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Energy use of compost pellets for small combustion plants

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Abstract. The purpose of this paper is to explore the thermal emission characteristics of alternative fuels gained from the composting process and intended for local energy use. The first goal is to determine the basic parameters of the examined samples (elemental analysis). The thermal emission parameters of the combustion device, such as the flue gas temperature and emission concentration of carbon monoxide, carbon dioxide and nitrogen oxides in relation to the operating conditions of the combustion device with an automatic feed fuel burner furnace are also considered. Pellets from oversized chips gained from the composting process and the pelleted mixtures of compost and spruce sawdust in the ratio 1:1 were burnt in the burner furnace.

The resulting values of the samples' individual elemental analyses indicate the optimal properties for further energy utilization. The amount of excess air generated during combustion, however, is high and this is also reflected in the great loss of flue gas sensible heat. The resulting parameters further prove that the excess air coefficient (n) depends on flue gas temperature, as well as carbon dioxide, monoxide and nitrogen oxides content in the flue gas. It was concluded during the combustion tests that the pollutants monitored in the flow did not reach the limit values. The scientific hypothesis of the author confirms that the stabilized dried mixture of plant biomass and appropriate biodegradable waste is suitable for biomass combustion. The available data suggest that the use of compost for energy purposes through combustion is possible, if biodried biomass is used, i.e., special products of composting processes are used in medium-sized and large combustion devices.

Key words: alternative fuel, elemental and stoichiometric analyses, emission concentrations.

INTRODUCTION

The available data suggest that the use of compost for energy purposes through combustion is possible if the biomass is biologically dried, i.e., a special product of the composting process (Kranert et al., 2010) is used. Compost is a stable and sanitized slow-acting organic fertilizer that does not contain soluble forms of nitrogen. It has a wide ratio of nutrients C : N; besides the basic macroelements (NPK), it contains Ca, Mg and microelements, stable humus, soil microorganisms and alkaline acting substances (Goyal et al., 2005).

Compost used for energy purposes (Raclavska et al., 2011), energy exploitable biomass, is a specific type of compost. Recently, technologies of energy compost production designed for the direct combustion, gasification or pyrolysis processing were developed in addition to traditional composting methods (Boldrin & Christensen, 2010). Generally, the end-product is so called solid fuel made from completely dried and shaped compost (Kranert et al., 2010). So that this fuel could be used for energy, it is essential to monitor its thermal properties, such as calorific value (Ruzbarsky et al., 2014), as well as emission characteristics (Hajek et al., 2013).

The article is based on the hypothesis that the stabilized dried mixture of biomass and appropriate biodegradable waste correspond to the requirements of biomass combustion in view of combustion emissions. To confirm or refute this hypothesis, the article aims to experimentally determine the thermal emission characteristics of alternative fuels generated from composting processes and intended for local energy use. The first goal is to establish the basic parameters of examined samples (elemental analysis). Parameters such as flue gas temperature and individual emission concentration in the flue gas depending on the operating conditions of the combustion device are monitored.

MATERIALS AND METHODS

The classic composting technology of piles without forced aeration was used for measurement purposes in the composting facility at the Jarošovice, Ltd composting site. For elemental analysis, oversized components of the composting process were used. These were mainly forestry waste, sawdust, shavings, cuttings, wood, veneer, biodegradable waste paper, cardboard, wood and biodegradable waste from gardens and parks. These oversized components of the composting process were mixed with spruce sawdust in the ratio 1:1 for improving thermal emission parameters.

Elemental analysis of the samples is the primary objective of the project. Carbon, hydrogen and nitrogen were detected with the Perkin-Elmer 2400 CHN analyser. For the determination of chlorine and sulphur content, the samples were burned in an oxygen-hydrogen flame on a Wickbold apparatus. Non-combustible fuel substances, i.e., ash and total water content were determined by burning and drying the sample. The gross calorific value of the examined biofuel samples was determined by performing measurements with the calorimeter IKA 2000. Net calorific value was determined by calculations, using the elemental analysis results of individual samples.

Thermal emission measurements were carried out with the KNP hot stove made by the company KOVO NOVAK; the device incorporates automatic fuel feeding and a burner furnace. The nominal thermo-technical specifications of the hot stove are: nominal power 18 kW, controllable output 8–18 kW and fuel consumption 1.5–4.9 kg h^{-1}.

The fuel samples were burnt at the nominal thermal parameters of the combustion device, whereas a constant fuel supply was guaranteed and the combustion air supply was modified. Each sample was burnt for three hours. Emission concentration measurements were performed by measuring flue gas with 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. The signal of transducers is proportional to the volume concentration of measured components in ppm. The record interval of the average individual components was set to one minute. The measuring device was calibrated before each measurement. Emission concentrations were converted from ppm concentrations to normal conditions and to mg m^{-3}. It was determined that reference oxygen content in the flue gas is 11%.

