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GASIFICATION PROCESS AS A COMPLEX METHOD OF SEWAGE SLUDGE TREATMENT

Sebastian WERLE
Silesian Univeristy of Technology, Insitute of Thermal Technology
44-100 Gliwice, ul. Konarskiego 22

Today, there is a rising interest in many countries in “traditional” (e.g. agro and forest) biomass and waste biomass (e.g. sewage sludge) utilization processes (e.g. combustion, co-combustion, gasification and pyrolysis). During the last twenty years, there has been a major change in the way that sludge is disposed. For example, in the European Union (EU) landfill or water deposition of the sewage sludge with the e.g. higher heating value (HHV) equal to 6 MJ/kg will be prohibited. In light of there is a large and pressing need for the development of thermal methods for the disposal of sewage sludge. Gasification has several advantages over traditional combustion process. This work investigates sewage sludge gasification in a fixed bed gasifier. The effects of operating conditions on the gasification process were investigated.

Keywords: gasification, sewage sludge, fixed bed reactor, gasification gas parameters

1. INTRODUCTION

The quantity of sludge production in Europe [2, 8, 16, 17] varies widely over different countries (16-94 g/(person·day)). As population increases, there is an increase in the production of sewage sludge. Moreover, the final of sewage sludge disposal depends on the sludge treatment methods used on the wastewater treatment plant (anaerobic or aerobic digestion, drying, thermal utilization etc.). In the European countries anaerobic stabilization is more popular (in 24 countries) than aerobic countries (in 20 countries) [8]. Unfortunately, the most popular way of final sewage sludge management is storage. In countries that are technologically less developed, direct agricultural application or storage is typical pathways to safely dispose of stabilized sludge from wastewater treatment plants. In countries where policy makers practically forbade such solutions (e.g., the European Union), only thermal disposal methods are available [4-7]. The thermo-chemical conversion of sewage sludge consists of four main processes: combustion, co-combustion, pyrolysis and gasification. One of the promising thermo-chemical conversion technologies that can be used to convert sewage sludge to useful energy forms suited for small to medium size throughput is gasification. Gasification has attracted attention as one of the most efficient methods for utilizing biomass as CO_2 emission has become an important global issue. This process has several advantages over a traditional combustion process [13]. First of all, as a consequence of the reducing atmosphere in the gasifier (amount of the oxidizer is much less than the stoichiometric amount), gasification prevents emissions of sulphur and nitrogen oxides, heavy metals and the potential production of chlorinated dibenzodioxins and dibenzofurans. Due to it most of sulphur, nitrogen, chloride and fluoride in sewage sludge may be released as H_2S, NH_3, HCl and HF. Secondly, a less volume of gas is produced compared to the volume of flue gas from combustion [1, 3, 9-11, 14, 15].

This article reports on experimental investigations of fixed-bed gasification of sewage sludge. In Poland, several industrial fixed bed gasifier plants using "traditional" biomass (mainly agricultural) are in operation. Nevertheless, there is a lack of experimental research on locally available sewage sludge feedstock. Considering that only 1% of the sewage produced in Poland is currently thermally decomposed and given the advantages of the gasification process, the analysis presented here is especially important. Analysis of influence of the gasification process operating conditions and sewage sludge feedstock composition on the gasification gas parameters is presented.

2. METHODOLOGY

2.1. Sewage sludge properties

Two types of sewage sludge feedstock were analysed. Sewage sludge no. 1 (SS1) was taken from Polish wastewater treatment plant operating in the mechanical-biological system and sewage sludge no. 2 (SS2) was taken from mechanical-biological-chemical wastewater treatment plant with phosphorus precipitation. In both analysed cases, sewage sludge is stabilized by anaerobic digestion and dehydration. After anaerobic digestion, sewage sludge is dried. In the case 1 (SS1) sewage sludge was dried in cylindrical dryer with heated shelf. The temperature of hot air was equal to $260^{o}C$ (high temperature). In the case 2 (SS2) air belt dryer was used. The temperature of hot air in this case was equal to $150^{o}C$ (low temperature). As a consequence, in the case 1 form of the dried sludge is similar to granulate and in the case 2 to “noodles”. Table 1 summarizes the main physical and chemical properties of sewage sludge. The main components in the sewage sludge were determined using automatic infrared (IR) analyzers. The moisture content of the sewage sludge was obtained following standard PN-EN 14774-3:2010. The sludge volatile content was determined according to standard PN-EN 15402:2011. The sludge ash content was obtained using PN-EN 15403:2011. Lower Heating Value was calculated on the basis of hydrogen content on dry basis.

