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DETERMINATION OF QUANTITY OF BIOGAS FROM SEWAGE SLUDGE

Jakub Sikora, Tomasz Jakubowski, Martyna Płaczek
University of Agriculture in Krakow

Abstract

Renewable energy sources have been amongst crucial elements of the European Union policy for a long time. Currently, they have become significant in terms of possibilities of the technology development, which may limit the effects and duration of the economic, energy and climatic crisis. The Directive 2009/28/EC obliges the increase of the share of Renewable Energy Sources in the final energy consumption up to 20% (in Poland up to 15%) by 2020.

Sewage sludge is waste that significantly affects the aspects of environment. The research considered the rationality of using the waste for the production of biomethane. The purpose of the work was to determine the dynamics of biogas production from sewage sludge of municipal origin. Its scope included a review of the literature based on the Polish and European law. Issues of technology, production and use of biogas and residue were presented. The research was based on determining the properties of sewage sludge – raw and after stabilization, and carrying out a fermentation process for a period of 30 days. The validity of using sewage sludge as substrate for biogas production was confirmed.

Keywords: sewage sludge, biogas, anaerobic digestion

INTRODUCTION

One of the ways of reducing the amount of organic waste is methane fermentation of biomass, as a result of which biogas called after purification biomethane, is created. It is a mixture produced with the participation of microorganisms under anaerobic conditions. It contains in its composition from 50 to 70% of methane and from 25 to 45% of carbon dioxide. There are also small amounts of hydrogen sulphide, oxygen, nitrogen and hydrogen in the biogas mixture. The detailed content of the components depends on the type of substrates and the method of conducting the fermentation process (Curkowski *et al*. 2009).

In Poland, there is a substantial increase in interest in biogas production. This results in a search for seeking alternatives to conventional energy and caring for the natural environment. This is a direct effect of the pro-ecological policy of the European Union which aims at a rise in the number of investments related to the production of electricity from renewable sources. The emergence of new installations producing energy in an unconventional way positively influences both the economic and social conditions (additional jobs to the community) and ecological (reduction of air and environmental pollution). Also, waste can be used as a substrate in biogas installations (Powałka *et al.* 2013).

On the electricity market for renewable energy carriers, biogas has high competition in the form of solid biofuels, wind energy and water. According to the Central Statistical Office (2016), the share of biogas in electricity production in 2015 amounted to 4%. This is more than a 0.5% increase compared to 2011. On the other hand, on the market for the production of thermal energy from renewable sources, solid biofuels which have a 96.42% market share are the only competitor. For comparison, biogas reaches 3.38%.

Specifying types of biogas produced in Poland, over the years 2011 – 2015, biogas from sewage treatment plants has the largest share. The production of this type of biogas is systematically growing and is over 630 TJ bigger than the landfill biogas. Figure 1 shows the production in individual groups and in total in the period of 2011 – 2015.

The National Municipal Sewage Treatment Program assumed that by the end of 2015 each agglomeration of which the Equivalent Number of Inhabitants fluctuated within 2000 – 100,000 or more will be connected to the collective sewage system (Kołodziejczak 2012). From the data presented, it can be concluded that the use of sludge for biogas production is justified. An additional argument for the management of sediments is the assumed constant increase in sewage sludge production. According to the Central Statistical Office, only the amount of municipal sewage sludge increased from 486.1 thousand Mg dry weight in 2005, up to 568 thousand Mg dry weight. This results from the modernization of operating sewage treatment plants, the use of new technologies, the increase in the number of households served by treatment plants and the construction of new purification facilities (Bień *et al.* 2011, Sikora and Tomal 2016). It is also worth noting that the amount of wastewater discharged into waters has significantly decreased.

The other legal standard is the Regulation of the Minister of Environment of 6 February 2015 on municipal sewage sludge (Journal of Laws 2015, item 257) which specifies the conditions of use, doses and research methods of municipal sewage sludge. Regulation of the Minister of Economy of 16 July 2015 on the acceptance of waste for landfill (Journal of Laws 2015, item 1277) which specifies criteria for the acceptance of waste for landfill in a given type of landfill.

