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SOLAR PYROLYSIS AND GASIFICATION OF THE SEWAGE SLUDGE - PRODUCED FUEL PROPERTIES ANALYSIS

PIROLIZA SOLARNA ORAZ ZGAZOWANIE OSADÓW ŚCIEKOWYCH - ANALIZA WŁAŚCIWOŚCI POWSTAŁYCH PALIW

Abstract: Sewage sludge is considered as a biomass due to its biodegradability. Legal conditions in the European Union prohibit sewage sludge storage. Therefore, there is a need to develop thermal methods for sewage sludge treatment. The most common way to date has been combustion. However, this process has a lot of disadvantages associated primarily with environmental harmfulness and the immediate need to use the heat produced. Pyrolysis and gasification are considered the most promising methods of sludge management. They have many advantages over combustion. However, it is difficult to tell which method is more likely to be widely used. Therefore, the paper presents a critical comparison of the solar pyrolysis process and gasification in the fixed bed of municipal sewage sludge. The analysis of the process parameters and combustible properties of the gaseous fuels obtained was analysed.

Keywords: solar energy, sewage sludge conversion, artificial light source, pyrolysis, gasification

Introduction

In the European Union (EU) countries, due to formal and legal conditions, the share of renewable energy sources in the production of final forms of energy is growing. The most important target is defined by European Commission (EC) - the share of the renewable energy sources in overall energy consumption in EU by 2030 must rise to 32 % [1]. Among these sources, solar energy and biomass deserve special attention. It is expected that the biomass potential in Europe is about 10 EJ, and solar energy - 600 EJ [2].

Despite this large resources, new sources of "green" energy are still looking for. The rise in population, industrialization as well as high requirements for sewage treatment enhanced the production of the sewage sludge. Statistical data shows that the production per person per year is more or less at the level of 25 kg of dry matter [3].

One of the possibilities is the energetic use of sewage sludge. Sewage sludge can be described as any solid, semi-solid or liquid waste generated from a wastewater treatment facility. Sewage sludge is considered as a biomass due to its biodegradability.

Therefore, sewage sludge can be subjected to the same processing processes as conventional biomass. There are 4 main methods of energetic use of sewage sludge: combustion, co-combustion, gasification and pyrolysis. Figure 1 presents schematically division of these methods.

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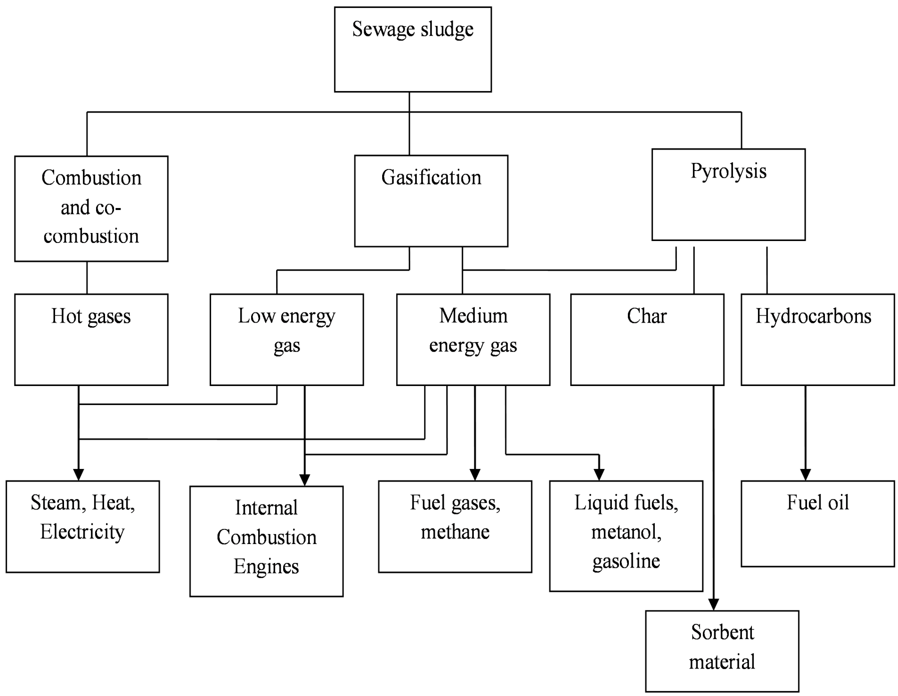

Fig. 1. Main thermochemical processes for sewage sludge conversion [4]

Table 1 presents the comparison of details of these technologies [5].

