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Experimental Investigation of the Sewage Sludge Gasification Process in the Fixed Bed Gasifier

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Paper presents the experimental investigation of a sewage sludge gasification process. Installation with an updraft gasifier was used. An analysis of how sewage sludge composition, volatile matter content, and water content influence the composition of the gas obtained in the autothermal gasification process was conducted. The results were presented as a function of the amount of gasification agent and show that higher oxygen content in sewage sludge is detrimental to the temperature of the reaction. Paradoxically, this results in an increase in the quantity of combustible components in the gas. As expected, an increase in the air flow rate causes a decrease in the heating value. Greater amounts of oxidizing agents tend to increase the amounts of noncombustible species and the volumetric fraction of nitrogen, thus decreasing the heating value of the gas obtained.

1. Introduction

Today, there is a rising interest in many countries in biomass utilization (e.g. combustion, co-combustion, gasification and pyrolysis). This is a result of the limited reserves of fossil fuels (and because of security of energy supplies in a world) and environmental and climate regulations on CO_2 emissions. Resources of fuels vary from country to country and are depend on geographic location, the climate, the population density and the degree of the industrialization of the country. The sludge production rang is quite large (16-94 g/(person·d)) (Cao and Pawłowski, 2012; Werle, 2012a; Werle, 2012b) thus indicating the different approach to wastewater treatment and sludge management in different countries. Biomass is the term used to describe renewable organic-rich material. Biomass is not a well-defined. Its composition may vary depending on origin, age, season and other factors (Ptasinski et al., 2007). The composition of the organic fraction in biomass doesn't vary much. However, the variation of the moisture and ash content is large. The change in composition of various solid fuels illustrates a diagram developed by Van Krevelen and Schuyer (1957). Figure 1 depicts the change in atomic ratios H/C and O/C in different types of organic substances (Judex et al., 2012; Park and Jang, 2011). Analyzing this figure it can be said that sewage sludge is characterized by significantly higher values of H/C ratio in comparison to other organic substances. Sewage sludge is a solid, semisolid, or liquid residue that results after the treatment process of waste water. The *6th Environment Action Programme 2002-2012* of the European Commission has been described as a major factor in reducing sewage sludge disposal by 50 % from 2000 by 2050. During the last twenty years, there has been a major change in the way that sludge is disposed. In the UE landfill or water deposition of the sewage sludge with the e.g. higher heating value equal to 6 MJ/kg is prohibited.
In light of there is a large and pressing need for the development of thermal methods for the disposal of sewage sludge.

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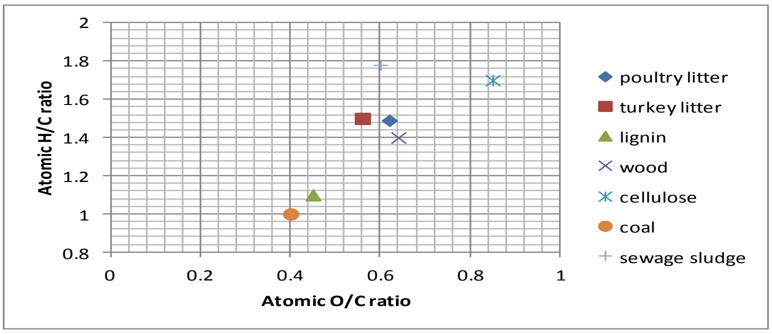

Figure 1. Van Krevelen diagram

Gasification has several advantages over a traditional combustion process. It is the process of converting a solid fuel into a gaseous fuel (Myréen et al., 2011) using gasification agent (e.g. O_2, atmospheric air, H_2O (g) and others). As shown in Marrero et al. (2004), sewage sludge gasification leads to combustible gas. This gaseous fuel can be used for the generation of useful form of final energy. It can be also used in such processes as the drying of sewage sludge directly on waste treatment plant. Volume of produced gas is lower in comparison of volume of flue gas from combustion process. This is due to the fact that gasification is the process characterizing by low level gasification agent environment. Sewage sludge is characterizing by low concentration of phosphorus, nitrogen and sulfur. Taking into consideration gasification process features, the formation of dioxins, SO_2 and NO_x is limited and S is mainly transformed to H_2S (Meng et al., 2010) and N_2 into NH_3 (Buckley and Schwarz, 2003). Phosphorus is partitioned into solid residues (Zhu et al., 2011). For all of these reasons, gasification requires smaller and less expensive gas-cleaning facilities (Werle and Wilk, 2010).
The paper presents an experimental investigation of a sewage sludge gasification process. An installation with an updraft gasifier was used. Analysis of the influence of composition, volatile matter content, water content and heavy metal content of the granular sewage sludge samples on the composition of the gas produced from the autothermal gasification process was conducted.