Table 1. Sewage sludge properties used in the gasification tests

	Symbol of sewage sludge	
	SS1	SS2
Proximate analysis, % (as received)		
Moisture	5.30	5.30
Volatile matter	51.00	49.00
Ash	36.50	44.20
Ultimate analysis, % (dry basis)		
C	31.79	27.72
H	4.36	3.81
N	4.88	3.59
O (by difference)	57.07	63.04
S	1.67	1.81
F	0.013	0.003
Cl	0.22	0.03
Calorific value		
LHV, MJ/kg (on dry basis)	12.96	10.75

Analysing ultimate analysis results it can be concluded that sewage sludge from mechanical-biological-chemical wastewater treatment plant with phosphorus precipitation (SS2) in comparison to the sewage sludge from mechanical-biological wastewater treatment plant (SS1) characterized lower amounts of C, H, N, F and Cl. This feature indicates on lower utility such sludge to thermal treatment. Additionally, this feature proves that in-depth waste treatment configuration has a direct impact on the sewage sludge calorific value (expressed by lower heating value LHV) of received derived fuel from sewage sludge. The LHV of SS2 is lower than SS1. Nevertheless, in both analysed cases, is lower than 6 MJ/kg what is the limit value for possibility of sewage sludge storage on waste landfill (based on the Polish criteria for the storage of sewage sludge in a non-hazardous waste landfill) [12].

2.2. Experimental instalation

The sewage sludge gasification tests were conducted using a fixed bed gasification facility [18]. The main system component was a stainless gasifier with a 150-mm internal diameter and a total height of 300 mm. The reactor was well insulated to prevent major heat loss. In this study, the granular sewage sludge was fed into the top of the gasifier. The gasification air was fed from the bottom by a blower. The sewage sludge was circulated in a countercurrent direction to the process gases. There were four zones in the gasifier. In the first zone (the drying zone), water was evaporated to form sewage sludge. In the second zone (the pyrolysis zone), the sewage sludge was thermally decomposed into volatiles and solid core. In the third zone, carbon was converted to the main combustible components of syngas. In the last zone, the remaining char was combusted. The combustion zone provides a source of energy for the gasification reactions in the upper zones. The gasification reactions are mainly endothermic. The internal reactor temperature was measured by six N-type thermoelements integrated with an Agilent temperature recording system. The thermocouples were located along the vertical axis of the reactor. The gasification gas temperature was also measured at the outlet of the reactor. The gasification air flow rate and the syngas flow rate were measured by flow meters. The syngas was transported from the gasifier by a gas pipe. The syngas was cleaned by a cyclone, a scrubber and a drop separator. The volumetric fractions of the main syngas components were measured online using a Fisher Rosemount and ABB integrated set of analyzers. The system was also equipped with a sampling port to collect gas for chromatographic analysis by an Agilent 6890N gas chromatograph.

A scheme of the installation is shown in Figure 1.