Table 1

Main thermal treatment methods comparison

	Combustion/co-combustion	**Gasification**	**Pyrolysis**
Air ratio	λ >1 Greater than stoichiometric supply of oxygen	λ <1 Less than stoichiometric supply of oxygen steam or other gasification agent	λ = 0 Absence of oxygen
Products	Heat	Heat and combustible gases	Heat, combustible liquid, combustible gas and char

Taking into consideration the products obtained during these processes, gasification and pyrolysis have more advantages compared to combustion (and co-combustion). This is especially important considering the European Union communication "The role of waste-to-energy in the circular economy" adopted on 26 January 2017 [6] clarifies the position of different waste-to-energy processes in the waste hierarchy as well as identifies the technology and processes which currently hold the greatest potential to optimize energy and materials outputs, taking into account expected changes in the feedstock for waste-to-energy processes. The introduction of secondary raw materials is crucial to ensure the transition to a circular economy.

Gasification is the process of converting a solid fuel into a gas by treating the solid fuel in a generator with oxygen, air, and steam, or by other gasification methods [7]. As shown by Marrero et al., gasification of sewage sludge leads to a high-quality flammable gas that can be used for the generation of electricity or support such processes as the drying of sewage sludge [8]. The lower heating value, LHV of the gas after gasification varies around a value of 4 MJ/m^3. The gas obtained can be used to generate electricity or to produce heat for the drying of sewage sludge [9].

Biomass pyrolysis is defined as a thermal degradation of the biopolymers present in the organic matter under an inert, oxygen-free, atmosphere [10]. Three products are always obtained (solid, liquid and gaseous), but the proportions can be varied over a wide range by adjustment of the process parameters [11]. Pyrolysis is a process carried out at a lower temperature in comparison to combustion or co-combustion [12]. Thanks to it, the formation of toxic substances is limited and the complex gas cleaning system is not necessary. There are many other important advantages of pyrolysis in comparison to combustion, as follows: (1) Pyrolysis can be performed at relatively small scale and at remote locations which enhance energy density of the biomass resource and reduce transport and handling costs; (2) Due to lower temperature of the process corrosion problem is reduced - the maintenance costs of the installation are lower; (3) Also due to the lower temperature of the process, recovery of the selected elements (mainly non-ferrous metals) from solid products is possible; (4) Due to the endothermic nature of the pyrolysis, control of the process is easier in comparison to combustion; (5) Pyrolysis is characterized by high level of the fuel flexibility.

The paper presents a critical comparison of the solar pyrolysis process and gasification in the fixed bed of municipal sewage sludge. The analysis of the process parameters and combustible properties of the gaseous fuels obtained was analysed.

Experiments

Fuel properties

The mass fraction (given in % mass) of main components of the fuel and also moisture, ash and volatile matter content and the lower heating value of analysed SS is displayed in the Table 2.

Table 2

Proximate and ultimate analysis of analysed samples [13]

Parameters	Sewage sludge
M - Moisture [% mass]	5.30
A - Ash [% mass]	49.00
VM - Volatile matter [% mass]	45.70
Carbon [% mass]	27.72
Hydrogen [% mass]	3.81
Oxygen [% mass]	3.59
Nitrogen [% mass]	13.53
Sulphur [% mass]	1.81
Fluor [% mass]	0.003
Chloride [% mass]	0.033
HHV [kJ/kg] (dry solid)	1171

The ultimate analysis was carried out using the infrared spectroscopy analyser. Following procedures and standards was used for the sewage sludge characterization. Moisture content has been determined according to EN ISO 18134-3:2015 [14]. The standard PN-EN 15402:2011 [15] was adopted to determine the volatile content and the PN-EN 15403:2011 [16] standard for the ash content. The ISO 17225-2:2014 [17] procedure was used for the calorific value (*HHV* - the higher heating value) determination.

Gasification

For presented study, a fixed bed gasification (FBG) reactor was used [18]. The installation is located in the Laboratory of Fuels Combustion and Gasification, Department of Thermal Technology of Silesian University of Technology, Gliwice, Poland. A whole system is presented in Figure 2. The key reactor element was insulated, stainless gasifier pipe. The internal diameter of the pipe is equal to 150 and the total height is equal to 300 mm. The sewage sludge in the form of granules was introduced to the reactor from the top located fuel box. The gasification agent was fed bottom up by the pressure fan. Six N-type thermoelements were used for measurements the temperature inside the reactor. All of the thermocouples were located along the vertical axis of the gasifier. All of thermoelements were connected to the temperature recording system (Agilent Company). In addition to the temperatures in the reactor, the temperature of the gas leaving the installation was also measured. The volume flow rate of gasification agent and flow rate of gasification gas was measured by flow meters. Gasification gas was transported by the gas pipeline, then was cleaned by gas cleaning installation. It consist of a cyclone, a scrubber and a drop separator. The main components of the gasification gas were measured online using the set of analysers. In Table 3 the gasification methodology has been presented.