All the aforementioned legal acts were introduced so as to comply with restrictions imposed on the Member States by the European Union and its bodies. The main directives on the basis of which national standards were created are: Council Directive of 30 May 2018on the protection of the environment, Directive of the European Parliament and Council of 30 May2018 on waste and the Directive on landfill of 26 April 1999.

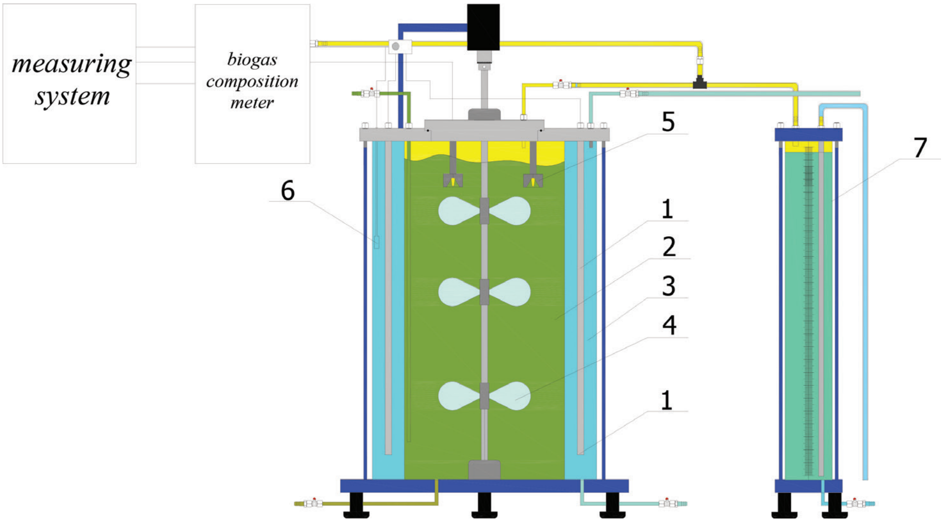
The purpose of the work was to determine the efficiency of the methane fermentation process of sewage sludge from an in-house treatment plant. The presented work discusses issues related to the formation, properties and management of this type of waste. The study also indicates the subsequent use of this resource. The above is in compliance with both Polish and European law.

MATERIAL AND METHODS

In the research part, the study material was prepared in the form of fermentation beds made on the basis of municipal sewage sludge coming from domestic sewage treatment plants. Properties such as humidity, ash content, dry weight, and organic dry weight were investigated. The main part of the research consisted in designing the inputs to the bioreactors and studying the course of fermentation and the final determination of the composition and the amount of the released biogas. The dynamics of biogas production was determined by DIN 38414 standard.

The research material was taken from the municipal sewage treatment plant. The treatment plant works on the basis of mechanical-biological purification. Two types of sewage sludge were used for the research. The first one (batch 2) was raw sewage sludge. In the second variant, the research material underwent partial oxygen stabilization (batch 1). The research was carried out in the biogas laboratory of the Faculty of Production and Power Engineering at the University of Agriculture in Krakow. The fractions were fragmented and five samples were collected from each fragment. Samples were weighed in order to determine their weight before drying. Fermentation was carried out in the digester of 20 dm^3 volume with the regulated temperature environment. The following parameters were controlled in the fermenter used: pH, redox potential and the batch temperature. The produced biogas was collected in the container of a variable volume. A schematic representation of the stand with a digester is presented in Figure 1.

Batch, accepted as control material is proved and introduced to the digester. Batch is placed in the digester (2) in which by means of probes (5) fermentation parameters, such as temperature, redox and pH are controlled. These parameters are automatically saved with time interval on the hard disc of a computer of the measuring system. In the digester, the batch is mixed with a mechanical mixer (4) to avoid delamination. The mixer may be smoothly regulated within 0 to 400 rot./min. and is equipped with three blades of regulated spacing, which enables the change of intensity of mixing zones in the fermenter.