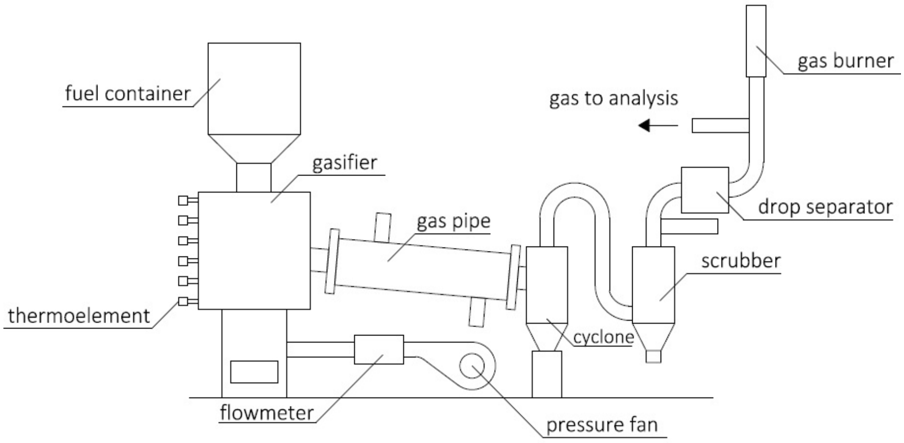

Fig. 1. Scheme of fixed bed gasifier installation

3. RESULTS

The study included the effect of the amount of supply air gasification on the composition of the gas from gasification.

The gasification process occurs in three major steps. The first step is associated with the initial decomposition of sewage sludge via the thermo-chemical processes that produce tar, volatiles and char residues. The second step involves reacting the volatiles. The last step comprises the heterogeneous reactions of the remaining carbonaceous residues with the gaseous producer gas and the homogeneous reactions of carbon monoxide, carbon dioxide, hydrogen, vapor and hydrocarbon gases.

Figure 2 and 3 shows the evolution of the H_2 and CO concentrations in gasification gas with varying air excess ratios for both analysed sludge (SS1 and SS2).

Analysing Figures 2 and 3 it can be confirmed that throughout the range of analysed air excess ratio (λ=0.12-0.27) volumetric fraction of main combustible components of gasification gas (CO and H_2) are higher in the case of the sewage sludge 1 (positive aspect) in comparison to SS2. This is mainly caused by the composition (as an effect of wastewater treatment configuration) of sewage sludge. Mechanical-biological-chemical (in-depth) wastewater treatment causes that sewage sludge is characterized by a lower utility to thermal treatment.

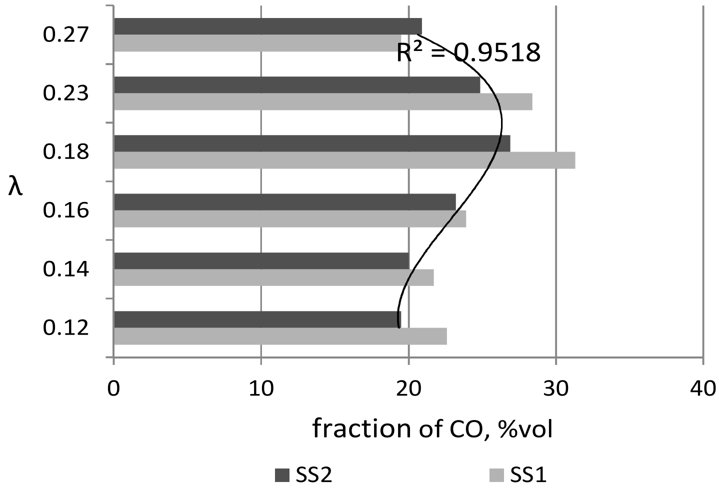

Fig. 2. Volumetric fraction of CO for different values of air excess ratio

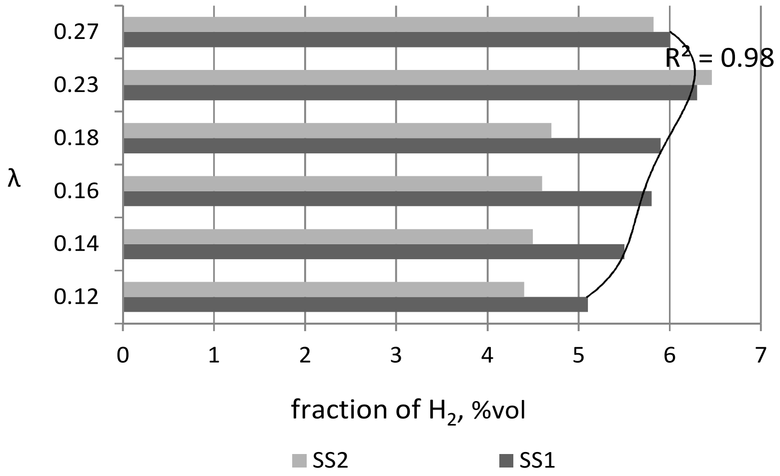

Fig.3. Volumetric fraction of H_2 for different values of air excess ratio

Figure 4 shows the evolution of the lower heating value of the both analysed sewage sludge feedstock gasification gas.