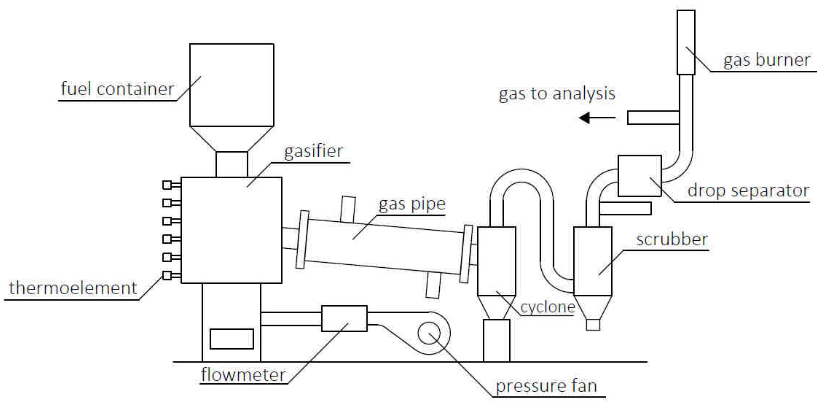

Fig. 2. Fixed bed gasification installation

Table 3

Gasification experiment methodology

Fuel	Gasification agent	Air ratio λ [-]	Test
Sewage sludge	Atmospheric air at ambient temperature	0.18	Fuel production

Solar pyrolysis

The solar pyrolysis experiment was conducted on the solar pyrolysis installation [19] - Figure 3. Control of the process temperature is executed by the variable output power (80-90 %) of the lamp controlled by the power supply of the lamp. After being loaded with sewage sludge pellets, the reactor was exposed to xenon lamp radiation for 90 min duration time. Measurements were carried out for 3 pre-selected lamp power values 80, 85.5 and 90%. During pyrolysis, the temperature and pyrolysis gas composition were recorded using WAGO© PFC 100 programmable logic controller (PLC). The heart of the laboratory station was artificial sun, the high-power xenon arc lamp. The 1.6 kW Sciencetech© lamp produces stable heat flux in a form of concentrated radiation, with spectral characteristics close to the natural sunlight. Lamp radiation is directed onto reactor surface, containing biomass samples. Reactor is a copper block with four ducted channels, with 169 mm of total length. Volatiles released during pyrolysis are moved out from reaction zone with flow of inert gas (nitrogen with 1.5 dm^3/min flow rate) and directed to liquid fraction (bio-oil) condenser. Bio-oil condenser consists of a set of water-cooled laboratory condensers with assigned Dreshl scrubbers in order to trap condensed bio-oil and pass non-condensable gases to ABB© gas analyser through Bronkhorst® El-Flow Prestige mass-flow meter. The methodology of the solar process is presented in Table 4.

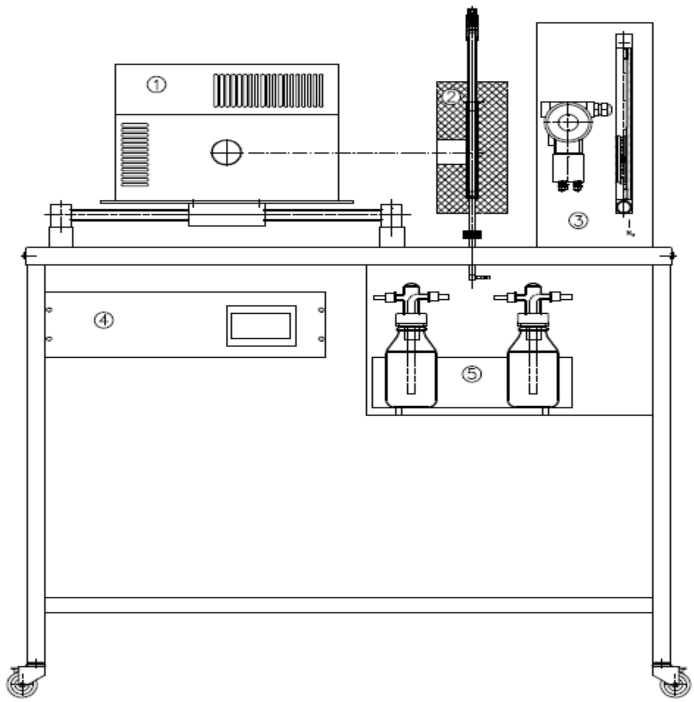

Fig. 3. Solar pyrolysis installation: 1 - xenon arc lamp, 2 - insulated copper reactor, with the exact view on the right, 3 - pressure sensor and inert gas rotameter, 4 - data activation system container, 5 - liquid fraction condenser

