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Combustion of briquettes from oversize fraction of compost from wood waste and other biomass residues

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Abstract. This article aims to determine experimentally the energy potential of samples from oversize compost fraction formed into briquettes. Theoretical combustion characteristics of the briquettes are determined and are compared with a reference fuel. Elemental analysis and stoichiometric calculations were performed for the samples. Classical grate combustion device with manual fuel supply was chosen for combustion tests. Flue gas temperature and emission parameters, such as the emission levels of carbon monoxide, carbon dioxide and nitrogen oxides, were monitored by a multi-purpose flue gas analyzer Madur GA-60. Dependence of these parameters on air input was followed.

Elemental analyses and stoichiometric calculations of individual samples indicate favourable properties of the energy compost for further energy utilisation, namely the gross calorific value of 16.42 MJ kg^{-1}. Excess air was causing high losses through heat of the flue gas during the experiments on combustion device. This fact occurred in a situation when the temperature of flue gas leaving the chimney reached high levels. The excess air coefficient also significantly influenced emissions of carbon dioxide and monoxide and nitrogen oxides in the flue gas. The trends are analysed statistically and are expressed by regression equations. The results can serve in practice for optimization of combustion processes in grate boilers with manual feed of the fuel.

Key words: biomass, combustion device, calorific value, combustion gases, heat loss.

INTRODUCTION

Interest in the production of alternative fuels from compost has increased and not only due to the volatility of oil prices in the market. Current composting technologies enable simultaneous production of quality compost as well as a product for energetic use (Winkler et al., 2007). The actual energy utilization of compost depends on the amount of combustibles. Most important is the content of carbon in the final compost, which is dependent on the composition of the original mixture and the composting process itself which is evident from studies of Mohee et al. (2015).

Oversize fraction of the composti consists mainly of non-compostable wood material that can be represented by a wide range of wood biomass (Skanderová et al., 2015). Characteristics of wood biomass are described by the author Brožek (2015), who evaluated quality of briquettes from wood biomass. Moisture and mineral composition in the final compost affect not only the energetic value, but also the mechanical properties of pressed fuel from the compost as shown in the study Zafari & Kianmehr

(2014). Therefore it is also important to focus on the optimization of the composting process to obtaine quality alternative fuel (Oh et al., 2013).

The increasing demands for processing of biodegradable by-products, not only from agriculture, leads to expansion of new utilization options for these products. One of these options is the energy use of composts (Kranert et al., 2010, Skanderová et al., 2015). Therefore, the aim is the experimental determination of the energy potential of samples from oversize compost fracton (composting in heaps) pressed into briquettes (briquetting press BrikStar 150), and also the determination of theoretical combustion characteristics in comparison with conventional fuel: wood logs. Elemental analysis and stoichiometric calculations are determined for these materials (semiautomatic calorimeter LECO AC-600, elemental analyzer CHN628 + S and analyzer LECO TGA-701). A classical grate combustion device with manual fuel supply was chosen for combustion tests (stove CALOR CZ). Heat and emission parameters are monitored by multi-purpose combustion analyzer (Madur GA-60), such as the flue gas temperature and the emission levels of carbon monoxide, carbon dioxide and nitrogen oxides depending on the amount of supplied combustion air.

MATERIALS AND METHODS

To fulfill the objectives of this research work oversize fraction from classical composting technology in piles without forced aeration was sampled. Oversize components increase the volume of compost, prolong the period of maturation and reduce market sales so an alternative use for them is beneficial. The original compost was made by composting of forestry waste, sawdust, shavings, cuttings, wood, veneers, biodegradable waste from paper, cardboard and wood and biodegradable waste from gardens and parks. Oversize fraction left after screening of this compost through a sieve with mesh size of 40 mm was used. It contained a higher percentage of wood material with the ratio of wood components to other components in samples being on average 85:15 by weight.

Subsequently the samples were pressed into the form of briquettes by a briquetting press BrikStar 150 with a hydraulic unit. This processing eliminates the need for finer crushing of the various components. Density of the briquettes reaches 1,100 kg m^{-3} at the operating pressure to 18 MPa and the operating temperature of 60 °C. Briquettes have a cylindrical shape with a diameter of 65 mm and length 50 mm. For comparison of the measurement results a reference standard fuel was chosen. It was a pure spruce wood in the form of logs.

