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INFLUENCE OF MAIZE SILAGE STORAGE CONDITIONS ON BIOGAS EFFICIENCY

Summary

The paper presents the issue of the influence of the conditions of maize silage storage on its energy value in the process of methane fermentation. For this purpose, the biogas and methane efficiencies of silage stored under anaerobic and aerobic conditions have been compared. On the basis of executed studies, it has been stated that the process of silage storage and its protection against the contact with air (oxygen) has a very large impact on its quality as a substrate for biogas plants. The silage stored in an oxygen atmosphere produced approx. 80 $m^3 \cdot Mg^{-1}$ of biogas less compared with silage stored under anaerobic conditions, and converting to an organic dry matter, its energy value expressed in produced methane decreases by approx. 70 $m^3 \cdot Mg^{-1}$.

***Key words**: maize silage, storage, methane fermentation, biogas*

WPŁYW WARUNKÓW PRZECHOWYWANIA KISZONKI Z KUKURYDZY NA JEJ WYDAJNOŚĆ BIOGAZOWĄ

Streszczenie

W pracy przedstawiono problem wpływu warunków przechowywania kiszonki z kukurydzy na jej wartość energetyczną w procesie fermentacji metanowej. W tym celu porównano wydajności biogazową i metanową kiszonki przechowywanej w warunkach beztlenowych oraz składowanej przy dostępie powietrza (w warunkach tlenowych). W wyniku realizacji badań stwierdzono, że sposób składowania kiszonki i jej ochrona przed kontaktem z powietrzem (tlenem) ma bardzo duży wpływ na jej jakość jako substratu do biogazowni. Kiszonka składowana w atmosferze tlenowej wyprodukowała bowiem ok. 80 $m^3 \cdot Mg^{-1}$ biogazu mniej w porównaniu do kiszonki składowanej beztlenowo, a w przeliczeniu na organiczną suchą masę jej wartość energetyczna wyrażona w produkowanym metanie spadła o ok. 70 $m^3 \cdot Mg^{-1}$.

***Słowa kluczowe**: kiszonka z kukurydzy, przechowywanie, fermentacja metanowa, biogaz*

1. Introduction

In recent years an intense development of renewable energy sources (RES) as well as increase in their participation in the national energy systems [2,11] has been observed. One of the type of RES installations includes agricultural biogas plants, where in result of methane fermentation process the biogas is produced - a high-energy energy carrier [3]. The biogas plants use various kinds of organic substrates. However, maize silage is one of the most popular in the whole Europe is maize silage [1, 14]. According to available data, the differences in the maize silage composition (eg. content of starch and dry matter) can be related to the differences occurring during flasks development, climatic and soil conditions, harvest date and method of silage [13]. These factors may have a significant impact on the selection of the substrate as animal feed or for biogas production [9, 14]. Very important effect on fermentation process may also have a method of material storage.

The basic method to store the maize intended for use as a substrate for biogas plants consists in a silage process in concrete silos, with storage capacity even higher than 10,000 Mg. This is the cheapest and most popular way of silage storage in biogas plants in Europe. The best way to obtain a high quality silage is to fill the silo as soon as possible (up to 3-4 days) while compaction of the individual layers of fresh material in order to push the air. Furthermore, the crushed material should be covered tightly with a foil to avoid contact with atmospheric oxygen. An access of the air into the stored silage leads to substantial waste and considerable decrease in nutritional value of the silage silage (and thus energy content).

The proper silo exploitation takes place by gradual, progressive selecting of the silage from the front of the pile in such a way to ensure barely minimal contact of the substrate with the atmosphere. However, it often happens that large face-surface of the prism causes that top layer of silage, having contact with the air, is degraded by aerobic bacteria resulting in a quasi-composting process. This process results in the biological oxidation of nutrients contained in the silage, combined with emission of carbon dioxide, water vapor, and in particular cases - an increase in the substrate temperature. Despite the obvious loss deteriorating the quality of the raw material, many biogas plants do not pay a special attention to the proper exploitation of the silage silos. Meanwhile, the decrease in substrate quality can lead to large losses for the plant. Thus, the objective of this study was to determine the degree of decrease in silage biogas efficiency from maize stored under different conditions: optimal (anaerobic) and with air access.

2. Methodology

2.1. Storage of maize silage

The experiment with maize silage storage was carried out on in two closeable 10 dm^3 containers. The bottom part of the first container had special holes of 5 mm diameter allowing oxygen flow inside. While the second bucket ensured tight closure of tested material (fig. 1).

