problems that occur in the furnace during the combustion of pellets, especially pellets of poorer quality, do not necessarily occur due to the large amount of ash, but when the melting temperature of the ash is too low. However, the large amount of ash still complicates the problem, in terms of the difficult removal of ash from the furnace, which creates the preconditions for the formation of slag. Therefore, the first step of the research was to determine the percentage of ash produced by burning pellets of different raw material compositions (Table 3).

Table 3. Characteristics of biomass pellets

Type of pellet	Moisture (%)	Ash (%)	HHV (MJ/kg)
Industrial pellet (Producer ENSA B&H)	5.82	1.62	19.19
Pellet made of soya straw	7.71	6.62	19.50
Pellets made of the chamomile waste	10.22	5.58	14.75

By observing the condition of burners and furnaces after the combustion experiment, it can be noticed that small agglomeration effects appeared during wood pellet combustion, as well as sticking of ash in small segments along the edges of the burner surface, which is a consequence of bark content in this wood pellet sample. Combustion of soybean straw pellets and chamomile processing residues, in the same furnace hearth, leaves a much larger amount of ash, which is expected given the high content of inorganic substances in this sample of pellets (Table 3). By prolonging the burning time of pellets made from chamomile processing residue, after only 13 minutes, the furnace hearth was overloaded and the entire combustion process was blocked. Figure 2 illustrates these situations and shows photographs of pellet furnace hearths after 10 minutes of combustion under the conditions described in the experiment, in the case of industrial wood pellets (a), soybean straw pellets (b) and chamomile waste pellets (c).

(a) **(b)** **(c)**

Figure 2. Pellet burner look after 10 minutes of the combustion experiments with wood pellet (a) soya straw pellet (b) and chamomile waste pellet (c).

According to relevant literature data, the use of various forms of waste biomass for energy production is often limited due to problems: ash sticking on the surfaces of combustion plants, corrosion processes on the grate due to high alkalinity of ash and sintering of ash. These problems are due to the presence of numerous inorganic elements in the biomass, which form complex gaseous, liquid and solid compounds during the thermal conversion of fuels. One way to solve these problems is to add additives with a high content of calcium (Ca) and magnesium (Mg), in other words elements that increase the melting temperature of ash. Based on the results of chemical analysis of ash, shown in Table 3, it can be concluded that when burning these types of pellets in small furnaces for household heating, all the previously mentioned problems can occur.

Figure 3 shows the results of measuring the concentration of carbon monoxide in flue gases during the combustion of the tested pellets, with and without additives. Considering the fact that the law regulations in BiH and Republic of Srpska did not define the limit values for carbon monoxide (CO) emissions in the exhaust gases for plants with ~~a~~ thermal power of less than 50 kW, the regulations of the EU member states were used to evaluate the obtained results. The EN 14785 standard defines the energy and environmental characteristics of flue gases from small domestic pellet boilers with a nominal power not exceeding 50 kW. According to the requirement of this standard, the CO emission at the oxygen reference value of 13% v/v, when testing the reduced thermal power, must be below 750 mg/m^3.

From the results of measuring carbon monoxide emissions, whose average values are shown in Figure 3, it is first noticed that there is a large difference in carbon monoxide emissions between the three tested types of pellets, without the addition of additives and that none meets the prescribed value of 750 mg/m^3. In the case of wood pellets, the use of additives reduced the emission of carbon monoxide, by 50% when using clay and 44% when using kaolinite, which reduced the emission below the prescribed value. In the case of pellets from chamomile processing waste, all three types of additives led to a reduction in carbon monoxide emissions by approximately 50%, but the measured values are still above the prescribed ones. In the case of soybean straw pellets, mixing all three types of additives led to an increase in carbon monoxide emissions by 14.6% for bentonite and over 70% for clay and kaolinite.

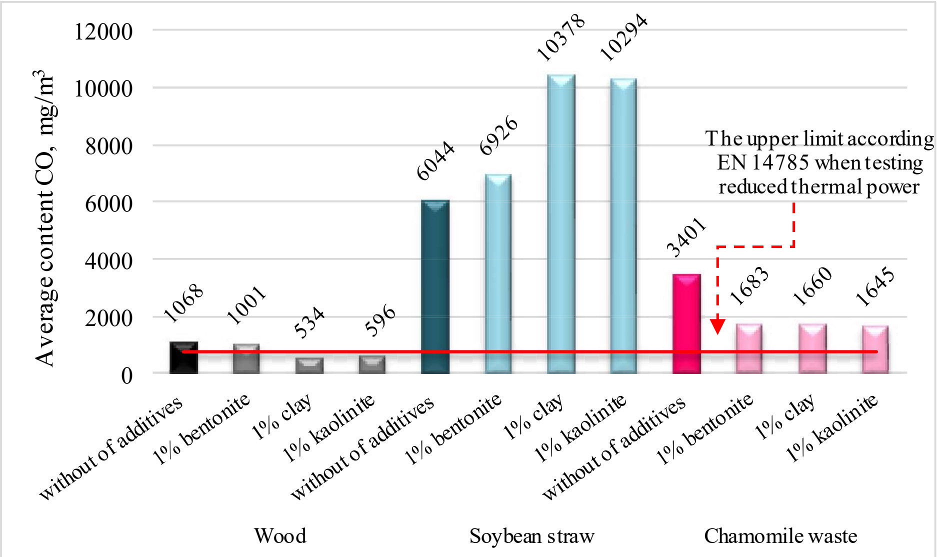

Figure 3. Average values of CO concentration in flue gases reduced to the reference oxygen content