2. Experiment

A commercial pre-dried sludge (granulated sewage sludge 1 (GS1) and granulated sewage sludge 2 (GS2)), whose properties are reported in Table 1, was investigated. For the purpose of experimental investigations, a laboratory system was designed and built. The main part of the installation (Figure 2) was a stainless updraft gasifier (G) 150 mm internal diameter and the total height of 250 mm. For this study, granular sewage sludge was inserted into the gasifier from the above. Gasification agent was fed (B) from the bottom. The sewage sludge pellets moved in a countercurrent direction to the processes gases. There are four specific zones in the gasifier. In the first zone (drying zone) the water form sewage sludge is evaporated. In the second zone (pyrolysis zone) sewage sludge thermal decomposition to volatiles and solid char was carried out. In the one before last zone, carbon was converted, and main combustible components of syngas were produced. In the last zone, the remaining char was combusted. The combustion zone is a source of energy for reactions in the upper zones. There are mainly endothermic reactions. The temperature inside the reactor was measured by six N-type thermoelements. They were located along the vertical axis of the reactor. Additionally, the temperature of the gasification gas at the outlet of the reactor was measured. The flow rate of gasification agent was measured by a flow meter. Syngas was transported from the

Table 1. Properties of the fuels tested

Fuel	Granulated sludge 1 (GS1)	Granulated sludge 2 (GS2)
Proximate analysis, % (as received)		
Moisture	9.00	25.00
Volatile matter	52.50	44.50
Ash	32.35	31.50
Ultimate analysis, % (dry basis)		
C (dry)	31.83	33.78
H (dry)	5.30	4.92
O (dry)	23.76	22.89
N (dry)	4.50	4.25
S (dry)	0.35	0.85
P (dry)	1.79	1.81
LHV, MJ/kg (on dry basis)	13.43	10.92
Heavy metals content, ppm		
Cu	170.5	490.1
Ni	18.2	102.9
Cr	489.7	192.0
Pb	67.7	119.2
Zn	1031.9	912.3
Cd	4.2	3.9

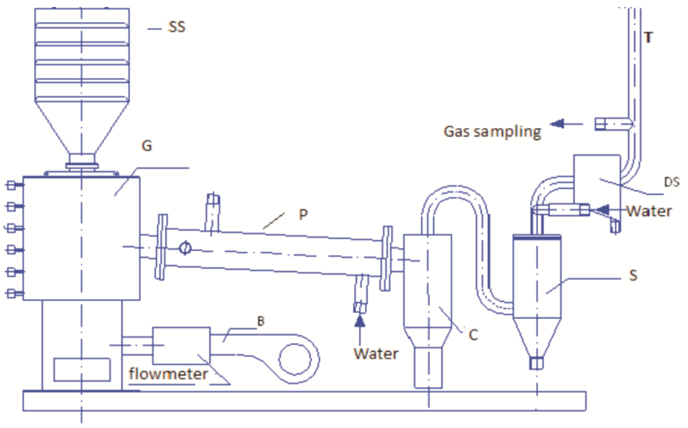

Figure 2. Schematic diagram of the experimental system

gasifier by the pipe (P) as shown in Figure 2. The syngas was cleaned by a cyclone (C), scrubber (S) and drop separator (DS). Volumetric fractions of the main components were measured online. Additionally, the installation is equipped by sampling point to collect gas to do chromatographic analysis.

3. Result and discussion

3.1 Influence of the air flow rate on the composition of syngas

Figure 3 presents the results obtained during the gasification of granulated sewage sludge 1 (GS1) using various air flow rates.

