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Comparison of sewage sludge biogas fermentation with different temperatures and addition of maize silage

Pablo César Rodríguez CARMONA[1]*, Jacek DACH*[1]

[1] *Poznan University of Life Sciences;Institute of Biosystems Engineering. ul. Wojska Polskiego 50, 60-637, Poznan, Poland. Tel: 532843703, e-mail: pablocesar1987@gmail.com.*

Abstract

Maize silage is the primary feedstock utilized in biogas plants in Poland. However, due to the increasingly high price of that substrate and the volatile prices of green certificates, it is necessary to search for different substrates for the biogas production. On the other hand, the large amount of sewage sludge produced in wastewater treatment plants creates an important environmental problem in Poland. The use of sewage sludge as a source of renewable energy reduces the amount of stored sludge and improves environmental safety. The problem during anaerobic digestion of sewage sludge is to provide a suitable C:N ratio in the range 20-30. Therefore, it is important to add to the sludge substances rich in carbon. It is because the sludge itself is an inefficient substrate in terms of biogas production. The use of co-substrates ensures maximum use of the potential of the digester, regulates the kinetics of methane fermentation by improving the C:N ratio, increasing its efficiency and economic viability. The aim of this paper is to find synergy between sewage sludge and maize silage in two different temperatures: 39ºC (mesophilic range) and 55ºC (thermophilic range).

Keywords: biogas, sewage sludge, maize silage, fermentation, mesophilic, thermophilic

Streszczenie

Porównanie wydajności biogazowej osadów ściekowych, w tym z dodatkiem kiszonki z kukurydzy w różnych temperaturach

Kiszonka z kukurydzy jest podstawowym surowcem wykorzystywanym w polskich biogazowniach. Jednak ze względu na coraz wyższe ceny tego substratu oraz wahania cen zielonych certyfikatów, koniecznym staje się poszukiwanie różnych substratów do produkcji biogazu. Z drugiej strony, duża ilość osadu wyprodukowanego w oczyszczalniach ścieków, tworzy poważny problem dla środowiska w Polsce. Stosowanie osadów ściekowych jako źródła energii odnawialnej może zmniejszyć ilość składowanych osadów i poprawić bezpieczeństwo środowiska. Problemem podczas beztlenowej fermentacji osadu ściekowego jest konieczność wystąpienia odpowiedniego stosunku C:N na poziomie 20-30. Dlatego ważne jest aby dodać do osadów innych, bogatych w węgiel materiałów. Przemawia również za tym fakt iż sam osad nie jest wydajnym substratem do produkcji biogazu. Zastosowanie ko-substratów pomoże maksymalnie wykorzystać potencjał fermentacyjny, reguluje kinetykę fermentacji metanowej poprzez poprawę stosunku C:N, zwiększa wydajność i opłacalność ekonomiczną procesu. Celem pracy było znalezienie synergii pomiędzy osadami ściekowymi oraz kiszonką z kukurydzy w dwóch różnych temperaturach: 39ºC (zakres mezofilowy) i 55ºC (zakres termofilowy).

Słowa kluczowe: biogaz, osad ściekowy, kiszonka z kukurydzy, fermentacja mezofilowa, fermentacja termofilowa

1. Introduction

Biogas is a renewable and sustainable energy carrier generated via anaerobic digestion (AD) of biomass. There are at least five main biomass resources from which biogas can be produced, i.e. sewage, landfill, livestock manure, organic wastes and energy crops. Depending on its origin biogas comprises methane (40–75%), carbon dioxide (20–45%) and some other compounds, usually in trace quantities [1].The use of biogas for energy production reduces the use of fossil fuels, the combustion of which contributes to the climate change [2].

Maize silage is the primary feedstock utilized in biogas plants in Poland. However, due to the increasingly high price of that substrate and the volatile prices of green certificates, it is necessary to search for different substrates for the biogas production [3]. Processing of the biowaste into the biogas is one of the most effective technologies providing to obtain a “green” energy and improvement of the environment [4].