Next, the results of thermal emission measurements were processed with regression statistical analysis for expressing the mathematical relationship between carbon monoxide, flue gas temperature and nitrogen oxides with the excess air coefficient. The formula of excess air coefficient (*n*) is:

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

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

RESULTS AND DISCUSSION

The values gained from the elemental analysis of selected pellet samples in their original state are shown in Table 1.

Table 1. Elemental analysis of pellet samples, diameter 6 mm

Sample	Water Content (% Wt.)	Ash (% Wt.)	Gross Calorific Value ($MJ \cdot kg^{-1}$)	Net Calorific Value ($MJ \cdot kg^{-1}$)	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
Compost + Spruce sawdust (1:1 ratio)	**6.37**	**22.39**	13.57	**12.66**	35.41	3.47	1.09	0.0	31.24
Oversized chips from the composting process	**6.72**	**36.85**	11.05	**10.24**	29.30	2.95	1.03	0.0	23.13

The elemental analyses reveals that the most decisive factor in terms of the thermal use of selected samples is calorific value, which depends on the water and ash content in the fuel (Ruzbarsky et al., 2014). Low water content in the samples is a positive factor because humidity affects the combustion process and exhaust gas volume produced per unit of energy (Malaťák et al., 2009). The ash content in the samples is high compared to various wood biomasses (Malatak & Kucera, 2013). The amount of ash decreases significantly after sawdust is added to the oversized chips gained from the composting process. Such a large amount of ash significantly affects the thermal properties of solid fuels under consideration and consequently affects both the selection and adjustment of the combustion device (Johansson et al., 2004).

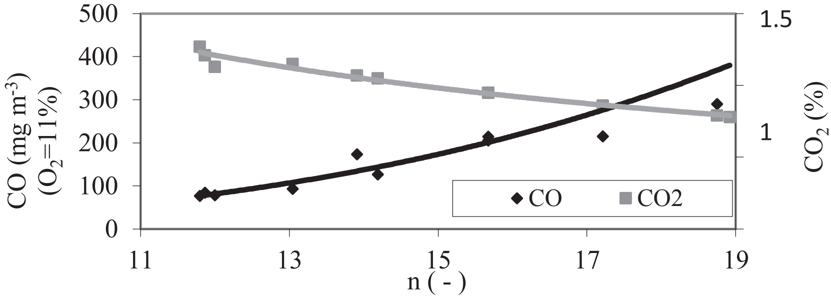

Figure 1. Dependence of carbon monoxide and carbon dioxide on the excess air coefficient – the combustion of compost and pelleted spruce sawdust mixture in the ratio 1:1.

During the combustion of the compost and pelleted spruce sawdust mixture in the ratio 1:1 (Fig. 1) the excess air coefficient *n* increased and with that, the emission concentration of carbon monoxide for *n* in the range of 12 to 19 according to the regression equation (1) at the confidence level of $R^2 = 0.90$ increased as well:

$$CO = 0.0183n^{3.3812}\ (mg{\cdot}m^{-3}) \qquad (2)$$

At the same time, the CO_2 concentration for *n* in the range of 12 to 19 according to the regression equation (2) gradually decreased:

$$CO_2 = 21.71n^{-1}\ (\%) \qquad (3)$$

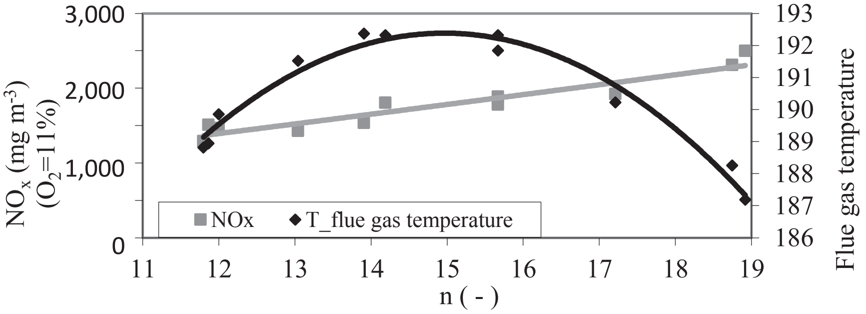

Figure 2. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – the combustion of compost and pelleted spruce sawdust mixture in the ratio 1:1.