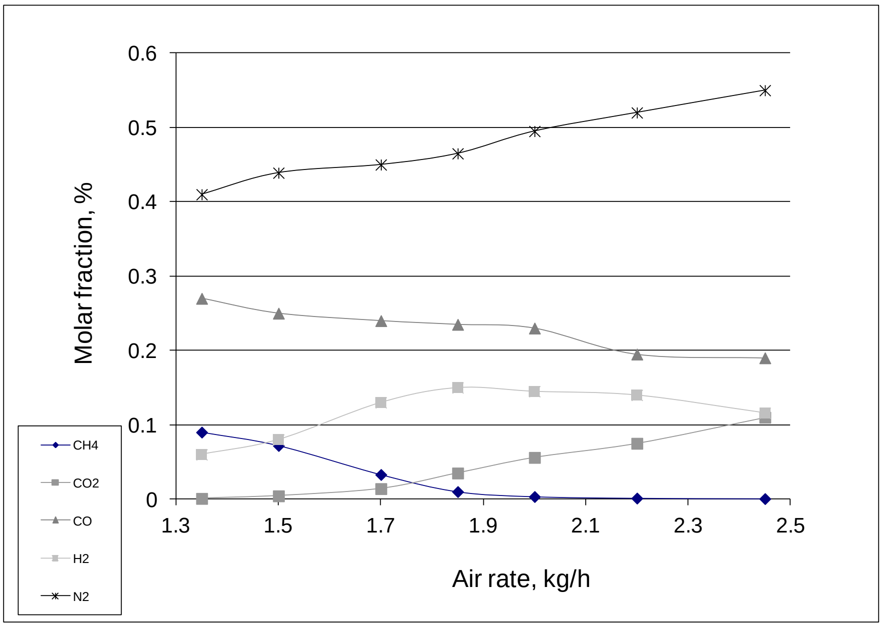

Figure 3. Molar fraction of hydrogen and carbon monoxide against the air flow rate

The results achieved for closely related types of granular sewage sludge were similar. Based on the data in the diagram, the amount of methane decreases as the ratio of air flow rate increases. For the majority of the range of ratios evaluated, the methane content was low. The percentage of hydrogen in the obtained gas was variable, but the changes were not very drastic (z_{H2} ranged from 0.07 - 0.12). The volumetric fraction of hydrogen peaked when the air flow rate was equal to 1.85 kg/h (excess ratio was λ=0.42). The molar fraction of carbon monoxide slightly decreased from approximately 27 % to 19 %. The molar fraction of carbon dioxide increased with increases in air flow rate. The amount of nitrogen also increases continuously with the increase in the air excess ratio, as has been confirmed by theoretical calculations presented earlier (Werle and Wilk, 2011).

3.2 Influence of sewage sludge on the composition of syngas

Figure 4 presents a comparison of the gasification results for two different granular sewage sludge samples (GS1 and GS2). Case 1 (GS1) is marked by the solid line, and case 2 (GS2) is marked by the dotted line. In case of GS1, the molar fraction of CO was within the range of 16-28 %, while in case GS2, the molar fraction of CO was ranged from 19-27 %. All of the parameters of the gasification process were the same in both cases and the difference in the molar fractions of CO was likely due to the reactivity of the fuel. The molar fractions of hydrogen in the syngas were on in both cases, ranging from 5-15 %.

3.3 Influence of initial moisture content in sewage sludge on the composition of syngas

The water amount content in the sewage sludge strong affects on the gasification gas composition. A rise in temperature in the reactor is caused by the heat that is needed to evaporate the moisture. This affects the quality of gas from gasification. Granulated sludge 2 (GS2) is more humid than GS1. The influence of the moisture content on derived syngas composition is presented in Figure 5.

3.4 Influence of air flow rate on the caloric value of the obtained gas

Figure 6 presents the dependence of the heating (caloric) value of the obtained gas on the air flow rate for the sewage sludge samples that were investigated. As expected, an increase in the air flow rate caused a decrease in the heating value. A greater amount of gasification agent increases the amounts of noncombustible species and the volumetric fraction of nitrogen, thus decreasing the heating value of the obtained gas.

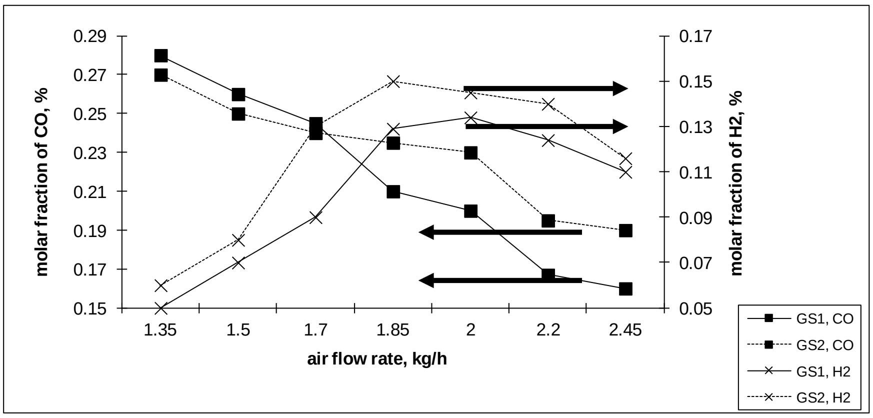

Figure 4. Molar fraction of hydrogen and carbon monoxide against the air flow rate