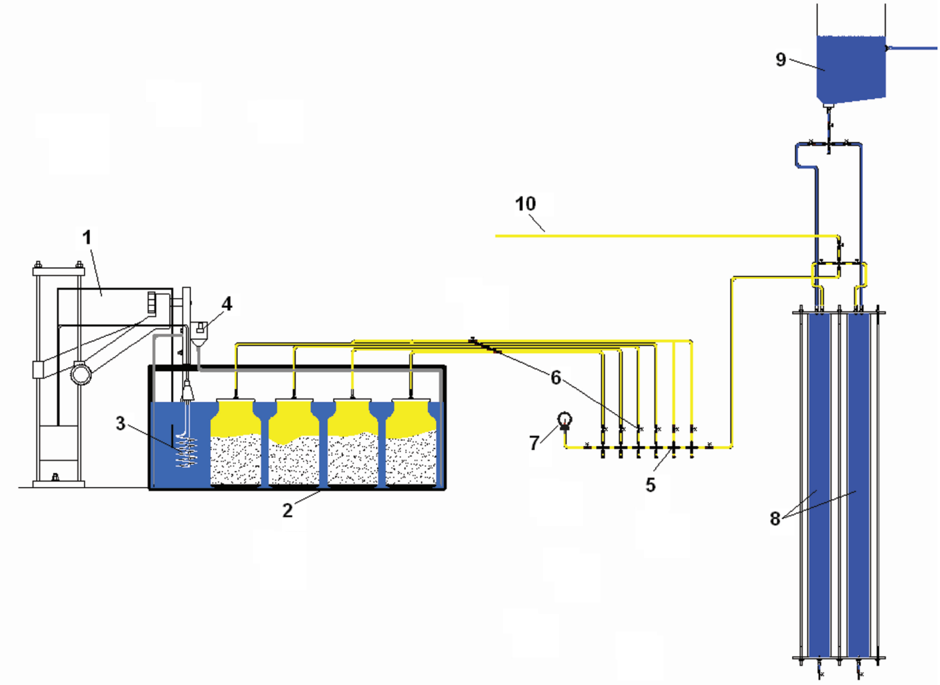


Source: (Sikora, 2012)

Figure 1. A schematic representation of the test stand with a 20 litre fermenter, where: 1 – cartridge heaters, 2 – batch, 3 – water jacket, 4 – mechanical mixer, 5-sondes, 6 – thermometer, 7 – container

The digester of the fermenter is equipped with a water jacket (3) where three cartridge heaters responsible for heating liquid are placed (1). The measuring system equipped with a thermometer (6) PT100 is responsible for controlling the process temperature. The produced biogas is collected over the surface of the batch in the fermenter and in the container (7) of variable volume, from which it is sucked in by the biogas composition measuring meter. This meter analyses the following parameters: moisture, temperature, pressure, methane (CH_4), oxygen (O_2), carbon dioxide (CO_2) and hydrogen sulphide (H_2S). The measured biogas composition parameters are automatically saved on the computer disc of the measuring system.

The determination of the intensity of the biogas production in the remaining batches was carried out according to DIN 38414 standard. Batch mixes were fermented under static conditions consisting in a single introduction of fraction to digesters and the process was conducted till the end of fermentation. Fermentation devices were installed in a container with the regulated temperature forming a part of the test stand, which was additionally composed of a switch panel and the measuring system.



Source: (Sikora, 2012)

Figure 2. A schematic representation of the test stand with a 2 litre fermenter, where: 1 – rack, 2 – container, 3 – heater, 4 – water pump, 5 – switch board, 6 – cut-off valves, 7 – manometer, 8 – system of measuring volume, 9 – columns, 10-conduit

A schematic representation of the test stand is presented in Figure 2. Devices for maintaining a constant temperature environment are mounted to a rack (1) located next to the container (2). Controlling takes place by means of the electronic thermostat ESCO ES-20 (unit switch 16A) with a precision up to

± 0.2°C resulting from a sensor hysteresis. The temperature decrease by value exceeding 0.1°C results in switching on a heater of 1500 W (3) power with a simultaneous start of the water pump Hanning DPO 25-205 (4) in order to ensure a uniform distribution of temperature in the whole chamber. After heating water to the temperature exceeding the set temperature by 0.1 °C the heater switches off with a 30 seconds delay of the pump.

Separators combined in a row along with cut-off valves (6) and a manometer (7) which measures pressure in particular measuring branches constitute a switch board (5). Due to the use of such a system for service of all fermenters, one measuring system was sufficient. The system of measuring volume (8) composed of two columns filled with water with drain valves and a container for filling up the liquid level in columns (9). The measuring system was connected to a switchboard and a biogas composition meter by means of a conduit (10) which is presented in Figure 2 (Sikora 2012).