Briquettes and logs were analyzed for elemental composition. Carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) were analyzed in a laboratory elemental analyzer LECO CHN628 + S. The detection method for carbon and hydrogen is non-dispersive infrared absorption, for nitrogen thermal conductivity and for sulfur infrared absorption. Accuracy range is from 0.01 mg to 0.05 mg. Non-combustible substances in fuel, i.e. the ash content, total water content and volatile matter were determined in a thermogravimetric analyzer LECO TGA-701 with an accuracy of ± 0.02%. Calorific values of examined fuel samples were determined by measuring in a semi-automatic calorimeter LECO AC-600 according to DIN 14918 (2010). Net calorific value was calculated. Results of the elemental analysis of individual samples were used for the calculations.

Subsequently stoichiometric analysis was done for individual samples in which real molar volumes of gas were used to determine the theoretical dependences of carbon monoxide CO and carbon dioxide CO_2 emission concentration on excess air coefficient.

The theoretical amount of emission concentrations of CO (m^3 kg^{-1}) is based on the equation:

$$CO = a \cdot \frac{22.37}{12.01} \cdot C \tag{1}$$

where: a is the proportion of carbon which burns to CO (-); C – the relative amount of carbon in the sample (% wt.).

The theoretical amount of emission concentrations of CO_2 (m^3 kg^{-1}) is based on the equation:

$$CO_2 = \frac{22.27}{12.01} \cdot C + 0.0003 \cdot L \tag{2}$$

where the theoretical amount of dry air L (m^3 kg^{-1}) is determined from the equation:

$$L = O_{\min} \cdot \frac{100}{21} \cdot n \tag{3}$$

where n is the excess air coefficient (-).

The theoretical amount of oxygen O_{min} (m^3 kg^{-1}) is based on the equation:

$$O_{\min} = \frac{22.39}{12.01} \cdot C + \frac{22.39}{4.032} \cdot H + \frac{22.39}{32.06} \cdot S - \frac{22.39}{31.99} \cdot O \tag{4}$$

where C, H, S, and O are contents of carbon, hydrogen, sulfur and oxygen in the fuel sample (% wt.).

The experimental measurements were carried out with a hot air combustion device CALOR CZ with grate fireplace and manual fuel feeding. Nominal thermal parameters of the combustion device were nominal power of 12 kW, controllable output 6–12 kW and fuel consumption 1.1 to 3.6 kg h^{-1}.

The fuel samples were burned at the nominal thermal parameters of the combustion device, where constant fuel supply was maintained and combustion air supply was modified. Each sample was burnt for six hours. Emission concentration measurement was performed by a multi-purpose flue gas analyzer Madur GA-60. The values of ambient temperature, exhaust temperature and the chemical composition of gases (O_2, CO, SO_2, NO, NO_2) were measured. Concentrations were measured in ppm and converted to $mg.m^{-3}$. Recording time of each measurement was set to one minute. The measuring device was calibrated before each measurement. Emission concentrations of dry flue gas were converted from ppm concentrations to normal conditions, to $mg.m^{-3}$ and to reference oxygen content in the flue gas of 13%.

Subsequently the results of measurements were processed by statistical regression analysis for expressing the mathematical relationship between carbon monoxide and dioxide, flue gas temperature and the total of nitrogen oxides against the excess air coefficient.

The equation of excess air coefficient (*n*):

$$n = 1 + \left(\frac{CO_{2,\max}}{CO_2} - 1 \right) \cdot \frac{V_{sp,\min}}{L_{\min}} \tag{5}$$

where: $CO_{2,max}$ – theoretical volumetric concentration of carbon dioxide in dry flue gases (%); CO_2– real (measured) volumetric concentration of carbon dioxide in dry flue gases (%); $V_{sp,min}$– theoretical mass amount of dry flue gas (m^3 kg^{-1}); L_{min}– theoretical amount of air for complete combustion (m^3 kg^{-1}).