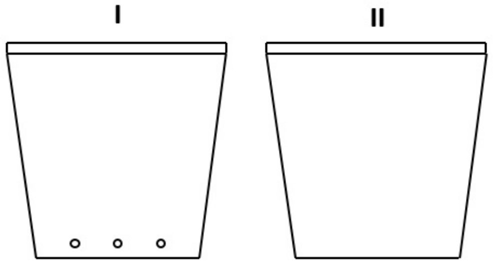

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Fig. 1. Containers to store maize silage: I- in aerobic conditions II- in anaerobic conditions
Rys. 1. Pojemniki do przechowywania kiszonki z kukurydzy: I – w warunkach tlenowych, II- w warunkach beztlenowych

Each container contained 3 kg of representatively taken sample of fresh maize silage, thoroughly tamped. Moreover, in order to reflect the anaerobic conditions prevailing in properly formed piles, before the closure of the container not equipped with the holes, its interior was flushed using inert gas (carbon dioxide).
The material was stored in aforementioned containers for 60 days at room temperature. After that time, the content of containers was thoroughly mixed in order to obtain representative samples.

2.2. Methane production efficiency of the substrate

The study was carried out at the Laboratory of Ecotechnologies – the biggest biogas laboratory in Poland. Laboratory working within the Institute of Biosystems Engineering (Poznan University of Life Sciences). The research tests were based on modified German standard DIN 38 414/S8 and the standardized biogas guide from the Association of German Engineers in Dresden - VDI 4630. Detailed methodology of performed research was presented by Cieślik et al. [5].

3. Results and discussion
3.1. Physical and chemical parameters analysis

The results of executed analyses of physical and chemical parameters of materials and inoculum used in the experiment have been collected in table 1.

Table 1. Physical and chemical parameters of substrates and inoculum
Tab. 1. Parametry fizykochemiczne substratów i inoculum

	pH	Conductivity [mS]	Dry matter [%]	Organic dry matter [% DM]
Inoculum	7.87	18.825	2.99	68.30
Maize silage from anaerobic storage	3.56	0.394	35.10	96.64
Maize silage from aerobic storage	5.60	0.251	29.03	95.38

Source: own work / *Źródło:* opracowanie własne

Obtained parameters allow determination of the proper ratio of fermentation blends and, subsequently, to calculate the biogas efficiency on fresh matter (FM), dry matter (DM) and organic dry matter (ODM) of the substrates.
Inoculum used in the experiments was characterized by dry matter content and organic dry matter content at the level of 2.99% and 68.3% sm. High pH and conductivity values (respectively 7.87 and 18.825 mS) indicate a high degree of mineralization of the material, i.e. properly run in methane fermentation process.

On the basis of conducted analysis of physico-chemical parameters, there have been observed the differences between maize silage stored in the silage under anaerobic conditions and kept under aerobic ones. The first material had pH of 3.56 and conductivity of 0.394 mS. The result of pH and conductivity for the second material amounted respectively 5.6 and 0.251 mS. Investigated substrates differed in the content of dry matter and organic dry matter, which for silage stored under anaerobic conditions was 35.1% DM, and 96.64% ODM, and in case of silage with oxygen access the obtained results were respectively the following: 29.03%, and 95.38% ODM. Lower content of dry matter and organic dry matter in maize silage stored in aerobic conditions has proved the decomposition of organic matter of the substrate, which led, in presence of oxygen, in quasi-composting process, to production of CO_2, H_2O and ash.

3.2. Daily biogas and methane production

Average time of fermentation of maize silage without oxygen amounted approx. to 18 days. In contrast, HRT (Hydraulic Retention Time) for the substrate stored under aerobic conditions amounted approx. to 22 days. It should also be noted that 90% of the fermentation substrate for first of the materials has been obtained during 12th day of fermentation, and for the second one – 15th day of the process. However, it is worth to remember, that time of fermentation (HRT) carried on an industrial scale, may not be less than 15-16 days. This is mainly due to the rate of proliferation of Figures 3 and 4 that show the daily dynamics of biogas production for different substrates.

For both tested materials the highest peak of biogas production was observed on the second day of the process (figures 3 and 4). It is due to intensive degradation of simple organic compounds - mainly of carbohydrates and proteins - in hydrolysis process [4]. Figure 5 shows the cumulative methane production per Mg dry organic matter of the substrate.

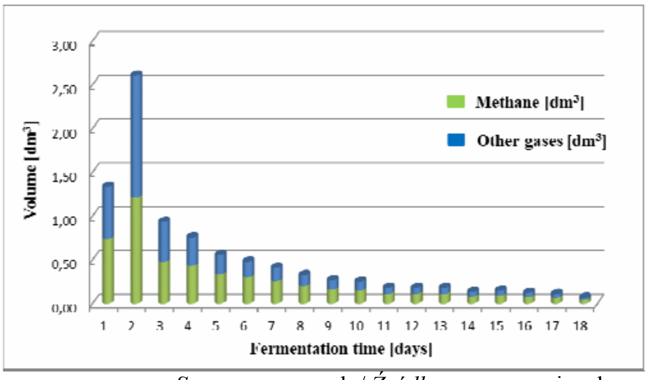

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Fig. 3. Daily biogas and methane production from maize silage stored in anaerobic conditions
Rys. 3. Wykres dobowej produkcji biogazu i metanu z kiszonki kukurydzy przechowywanej w warunkach beztlenowych