Sewage sludge is a widely used substrate for biogas production as well. It is a waste which is difficult to manage, but after fermentation it is a suitable fertilizer. The problem during anaerobic digestion of sewage sludge is to provide a suitable C:N ratio in the range 20-30. Therefore, it is important to add to the sludge substances rich in carbon. It is because the sludge itself is an inefficient substrate in terms of biogas production. The use of co-substrates ensures maximum use of the potential of the digester, regulates the kinetics of methane fermentation by improving the C:N ratio, increasing its efficiency and economic viability [1].

The aim of this paper is to find synergy between sewage sludge and maize silage in two different temperatures: 39ºC (mesophilic range) and 55ºC (thermophilic range).

2. Materials and methods

The study was conducted in Laboratory of Eco-technologies – the biggest biogas laboratory in Poland, Laboratory working within the Institute of Biosystems Engineering (Poznan University of Life Sciences). The research based on modified German standard DIN 38 414/S8, while chemical and physical analytical methods based on Polish Standard System. The samples were fermented at mesophilic temperature range (around 38ºC) and thermophilic temperature range (around 55ºC). The analytical procedures concerning biowaste were also developed within several scientific projects financed within EU 6th Framework Program and Polish Ministry of Sciences within the years 2006-12 [5].

2.1. Substrates and inoculum

The sewage sludge was taken from the waste water treatment plan „Lewobrzezna” in Poznan. More precisely, it was raw sludge after densification. The inoculum (digested pulp) was taken from an agricultural Polish biogas plant working on caw slurry and maize silage. And the maize silage was taken from the biogas plant in the municipality of „Dzialyn”, the same maize silage that they use for fermentation. It is possible to observe in the table 2.1their parameters.

Table 2.1 Substrates parameters

Sample	pH	Conductivity (mS/m)	Total solids (%)	Volatile solids (% TS)
Inoculum	7.93	16.35	3.65	86.39
Sewage sludge	6.23	2.23	3.63	75.39
Maize silage	4	1.8	38.06	96.57

2.1. Methane production set-up

The experiment of biogas production was conducted through anaerobic digestion in the set of multichamber biofermenter (Fig. 2.1). This biofermenter is commonly used for testing biogas efficiency for large amount of biomass samples.

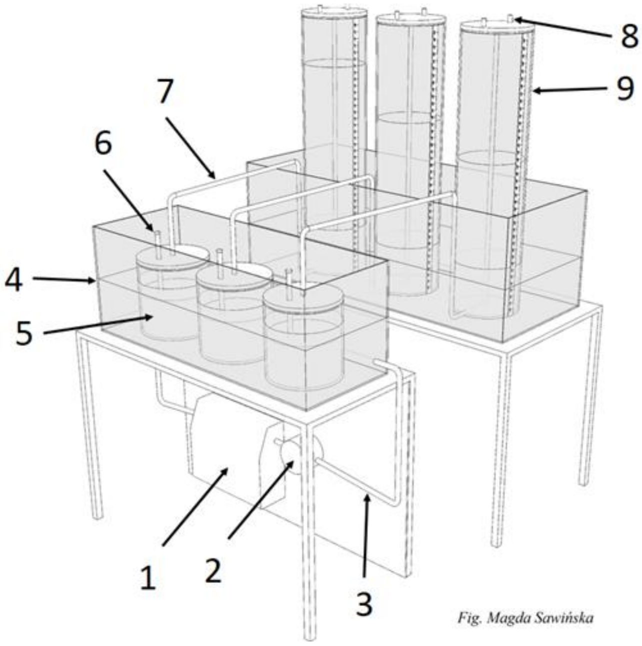

Fig 2.1. Scheme of biofermenter for biogas production research (3-chamber section) 1. Water heater with a temperature in the range of 20-70 ºC; 2.Water pump; 3.Isolated hot liquid tube; 4.Layer of water at mesophilic or thermophilic temperature; 5.Biofermentor with the input of 1.4 dm3 of capacity; 6.Sampling tube; 7.Tube for biogas flow; 8.Security valves (also use for taking biogas samples); 9.Biogas container (made of poly (methyl methacrylate)).