A physical and chemical analysis were carried out for all the tested batches before the commencement of fermentation. Dry weight of fraction and reaction were determined. For each batch, fermentation was carried out simultaneously. The amount of the produced gas was read out twice daily at the same time.

RESULTS

Table 1 presents the results of tests regarding dry matter content and ash content. Taking into account the raw sediments, the obtained humidity results are at the level specified in Bień's (2012) study. He determined that the humidity, which was supplemented with dry matter, for this type of sediment varied between 85 and 99%.

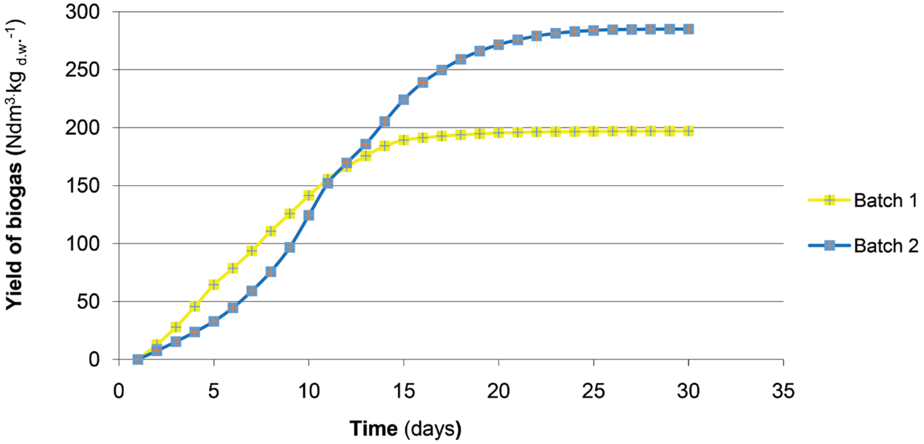
Table 1. Dry matter and ash content in the study materials (sewage sludge)

Type of sediment	Dry matter content [%]	Ash content [% d.w.]
Batch 1 (sewage sludge after stabilisation)	14.17	24.29
Batch 2 (raw sewage sludge)	4.95	31.79

Source: Own elaboration

As far as the ash content in the analysed sample is concerned, Błaszczyk and Krzyśko-Łupicka (2014) note that depending on the type of sewage treatment plant, it ranges from 28% up to 50%. In the discussed case, the value was at the lower limit, which may indicate that there were more substances for potential use in the composition than in the case when ashes accounted for 50% of the total share. In the second case, literature sources state that the dry matter content starts at 15% for the stabilized sewage sludge. The value obtained was slightly lower than the value given by Szwedziak and Woźniak (2005).

The ash content is directly connected to roasting losses. For stabilized sewage sludge, these values range from less than 60% dry matter up to 76% dry matter in the research presented by Włodarczyk *et al.* (2014). The residue is ash, so it can be stated that the amount obtained, in this case, corresponds to the other, independent studies.



Source: Own elaboration

Figure 3. The total amount of biogas released during the fermentation of the research material

In the case of raw sewage sludge (batch 2) the total biogas yield from the chamber increased from 7.41 $dm^3 \cdot kg_{d.w.}^{-1}$ to 285 $dm^3 \cdot kg_{d.w.}^{-1}$. The highest daily biogas yield occurred during the 11th day and amounted to 2.78 $dm^3 \cdot kg_{d.w.}^{-1}$. After the time, there was a gradual decrease in biogas yield. The point of maximum daily biogas yield is evidently visible in Figure 3 in the form of a breakdown. Taking into account the lowest daily yield, the lowest values were recorded during the last days of the study. The daily yield for the 29th day reached only 0.008 $dm^3 \cdot kg_{d.w.}^{-1}$ and on the last day fluctuated around 0 $dm^3 \cdot kg_{d.w.}^{-1}$.

According to Montusiewicz (2012), the potential for using sewage sludge for biogas production ranges between 0.25-0.75 $m^3 \cdot kg_{d.w.}^{-1}$ however, most often in practice, it is between 0.25-0.35 $m^3 \cdot kg_{d.w.}^{-1}$. In the case of the studies carried out, the results for raw sewage sludge were in the lower yield limit.