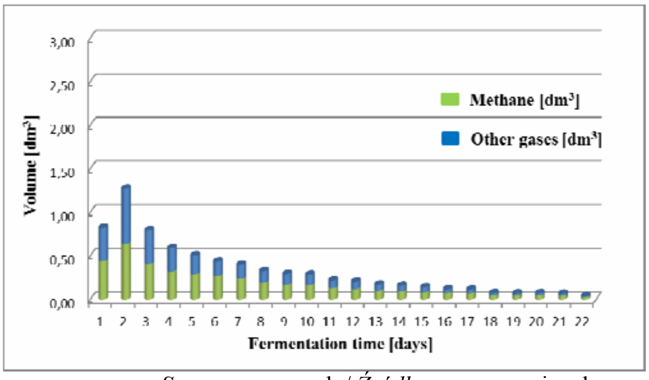

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Fig. 4. Daily biogas and methane production from maize silage stored in aerobic conditions
Rys. 4. Wykres dobowej produkcji biogazu i metanu z kiszonki kukurydzy przechowywanej w warunkach tlenowych

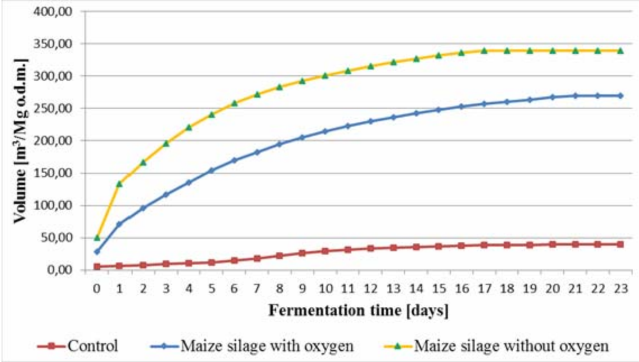

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Fig. 5. Cumulated methane production from Mg organic dry matter
Rys. 5. Skumulowana produkcja metanu z Mg suchej masy organicznej

Table 2. Biogas efficiency of the substrates in mesophilic fermentation
Tab. 2. Wydajność biogazowa substratów w fermentacji mezofilowej

		Fresh matter		Dry matter		Organic dry matter	
Sample	Methane content [%]	Cumulated methane [m^3•Mg^{-1} FM]	Cumulated biogas [m^3•Mg^{-1} FM]	Cumulated methane [m^3•Mg^{-1} DM]	Cumulated biogas [m^3•Mg^{-1} DM]	Cumulated methane [m^3•Mg^{-1} ODM]	Cumulated biogas [m^3•Mg^{-1} ODM]
Maize silage from anaerobic storage	52.35	115.10	21.72	327.88	623.05	339.27	644.69
Maize silage from aerobic storage	53.35	74.1	139.67	256.63	481.11	269.05	504.34

Source: own work / *Źródło:* opracowanie własne

The research has proven that maize silage stored in anaerobic conditions (without oxygen presence) had clearly higher biomethane productivity compared with the substrate stored in aerobic conditions (with presence of oxygen).

3.3. Biogas and methane efficiency

The table 2 presents the biogas efficiencies and concentration of methane in biogas from tested maize silages subjected to methane fermentation under mesophilic conditions.

In the process of mesophilic fermentation of maize silage stored under anaerobic conditions, converting to Mg of fresh matter of substrate, it has been obtained approx. 220 m^3 of biogas with an average content of methane approx. 52.35% (table 2). The obtained results are comparable to those gained by other researchers and available literature data [1, 6, 7, 10]. However, in case of maize silage stored under oxygen conditions, it have been observed significantly lower results of biogas production efficiency and methane amounting respectively to approx. 80 m^3•Mg^{-1} of fresh matter and approx. 40 m^3•Mg^{-1} FM. Converting to an organic dry matter, the energy efficiency of silage stored with air access decreased by 20.7% (from 339.27 to 269.05 m^3•Mg^{-1} ODM). Such a huge decrease in biogas efficiency can lead to significant economic losses for biogas plant. With a standard assumption, that the biogas plant with a capacity of 1 MWe per year needs 20,000 Mg corn silage, the decline in its productivity by 20% requires additional power supply for installation with mass of 4000 Mg. According to average price of maize for silage in Poland which is at the level of 30 euros - it gives an additional cost of 120,000 euros.

4. Conclusions

On the basis of obtained research results, the following conclusions have been formed:
1. The method of silage storage and its protection against contact with air (oxygen) has a considerable impact on its quality as a substrate intended for biogas plant.
2. The silage stored in an aerobic atmosphere gives approx. 80 m^3•Mg^{-1} of biogas less in comparison to silage stored anaerobically, and converting to an organic dry matter its energy value expressed in produced methane decreases of approx. 70 m^3•Mg^{-1}.
3. Reduction in energy value of the silage due to improper storage leads to the necessity to purchase additional quantity of material, which can be a significant cost for biogas plant.

5. References

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