The conditions present within the fermentation chamber allowed to create an ideal condition for methane fermentation of the samples, thanks to the absence of oxygen and the addition of fermentation inoculum. Glass chambers with samples were placed in water with regulated temperature (around 39°C for mesophilic fermentation and 55ºC for thermophilic fermentation), which are real conditions of biogas plant. Biogas produced in each separate chamber was transferred to a cylindrical store, filled in with neutral liquid. When the gas enters into the cylindrical tube, the level of neutral liquid drops. It allows to determinate the exact volume of biogas into the cylinder. The samples were tested in 3 repetitions in order to create an exact average.

2.3. Solid samples

Prepared samples needed to be analyzed in respect of the correct physical and chemical parameters. The most important one was pH (optimum between 6.8 and 8) and ammonium nitrogen concentration (lower than 2,5 g/dm3 of prepared mixture). The pH was measured using laboratory multi-meter CP-411 (Elmetron). Additionally, T.S. and V.S. were determined. It was necessary to calculate biogas production efficiency in typically used units; m3 • ton-1 V.S.

During the experiment the following standard methodology established by Polish Norms (PN) has been used: for dry matter PN-75 C-04616/01, pH – PN-90 C-04540/01, conductivity PN-EN 27888:1999 and organic dry matter PN-Z-15011-3. Ammonia was determined according to Standard Methods [6].

2.4. Gas samples

The volume of produced biogas was measured every 24 hours. The gas composition was checked when the production of biogas was at least 0.45 dm^3 (at the beginning of the experiment it was once a day, and after the culmination point, when the production slowed down, each three days). The concentration measurements of methane, carbon dioxide, hydrogen sulphide, ammonia and oxygen in the produced biogas were carried out with the use of the absorption sensors working in an infrared and electrochemical sensor line. The analyzer used for measurements was the model GA 5000 from the GEOTECH firm.

The ranges of detected gaseous compounds were: 0-100% CH_4, 0-100% CO_2, 0-25% O_2, 0-2000 ppm H_2S and 0-2000 ppm NH_3, respectively. Therefore, each sample for biogas production was monitored for the gas compounds daily. The volume of biogas production and the methane content of biogas were calculated in an Excel sheet. According to the Excel generated graph, it was possible to determine if the sample was working properly during the experiment. Gas-monitoring system was calibrated each week using calibration gases provided by Messer Company, using the following concentration of gas calibration: 65% of CH_4, 35% of CO_2 (in the same mixture). 500 ppm of H_2S and 100 ppm of NH_3. For O_2 sensor calibration, the typical synthetic air was used (20% of O_2).

2.5. Mixture preparations

The used mixture, with their parameters, can be seen in the table 2.2 for mesophilic fermentation and in the table 2.3 for thermophilic fermentation.

Table 2.2. Mesophilic fermentation mixtures and their parameters

Sample	Substrate (g)	Inoculum (g)	pH	Conductivity(mS/m)
Inoculum	-	1212,3	7,99	16.35
Inoculum 2	-	1213,45	7,99	16.35
Inoculum 3	-	1224,6	7,99	16.35
Sewage sludge 1	437,05	773,08	7.51	0.571
Sewage sludge 2	441,84	767,76	7.51	0.571
Sewage sludge 3	433,23	771,31	7.51	0.571
Maize silage + sewage sludge 1	28,27 + 85,8	1093,31	7.7	0.544
Maize silage + sewage sludge 2	28,84 + 86,07	1115	7.7	0.544
Maize silage + sewage sludge 3	28,6 + 85,77	1086,97	7.7	0.544
Maize silage 1	35,16	1165,76	7.7	7.8
Maize silage 2	35,22	1168,01	7.7	7.8
Maize silage 3	35,88	1167,77	7.7	7.8