Table 4

Solar pyrolysis methodology

Fuel	**Inert gas**	**Air ratio λ [-]**	**Tests**
Sewage sludge	Nitrogen (1.5 dm^3/min)	0	Fuel production

Results

Figure 4 presents the composition (given in volumetric fraction - % vol.) of the pyrolysis and gasification gases.

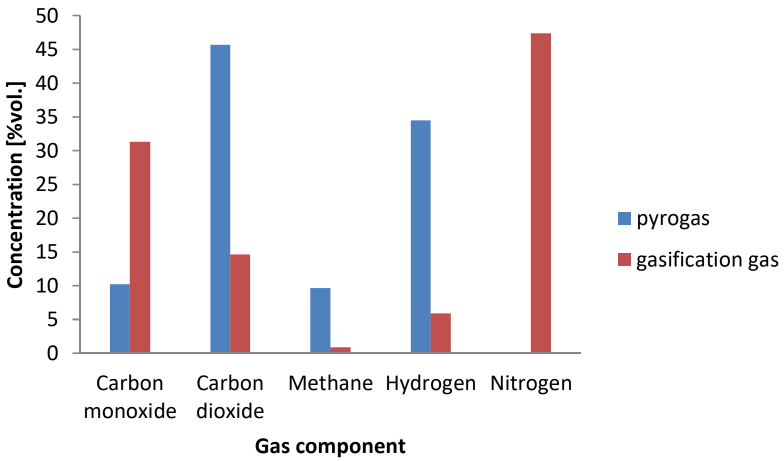

Fig. 4. Main components in pyrogas and gasification gas

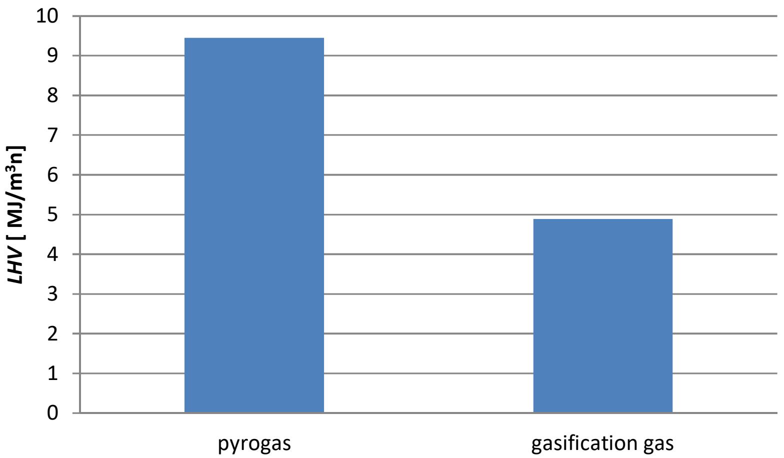

Fig. 5. The lower heating value, *LHV* of the gasification gas and pyrogas (n subscript - in thermodynamic normal conditions)

Analysing this data it can be concluded that in the case of the pyrogas, the combustible components (carbon monoxide and hydrogen) are higher in comparison to gasification gas. It is mainly due to difference in process atmosphere. It is a process without oxygen presence, and the flowing inert gas does not participate in the chemical reaction. The implemented gasification process was carried out using air as a gasification agent. Oxygen from the air is necessary to carry out the gasification reaction, while nitrogen remains after the process as a component of the process gas. Therefore, taking into account the production of gaseous fuel, it can be stated that solar pyrolysis gives the opportunity to obtain gas in which the share of flammable components is higher. This can also be seen in the Figure 5, where the calorific value of produced post-process gases is shown.