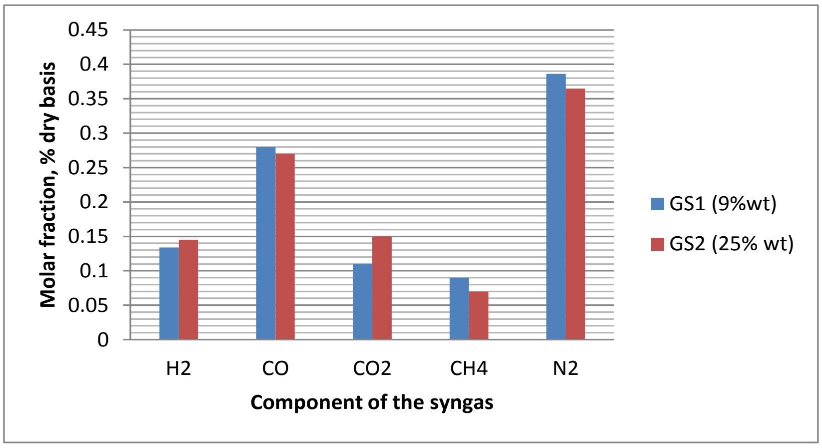

Figure 5. Comparison of the syngas composition in the case of dry and wet sewage sludge feedstock

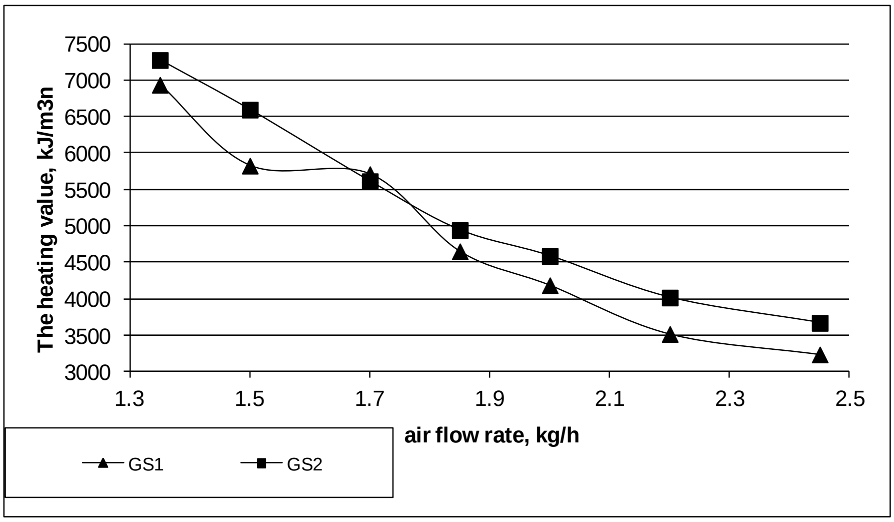

Figure 6. The heating value of syngas against the air flow rate

4. Conclusions

New, original experimental results on sewage sludge gasification are presented in this study. Air sewage sludge gasification was investigated. Fixed bed reactor was used. An analysis of the influence of sewage sludge composition, volatile matter content, and water content on the composition of the gas obtained in the autothermal gasification process was conducted. The results, presented as a function of the amount of gasification agent, show that greater oxygen content in sewage sludge causes a reduction in the reaction temperature. Paradoxically, this effect causes an increase in the quantity of combustible components in the gas. As expected, increasing the air flow rate caused a decrease in the heating value of the produced gas. A higher amount of oxidizer increases the amounts of noncombustible species and volumetric fraction of nitrogen, thus reducing the heating value of the obtained gas. Higher water content in the sewage sludge affects the gasification gas composition. As a result, combustible components are in the minority in the syngas.

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