While the excess air coefficient (if the value of the excess air coefficient is over 21) increases, as seen in Fig. 2, the combustion process is supressed and combustion temperatures also decrease. This process can be expressed with the regression equation (3) for *n* in the range of 12 to 19 at the confidence level of $R^2 = 0.89$:

$$T_{flue\ gas} = 89.7736n^{1.1035}\ (°C) \qquad (4)$$

At the same time, it is evident that the nitrogen oxides *NOx* emission concentrations increase; while this is expressed with the regression equation (4) for *n* in the range of 12 to 19 at the confidence level of R² = 0.96:

$$NOx = -0.3235n^2 + 9{,}6916n + 119.94 \ (mg\ m^{-3}) \quad (5)$$

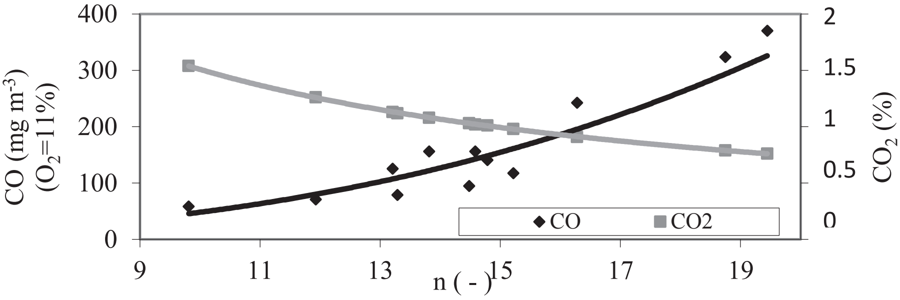

Figure 3. Dependence of carbon monoxide and carbon dioxide on the excess air coefficient – the combustion of pelleted oversized chips gained from the composting process.

The emission concentration of carbon monoxide *CO* (see Fig. 3) increases with the combustion of the compost sample, while the excess air coefficient *n* expressed with the regression equation (5) for *n* in the range of 10 to 20 at the confidence level of R² = 0.84 also increases:

$$CO = 0.0641n^{2.8756} \ (mg{\cdot}m^{-3}) \quad (6)$$

On the other hand, the concentration of carbon dioxide CO_2 reduces according to the regression equation (6) for *n* in the range of 10 to 20:

$$CO_2 = 20.862n^{-1.0004} \ (\%) \quad (7)$$

The ever increasing excess air coefficient, as shown in Fig. 4, leads to the attenuation of combustion processes and reduction of combustion temperatures. This process is described with the regression equation (7) at the confidence level of R² = 0.86:

$$T_{flue\ gas} = 0.2733n^2 - 11.88n + 311.6 \ (°C) \quad (8)$$

At the same time, the emission concentrations of nitrogen oxides *NOx* are constantly increasing, which is described with the regression equation (8) for *n* in the range of 10 to 20 at the confidence level of R² = 0.83:

$$NOx = 1.766n^{2.5735} \ (mg{\cdot}m^{-3}) \quad (9)$$

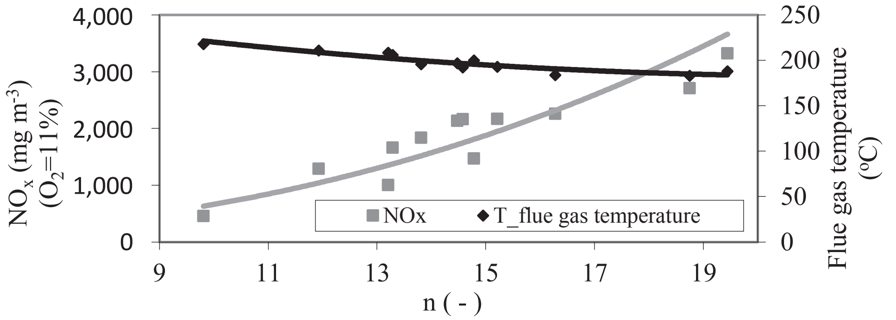

Figure 4. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of pelleted oversized chips gained from the composting process.

The resulting values of thermal emission measurements show high concentrations of carbon monoxide *CO* and nitrogen oxides *NOx* in the areas of high excess air coefficient *n*. As shown in research works by the authors 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.

The quality (efficiency) of combustion (Johansson et al., 2003) can be determined from the content of CO_2 in the flue gas. If excess air content is low (complete combustion) and the highest possible concentration of CO_2 is achieved, the loss caused by the flue gas is minimal (flue gas at the same temperature). 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 fuel (Malatak & Kucera, 2013). This value is within the measurement uncertainty limits.

CONCLUSIONS

- The excess air value *n* is generally high during combustion in a burner furnace and this is also reflected in the high heat losses of the flue gas (chimney losses) and even in the carbon dioxide and nitrogen oxides' concentrations. The measurement results provide more ways for the optimal energy use of compost and separates that are not suitable for, e.g., fertilizer for various reasons.
- The increased amount of ash hinders the energy use of compost and separates for small combustion plants. These samples can be energetically used for medium-sized and large combustion devices with a controlled combustion process and exhaust gas cleaning systems.
- In terms of processing procedures, the biodrying of biomass is the most efficient for the energy use of compost. Thus, it can be used as a solid biofuel for direct combustion in medium-sized and large power plants or as feedstock for the thermochemical conversion process of carbonization, gasification or pyrolysis.

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