RESULTS AND DISCUSSION

The resulting values of the elemental analysis of original samples shown in Table 1 indicate that the most decisive parameter for energetic utilization of selected samples of compost briquettes and spruce logs is the net calorific value, which depends on water and ash contents in the fuel (Ruzbarsky et al., 2014).

Table 1. Elemental analysis of samples

Sample / Average values	Water Content (% wt.)	Ash (% wt.)	Gross Calorific Value (MJ kg^{-1})	Net Calorific Value (MJ kg^{-1})	Carbon C (% wt.)	Hydrogen H (% wt.)	Nitrogen N (% wt.)	Sulphur S (% wt.)	Oxygen O (% wt.)
	W	*A*	Q_s	Q_i	*C*	*H*	*N*	*S*	*O*
Briquettes from compost	**7.87**	**11.30**	16.42	**15.23**	44.88	4.57	1.39	0.00	**29.97**
Reference standard fuel – wood logs	**6.60**	**2.23**	18,95	**17.48**	47.19	5.98	0,12	0.02	**37.40**

A positive factor is the low water content in the samples because moisture affects behaviour during combustion process and flue gas volume produced per unit of energy (Malaťák & Bradna, 2014). The results of elemental analysis show several times higher content of ash in the samples of compost briquettes in comparison with woody biomass. Wood logs were analysed together with bark, which forms a small percentage of wood matter. That is the reason why the determined ash content in reached value of 2.23% wt. DM rather than usual ash content of wood around 1% wt. DM. High content of ash significantly reduces the calorific value of briquette samples and consequently affects both the selection and the adjustment of combustion device. This fact is confirmed by Johansson et al. (2004). Other parameters which directly influence the combustion process are the amount of oxygen in the fuel and the amount of volatile matter. Spruce logs provided higher percentage of oxygen in the fuel and 77.29% wt. amount of volatile matter. Volatile matter in briquettes from compost is 67.34% wt. Determination of the briquettes properties and its comparison to chosen standard fuel in the form of wood logs is very important for its application as additional heating source. This type of fuel is still applying as additional heating source for residential as well as commercial premises.

The resulting trends of combustion experiments are compared with theoretical values and shown in Figs 1–4.

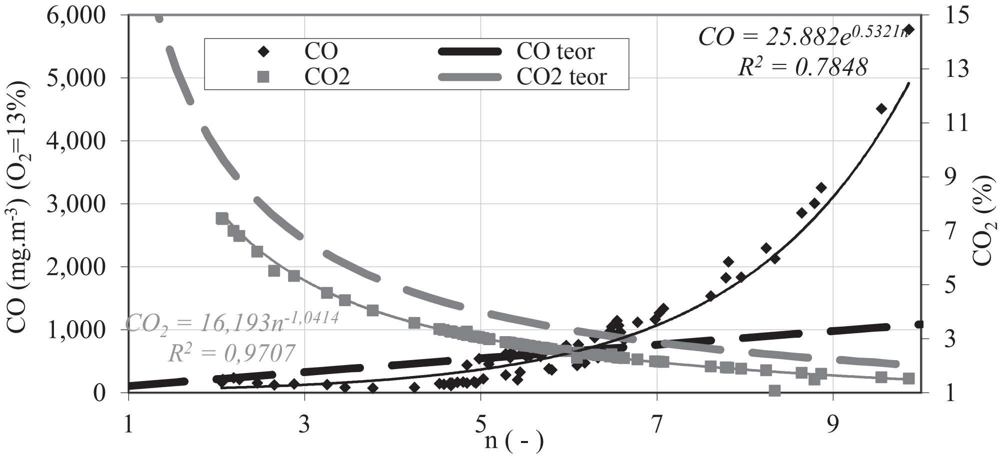

Figure 1. Theoretical and real dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of briquettes from compost.