Conclusions

The following conclusions can be drawn:

- sewage sludge is considered as a biomass due to its biodegradability,
- the circular economy idea promotes gasification and pyrolysis as the more effective thermal methods in comparison to combustion (and co-combustion),
- thermal processes with complex characters and mechanisms, such as pyrolysis and gasification, provide a field for further complex experimental investigation,
- two original laboratory stands were used for solar pyrolysis and fixed bed gasification experiments,
- the solar pyrolysis gas (pyrogas) is characterised by higher calorific value in comparison to gasification gas.

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References

[1] Report from the Commission to the European Parliament and the Council on the implementation of the EU Strategy on adaptation to climate change, COM(2018)0738, 12 November 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0738

[2] Zappa W, Juginger M, van der Broek M. Appl Energy. 2019;233-234:1027-50. DOI: 10.1016/j.apenergy.2018.08.109.

[3] http://mirror.unhabitat.org/pmss/getElectronicVersion.aspx?nr=2551&alt=1.

[4] Werle S, Dudziak M. In: Industrial and municipal sludge: emerging concerns and scope for resource recovery. Elsevier; 2009. DOI: 10.1016/B978-0-12-815907-1.00025-8.

[5] Panahi HKS, Tabatabaei M, Aghbashlo M, Dehhaghi M, Rehan M, Abdul-Sattar Nizami A-S. Biores Technol Reports. 2019;7:100216. DOI: 10.1016/j.biteb.2019.100216.

[6] https://ec.europa.eu/environment/waste/waste-to-energy.pdf.

[7] Magdziarz A, Wilk M. J Therm Anal Calorim. 2013;114:519-29. DOI: 10.1007/s10973-012-2933-y.

[8] Marrero TW, McAuley BP, Sutterlin WR, Morris JS, Manahan SE. Waste Manage. 2004;24:193-8. DOI: 10.1016/S095-053X(03)00127-2.

[9] Hamilton CJ. Water Environ Manage. 2000;14:89-93. DOI: 10.1111/j.1747-6593.2000.tb00232.x.

[10] Rutkowski P, Kubacki A. Energy Convers Manage. 2006;47:716-31. DOI: 10.1016/j.enconman.2005.05.017.

[11] Yaman S. Energy Convers Manage.2004;45:651-71. DOI: 10.1016/S0196-8904(03)00177-8.

[12] Basu P. Biomass Gasification and Pyrolysis. Practical Design and Theory. Elsevier; 2010. ISBN: 9780123749888.
[13] Kaczor Z, Buliński Z, Werle S. Therm Sci. 2019;23:1153-62. DOI: 10.2298/TSCI19S4153K.
[14] EN ISO 18134-3:2015 Solid biofuels - Determination of moisture content - Drying method - Part 3: Moisture in general analysis sample. https://www.iso.org/standard/61637.html.
[15] PN-EN 15402:2011 Solid secondary fuels - Determination of volatile matter content. http://sklep.pkn.pl/pn-en-15402-2011e.html.
[16] PN-EN 15403:2011 Solid secondary fuels - Determination of ash content. http://sklep.pkn.pl/pn-en-15403-2011e.html.
[17] ISO 17225-2:2014 Solid biofuels -- Fuel specifications and classes. www.goo.gl/DyYPDD.
[18] Wilk RK, Werle S. Patent P-397225 based on the application from 2.12.2011, Biomass gasification installation, mainly for sewage sludge. www.goo.gl/49jUao.
[19] Sobek S, Werle S. Renew Energy. 2019;143:1939-48. DOI: 10.1016/j.renene.2019.06.011.

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Abstrakt: Osady ściekowe są uważane za biomasę ze względu na swą biodegradowalność. Warunki prawne w Unii Europejskiej zabraniają składowania osadów ściekowych, dlatego istnieje potrzeba rozwoju termicznych metod wykorzystania osadów ściekowych. Dotychczas najczęstszym sposobem jest spalanie. Proces ten ma jednak wiele wad związanych przede wszystkim ze szkodliwością dla środowiska i natychmiastową potrzebą wykorzystania wytworzonego ciepła. Piroliza i zgazowanie są uważane za najbardziej obiecujące metody zagospodarowania osadów. Mają wiele zalet w porównaniu do spalania. Trudno jednak stwierdzić, która metoda będzie częściej stosowana, dlatego w artykule przedstawiono porównanie procesu pirolizy słonecznej i zgazowania w złożu nieruchomym komunalnego osadu ściekowego. Przeanalizowano wpływ parametrów procesu na właściwości palne otrzymanych gazów procesowych.

Słowa kluczowe: energia słoneczna, wykorzystanie osadów ściekowych, sztuczne źródło światła, piroliza, zgazowanie