Figure 4 shows the results of measuring the concentration of nitrogen oxides (NO_x) in the flue gases during the combustion of the tested pellets with and without additives. Considering the fact that the law regulations in BiH and Republika Srpska did not define the limit values of nitrogen oxide emissions from solid fuel combustion plants with a power of less than 100 kW, EU regulations were used to evaluate the obtained results. According to the EU directive from 2020, *EkoDesigne Directive 2015/1185* and *2015/1189*, from January 1, 2022. NO_x emissions from furnaces and boilers for local space heating, with thermal power of 50 kW or less, which burn biomass, shall not exceed 200 mg/m^3 at an oxygen reference value of 13% v/v (Ozgen, Cernuschi & Caserini, 2021).

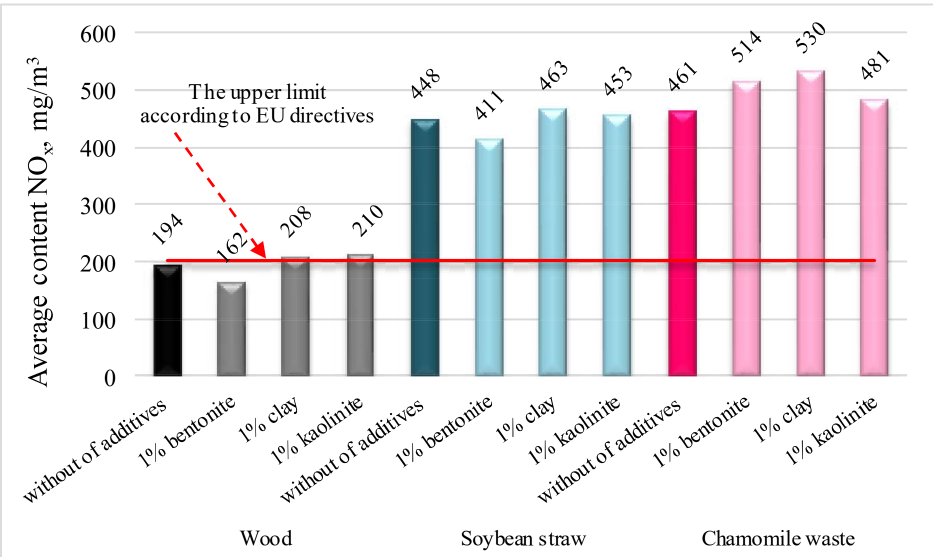

Figure 4. Average values of NOx concentration in flue gases reduced to the reference oxygen content

Based on the presented results, it can be concluded that the type of biomass from which the pellet is made has an impact on NO_x emissions during combustion. The lowest emission of nitrogen oxides was measured during the combustion of wood pellets, which is an expected result considering that the nitrogen content in agricultural biomass is higher than in wood. It is important to mention that the temperature in the combustion chamber was constantly measured during the combustion experiments. The temperature never exceeded 550 °C, so it can be said with certainty that nitrogen oxides in flue gases are formed by the oxidation of nitrogen compounds from biomass. The average value of NO_x concentration in flue gases during wood pellet combustion is slightly below the limit value of 200 mg/m^3, which is prescribed by Directives 2015/1185 and 2015/1189. The addition of 1% w/w bentonite reduced NO_x emissions by approximately 16%, while the emissions after other additives additions were approximately the same as for pure wood pellets. The mixing of additives in soybean straw pellets and chamomile processing waste mainly led to an increase in NO_x emissions in flue gases in the amount of 1.11% to 14.96%. Only the combination of soybean straw pellet and bentonite resulted in a small emission reduction, about 8%. All combinations of agricultural pellets and additives exceeded twice the mentioned limit value of 200 mg/m^3.

CONCLUSION

The obtained results show that the values of emissions of carbon monoxide and nitrogen oxides, for the type of furnace for low power households, meet the regulations of the European Union, if they burn wood pellets, for which the furnace is designed. While the emissions of these gases, when burning biomass containing a higher percentage of nitrogen, such as soybean straw pellets or chamomile processing waste, are far above the prescribed values. Certain additives to improve the melting characteristics of ash can reduce the emission of photochemically active gases, carbon monoxide and nitrogen oxides, which indirectly contribute to the greenhouse effect. All types of additives led to a reduction in carbon monoxide emissions during the combustion of wood pellets and chamomile waste pellets, while soybean straw pellets increased their emissions. Nitrogen oxide emission values, after the addition of anti-sintering ash additives, did not change significantly in wood pellets compared to the combustion of pure wood pellets, and in pellets from agricultural residues they increased mainly. The results of these researches show that for each pellet, additive and firebox it is necessary to perform additional, more detailed research, especially for pellets from agricultural biomass, which have so far been less used and researched than wood pellets.

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