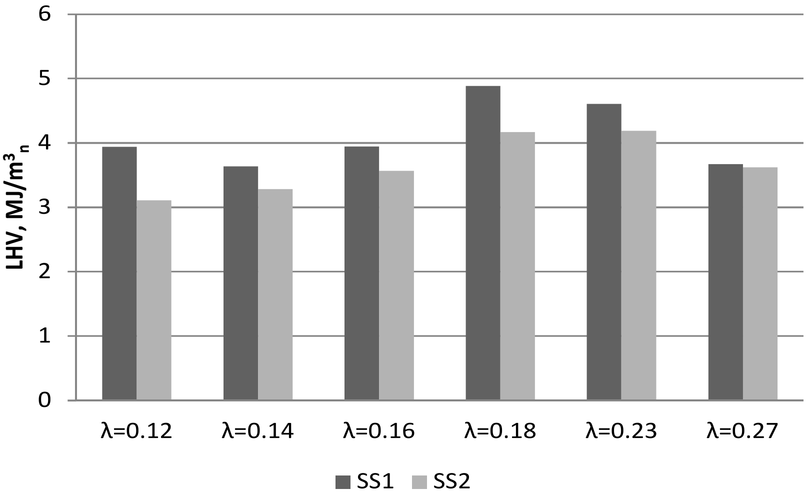

Fig. 4. Evolution of the LHV of the gasification gas with varying air excess ratios for both analysed sludge

Analysing the data presented in Figure 4 it can be concluded that taking into consideration the lower heating value LHV of the gasification gas there is the optimum value of the air excess ratio equal to 0.18 in which the LHV takes its maximum value. It is true irrespective of the sewage sludge type. Above that optimal value, the thermo-chemical process could be shifted from gasification to combustion.

4. CONCLUSIONS

The main conclusions from the study are as follows:

1. Original experimental results on sewage sludge gasification are presented in this study. Air gasification of sewage sludge was investigated, and a fixed bed reactor was used. Experiments have not been previously conducted on Polish sewage sludge used as a feedstock in the gasification process. The results obtained showed that it is technically feasible gasification of sewage sludge in fixed bed gasification installation.
2. Sewage sludge has a high economic potential due to its extremely low price.
3. The operating conditions (amount of the gasification agent) of the sewage sludge gasification process greatly influence the syngas composition distribution.
4. Higher values of the main components (especially C and H) in the sewage sludge plant affect on the increase of the LHV of gasification gas. 5. Throughout the range of analysed air excess ratio (λ=0.12-0.27) volumetric fraction of main combustible components of gasification gas (CO and H_2) are higher in the case of the sewage sludge 1 (positive aspect) in comparison to SS2.
5. Taking into consideration the lower heating value LHV of the gasification gas there is the optimum value of the air excess ratio equal to 0.18 in which the LHV takes its maximum value.

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ZGAZOWANIE JAKO KOMPLEKSOWA METODA ZAGOSPODAROWANIA OSADÓW ŚCIEKOWYCH

Streszczenie

W wielu krajach obserwuje się rosnące zainteresowanie termicznym przekształcaniem (spalanie, współspalanie, zgazowanie i piroliza) tradycyjnej (typu “agro” i leśną) biomasy a także biomasy odpadowej. W ostatnim dwudziestoleciu zaszły duże zmiany w sposobie zagospodarowania osadów ściekowych. Na przykład w kracjach Unii Europejskiej składowanie osadów, które charakteryzują się ciepłem spalania równym przynajmniej 6 MJ/kg jest (lub będzie w ciągu najbliższych trzech lat) zakazane. W związku z tym istnieje duża potrzeba rozwoju termicznych metod utylizacji osadów ściekowych. Zgazowanie posiada w stosunku do tradycyjnego spalania wiele zalet. Praca zawiera rezultaty badań procesu zgazowania osadów ściekowych w reaktorze ze złożem stałym. Przeanalizowano wpływ parametrów procesowych na proces zgazowania osadów.