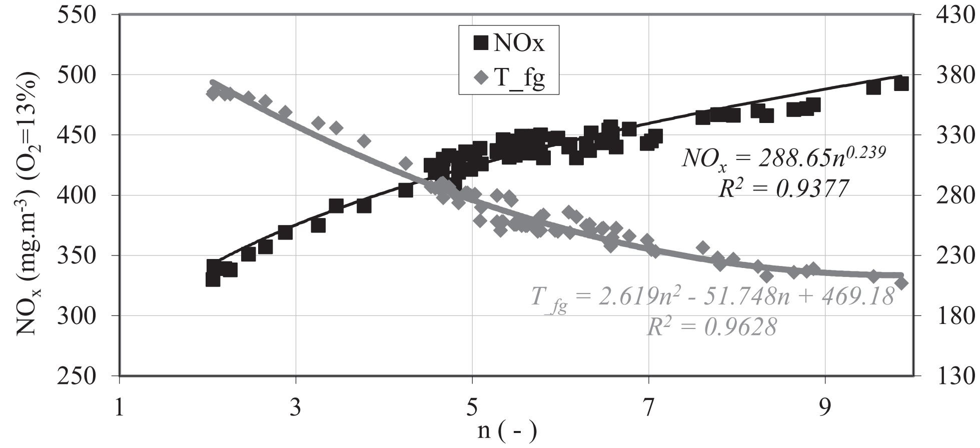

Figure 2. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of briquettes from compost.

The trends of the carbon dioxide emission concentrations correspond well to the theoretical ones. Emission concentrations of carbon dioxide decrease with increasing amounts of excess air coefficient in a power law fashion. The measured values of carbon monoxide grow exponentially with increasing excess air coefficient. While theoretically linear dependence can be derived this does not correspond to the actual values at higher excess air coefficient values.

Flue gas temperature and nitrogen oxides show similar trends against excess air coefficient during combustion of samples. With increasing excess air coefficient dampening of combustion processes occurs and also combustion temperatures is reduced. At the same time there is a perceptible increase in nitrogen oxides emission concentration with increasing excess air.

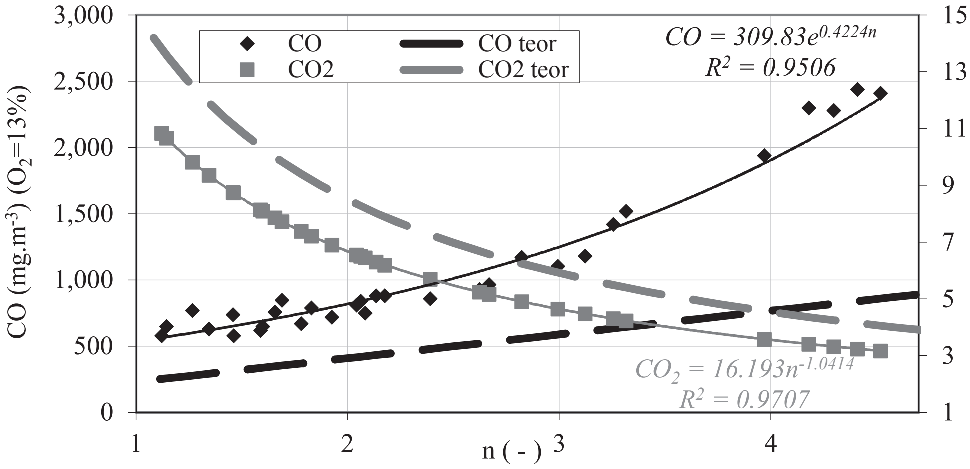

Figure 3. Theoretical and real dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of spruce logs.