Table 2.3 Thermophilic fermentation mixtures and their parameters

Sample	Substrate (g)	Inoculum (g)	pH	Conductivity(mS/m)
Inoculum	-	1200,45	7,72	7,26
Inoculum 2	-	1209,95	7,72	7,26
Inoculum 3	-	1220,05	7,72	7,26
Sewage sludge 1	285,65	931,29	7,72	11,8
Sewage sludge 2	285,73	920,52	7,72	11,8
Sewage sludge 3	285,94	921,55	7,72	11,8
Maize silage + sewage sludge 1	24,01 + 71,94	1134	7,75	15
Maize silage + sewage sludge 2	23,7 + 71,9	1105,5	7,75	15
Maize silage + sewage sludge 3	23,77 + 72,01	1104,8	7,75	15
Maize silage 1	35,21	1171,75	7,64	6,75
Maize silage 2	35,21	1166,15	7,64	6,75
Maize silage 3	35,34	1173,85	7,64	6,75

2.6. Cumulative production calculation

The proportion of gas production from the inoculum in the mixtures is calculated following the equation 2.1:

$$V_{IS(korr.)}=\frac{\Sigma V_{IS}\, m_{IS}}{m_M} \qquad \text{Eq. (2.1)}$$

Where:

$V_{IS(korr.)}$	gas volume which was produced from the inoculum, in $l_{N.}$
ΣV_{IS}	total of the gas volumes in the whole research, in $l_{N.}$
m_{IS}	mass of the inoculum used for the mixture, in g.
m_M	mass of the inoculum used in the control test, in g.

The net gas normal volume of the substrate in the research is obtained for the same research times as the difference between the normal volumes of the dry gas in the research, minus the normal volume of the dry gas from the inoculum. The specific fermentation gas production Vs from the substrate as a function of the research duration is calculated step by step from reading to reading in accordance with the equation 2.2:

$$V_S=\frac{\Sigma V_n\, 10^4}{m\, w_T w_V} \qquad \text{Eq. (2.2)}$$

V_S	the specific fermentation gas production relative to the ignition loss mass during the research period, in l_N/kg GV;
ΣV_n	net gas volume of the substrate from the whole research, in $l_{N;}$
m	mass of the substrate, in g;
w_T	dry residue of the sample, in %;
w_V	loss on ignition (GV) of dry mass of the sample [%].

The net methane normal volume of the substrate in the research is obtained for the same research times as the difference between the normal volumes of the methane in the research, minus the normal volume of the methane from the inoculum. The methane normal volume is calculated by multiplying the normal volume of the dry gas by the methane content of the dry gas. If only the carbon dioxide content of the dry gas is available rather than the methane content, the methane content is calculated under the assumption that the dry gas is composed only of methane and carbon dioxide.

3. Results

The fermentation time for sewage sludge and sewage sludge mixed with maize silage in mesophilic conditions lasted 33 days, while maize silage without sewage sludge was 22 days. In thermophilic conditions, the fermentation process for sewage sludge and maize silage mixed with sewage sludge lasted 28 days, and for maize silage was 16 days.