The analysis of the stabilized sewage sludge (batch 1) showed that the daily maximum yield of biogas was reached on the fifth day of the process, which caused a slight inequality of the process. During this time, the biogas yield had a value of 3 $dm^3 \cdot kg_{d.w.}^{-1}$. This value was higher than in the raw sewage study. After this day, daily biogas yields began to fall harmoniously. The total yield of biogas for stabilized sediments amounted to 197 $dm^3 \cdot kg_{d.w.}^{-1}$ and was smaller by more than 0.05 m^3 from the smallest value indicated by Montusiewicz (2012). The lowest values of daily yield were obtained on the first and the last day of the experiment, about 0 $dm^3 \cdot kg_{d.w.}^{-1}$ and 0.004 $dm^3 \cdot kg_{d.w.}^{-1}$ respectively.

The largest share in the biogas of its most important component that is methane in the case of raw sewage sludge was obtained after the 20th day of the experiment. After reaching this level, the value of this relationship remained at a similar level until the end of the process. In the case of carbon dioxide, a significant increase in the share occurred during the first five days of fermentation. On the subsequent days, there was a continuous, but less dynamic growth. It is worth noting that for these two compounds, there was a great similarity between the courses of the function in the general share of biogas. With the increase of methane, the content of carbon dioxide also increased. The amount of oxygen was noticeable only during the first days, and then it was at the level of 1.5%. It resulted from the anaerobic nature of the process.

The average values of methane and carbon dioxide share were 46.6% of methane and 23.3% of carbon dioxide and 1.97% of oxygen for raw sewage sludge. These values coincided with literature sources. Methane content should be between 45-70%, carbon dioxide between 25 and 40%. The amount of oxygen cannot exceed 2% (Lachwacka 2009).

The average values for the three basic components of biogas obtained from stabilized sludge that is methane, carbon dioxide and oxygen were 52.9%, 36.6% and 0.9%, respectively. Methane content in biogas from stabilized sewage sludge increased rapidly from 20% in the first to 56% in the fifth day of the experiment. The optimum content was reached on 20th day of the study. During the first days, carbon dioxide prevailed in the biogas composition. This tendency, however, changed at the turn of the third and fourth day. At a later stage of the process, the content of carbon dioxide dropped. The difference in comparison with the previous case where the course of the function had been similar was noticeable. In the analysed example, the course of methane and dioxide functions differed significantly in the initial days of fermentation. The oxygen content of the process oscillated around 0.5%. Bearing in mind the research conducted by Dąbrowska (2015), it can be concluded that the content of individual compounds did not deviate from the standard. The author points to CH_4 content ranging from 43.8% to 64.3% and CO_2 from 31.7% to 36.8%. These values depended on the stage of the methane fermentation process.

CONCLUSIONS

As it can be seen from the conducted research, a much better raw material is the feed formed from raw sewage sludge. The total biogas yield is noticeable, larger almost by 1 dm^3 from one kilogram of dry matter. This raw material, however, is less efficient when it comes to the most important component of biogas which is methane. In this case, stabilized sewage sludge is of a greater value. Nevertheless, the results of the research show that research materials constitute appropriate raw material for biogas production. This is confirmed both by the results of research and comparison with independent research. However, it should be noted that both the total biogas yield and its composition do not meet the highest values in this group. Their value inclines towards the lower limit. Therefore, it is worth determining the technological possibilities that could improve the final yield of biogas. In addition, it is reasonable to determine the optimal conditions that would lead to a more favourable use of the potential of this type of waste. It is rational from the point of view of the conducted research to consider the co-fermentation mentioned in the study.

It should be noted that the biogas yield may differ due to the seasonal composition of the raw material under consideration. The composition of sewage sludge and at the same time the subsequent composition of biogas is related to the quantity and quality of sewage flowing into the sewage treatment plant.

Considering the possibility of using municipal sewage sludge generated in this sewage treatment plant on a larger scale, it is necessary to improve the course of fermentation processes and determine the properties of sewage sludge over a longer period of time.