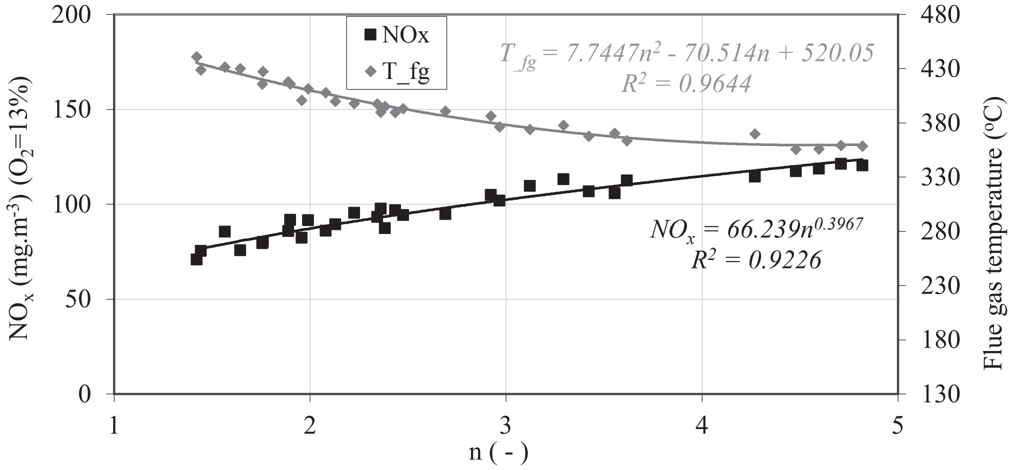

Figure 4. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of spruce logs.

The resulting values of emission measurements showed high concentrations of carbon monoxide *CO* and nitrogen oxides *NOx* in the areas of high excess air coefficient *n*. As shown in a research work of Fiedler & Persson (2009), the combustion process is the most efficient at nominal parameters. Any uncontrolled change in the flow of combustion material and combustion air leads to high emissions of carbon monoxide and nitrogen oxides, and reduces the combustion temperature. Much lower emission concentrations in flue gas were measured for the reference fuel, but also only, a small range of excess air coefficient has been achieved.

The quality (efficiency) of combustion process (Johansson et al., 2003) can be inferred from the content of CO_2 in the flue gas. If excess air coefficient is low (complete combustion) and the highest possible concentration of CO_2 is achieved, the loss caused by the flue gas is then minimal (at otherwise the same temperature of flue gas). For each solid fuel, there is a maximum achievable stoichiometric proportion of carbon dioxide CO_2 in the flue gas, which is determined by the elemental composition of combustible in the fuel. This value is unattainable within the experimental measurements.

Major impact on the overall efficiency of the combustion device has the flue gas temperature. Both samples achieved high flue gas temperatures during measurements. High flue gas temperature was measured with the reference fuel from spruce logs during the whole time of combustion. This resulted in very high losses through heat of combustion device. The same results were achieved in the work of the Oh et al. (2013). Rossi et al. (2015), Kranet et al. (2010) etc. recommend energy use of compost and by-products from composting technology through combustion at medium and large combustion plants. Despite claims by these authors, who point to higher emission levels primarily in combustion of energy compost pellets in small combustion plants, there is a lot of research outputs looking for new construction of combustion devices for these alternative fuels, eg. combustion installations with a rotary burner. The results of the experimental measurements published in this article refer to energy utilization of this type of alternative fuel in small combustion devices with manual fuel supply, which are still currently used.

CONCLUSIONS

Elemental analyses of the compost briquette samples indicate optimal characteristics of oversize compost fraction for its energy utilization. Above all, it was the moisture content of the compost briquettes (7.87% wt.) and the value of gross calorific value, which averaged at 16.42 MJ kg^{-1}. On the other hand the high percentage of ash content (11.30% wt.) in the samples causes not only rapid clogging of the combustion device, but also reduces the rate of burning fuel. Slower speed of burning is often perceived by users as a positive element in the comfort way of using briquettes as a supplementary source of heat.

During combustion of samples excess air caused high losses through heat of the flue gas mainly in spruce logs, where the temperature of the flue gases, leaving to chimney, reached high values at low excess air. The coefficient of excess air also significantly affected the emission levels of carbon dioxide, carbon monoxide and nitrogen oxides in the flue gas. The most problematic part of flue gas is carbon monoxide, which reached high concentrations at higher excess air coefficient.

The concentration of nitrogen oxides emissions increased with the coefficient of excess air and reached high values during combustion of compost briquettes in contrast to wood logs combustion. These trends were analysed statistically and expressed by regression equations, which in practice can be used to optimize the combustion process in small devices with manual fuel supply. The measurement results provided additional suggestions for optimum energy use of material as an oversize compost fraction, which might not be suitable as a fertilizer for various reasons mentioned above. The efficiency of energy recovery is the aim of further research.

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