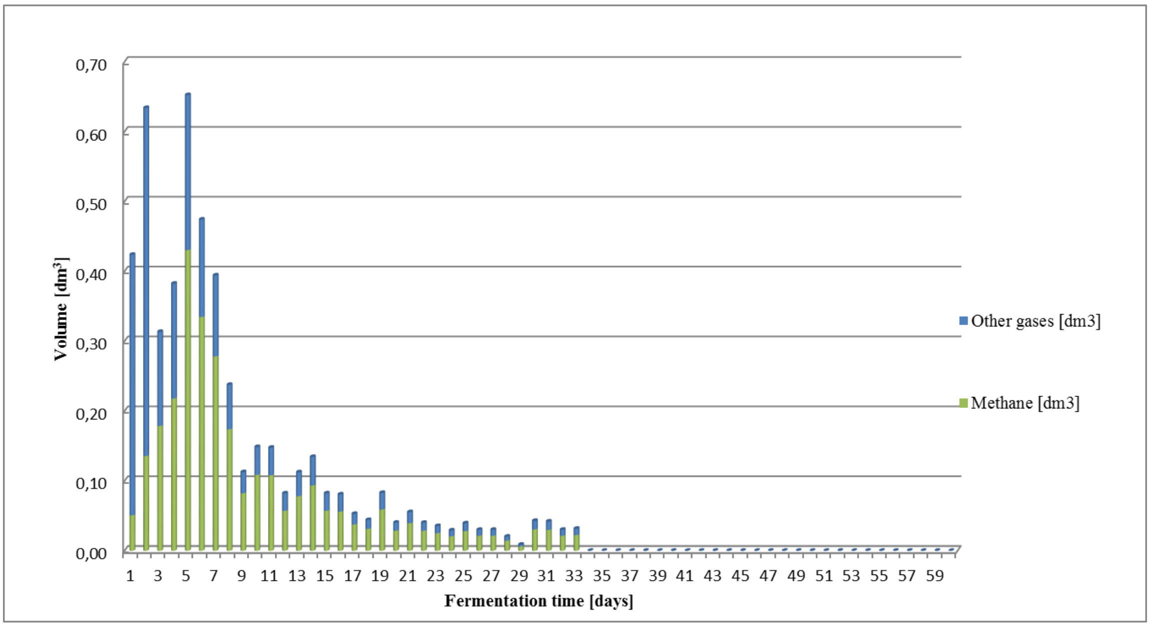

Fig 3.1. Daily mesophilic fermentation of sewage sludge.

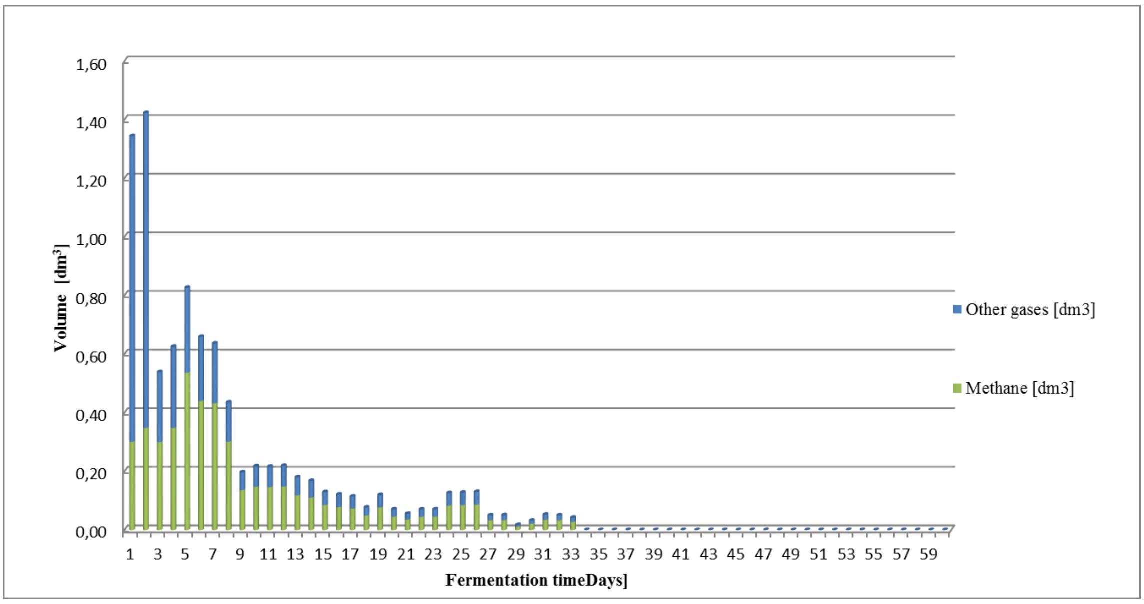

Fig 3.2. Daily mesophilic fermentation of sewage sludge mixed with maize silage.