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REFERENCES

Bień, J., Neczaj, E., Worwąg, M., Grosser, A., Nowak, D., Milczarek, M., Janik, M. (2011). *Kierunki zagospodarowania osadów ściekowych w Polsce po roku 2013.* Inżynieria i Ochrona Środowiska, 14 (4) : 375-384

Bień, J. (2012). *Zagospodarowanie komunalnych osadów ściekowych metodami termicznymi.* Inżynieria i Ochrona Środowiska, 15(4): 439-449

Błaszczyk, K., Krzyśko-Łupicka T. (2014). *Przegląd metod badania osadów ściekowych stosowanych w Polsce*. Inżynieria i Ochrona Środowiska, 17: 117-133

Curkowski, A., Mroczkowski, P., Oniszk-Popławska, A., Wiśniewski, G. (2009). *Biogaz rolniczy – produkcja i wykorzystanie*. Mazowiecka Agencja Energetyczna Sp. z o.o., Warszawa: 11

Dąbrowska, L. (2015). *Wpływ sposobu prowadzenia fermentacji osadów ściekowych na produkcję biogazu.* Rocznik Ochrona Środowiska, 17 : 943-957

DIN 38414 S 8. Niemiecka znormalizowana metoda badań wody i ścieków i osadów. Osady i sedymenty (grupa S).

Dyrektywa Rady z dnia 12 czerwca 1986 roku w sprawie ochrony środowiska

Dyrektywy Parlamentu Europejskiego i Rady 2018/851 z dnia 30 maja 2018 roku w sprawie odpadów.

Dyrektywa Parlamentu Europejskiego i Rady 1999/31/WE z 26 kwietnia 1999 roku w sprawie składowania odpadów.

Kołodziejczak, G. (2012). *Możliwości wykorzystania potencjału energetycznego biogazu powstającego w trakcie oczyszczania ścieków. Analiza opłacalności proponowanych rozwiązań.* NAFTA-GAZ, LXVIII, Kraków

Lachwacka, M. (2009). *Technologie uszlachetniania biogazu do jakości gazu ziemnego*. Wydawnictwo Abrys. Czysta Energia, Poznań

Montusiewicz, A. (2012). *Współfermentacja osadów ściekowych i wybranych kosubstratów jako metoda efektywnej biometanizacji.* Polska Akademia Nauk. Komitet Inżynierii Środowiska, Lublin

Rozporządzenie Ministra Środowiska z dnia 6 lutego 2015 r. w sprawie komunalnych osadów ściekowych (Polish Journal of Law 2015, item 257)

Rozporządzenie Ministra Gospodarki z dnia 16 lipca 2015 r. w sprawie dopuszczenia odpadów do składowania na składowiskach (Polish Journal od Law 2015, item 1277)

Sikora, J., Tomal, A. (2016). W*yznaczenie potencjału energetycznego biogazu w wybranym gospodarstwie rolnym*. Infrastruktura i Ekologia Terenów Wiejskich III(2): 971-982. doi: http://dx.medra.org/10.14597/infraeco.2016.3.2.071

Sikora, J. (2012). *Badanie efektywności produkcji biogazu z frakcji organicznej odpadów komunalnych zmieszanej z biomasą pochodzenia rolniczego*. Infrastruktura i Ekologia Terenów Wiejskich IV(2): 89-98

Szwedziak, K., Woźniak, A. (2005). *Charakterystyka osadu pościekowego pochodzącego z oczyszczalni ścieków w Strzelcach Opolskich*. Infrastruktura i Ekologia Terenów Wiejskich 1: 147-156

Ustawa z dnia 14 grudnia 2012 r. o odpadach (Polish Journal of Law 2013, item 21 with amend.)

Corresponding author: Dr inż. Jakub Sikora
inż. Martyna Płaczek
University of Agriculture in Krakow
Faculty of Production and Power Engineering
Institute of Agricultural Engineering and Computer Science
Ul. Balicka 116 b
30-149 Kraków
phone: +48 12 662 46 60
e-mail: Jakub.Sikora@ur.krakow.pl

Dr hab. inż. Tomasz Jakubowski
University of Agriculture in Krakow
Faculty of Production and Power Engineering
Institute of Machinery Management, Ergonomics and Production Processes
Ul. Balicka 116 b
30-149 Kraków
phone: +48 12 662 46 68
e-mail: Tomasz.Jakubowski@ur.krakow.pl

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