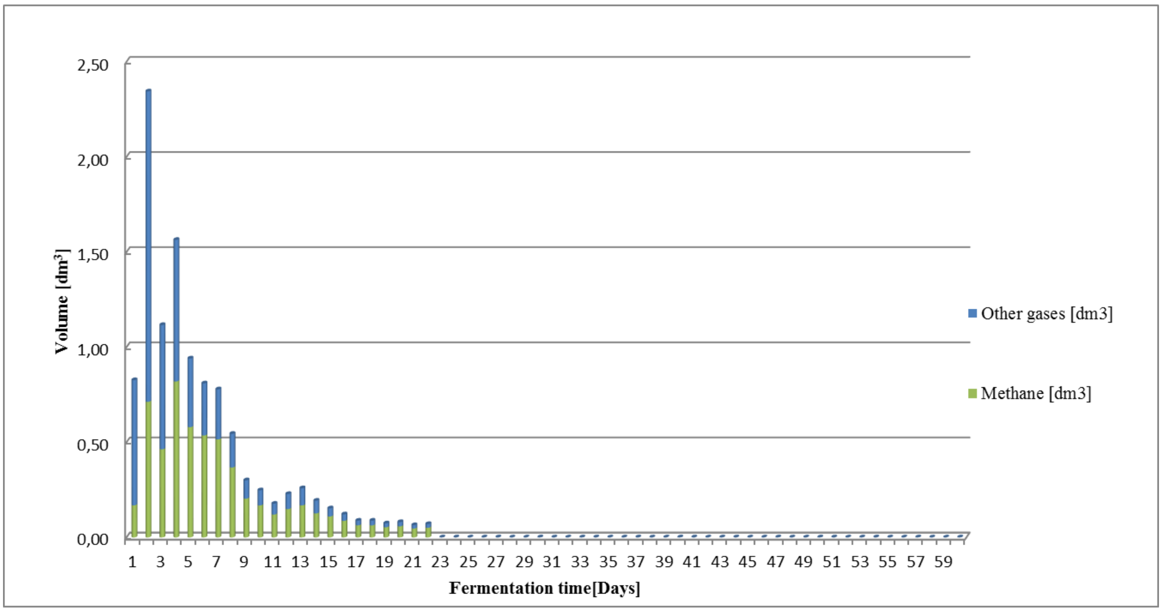

Fig 3.3. Daily mesophilic fermentation of maize silage.

As observed in those graphics, the fermentation of maize silage is much more intense than the other ones, but sewage sludge has a higher amount of methane into the biogas than the other substrates.

In thermophilic fermentation, the results are similar but in shorter time. It can be stated that the thermophilic fermentation has a better efficiency as shown in the figures 3.4 and 3.5.

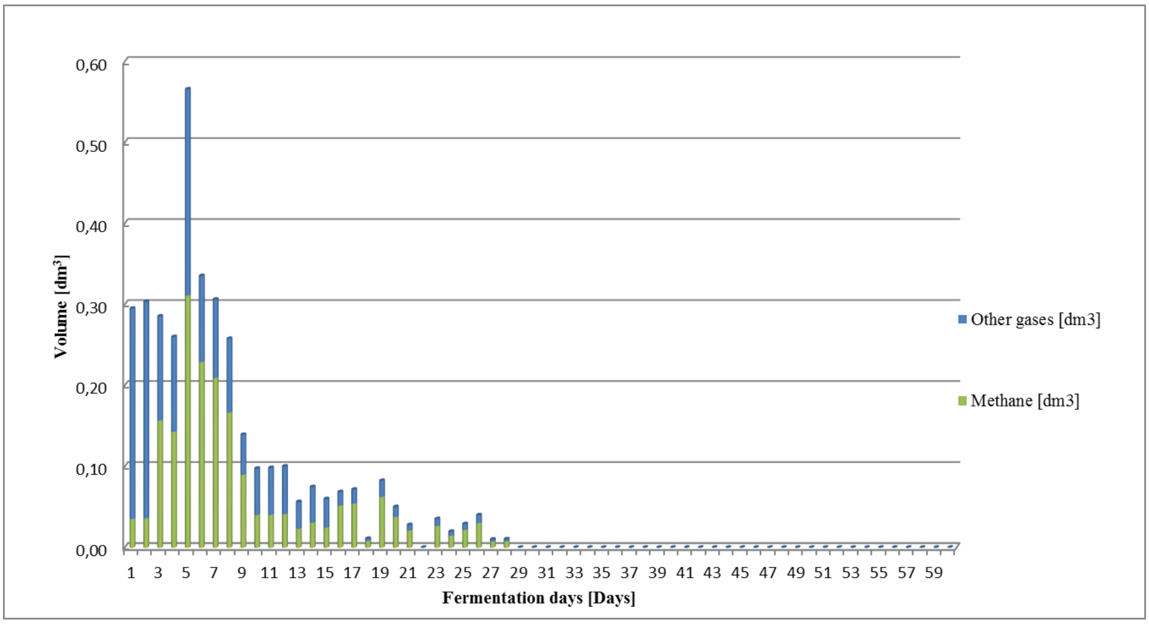

Fig 3.4. Daily thermophilic fermentation of sewage sludge.

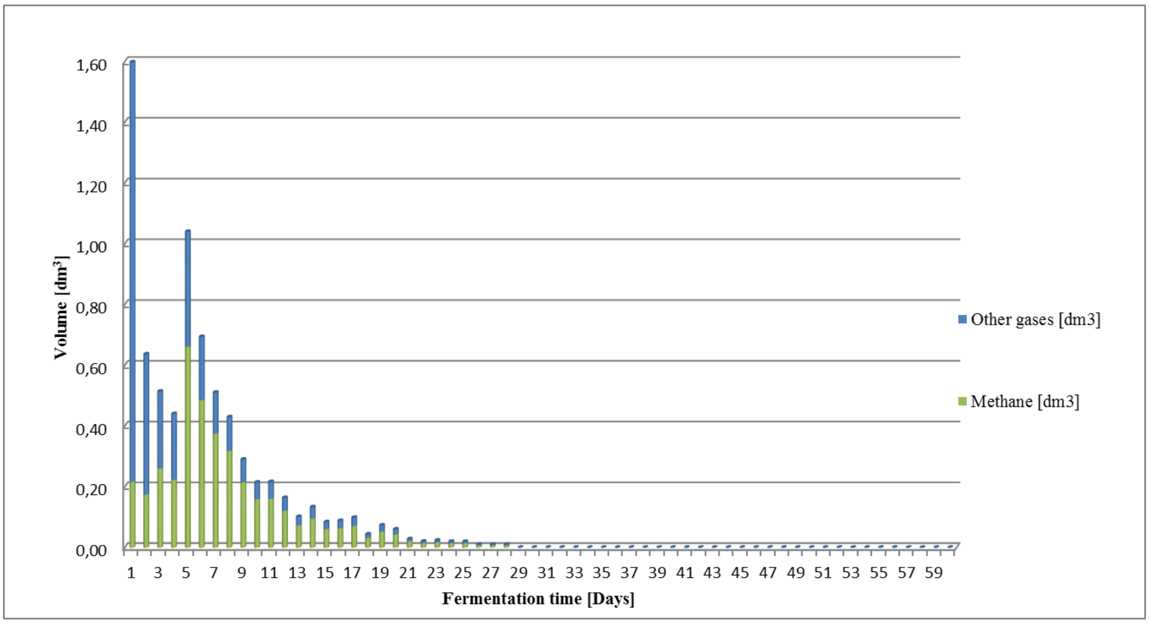

Fig 3.5. Daily thermophilic fermentation of sewage sludge mixed with maize silage.

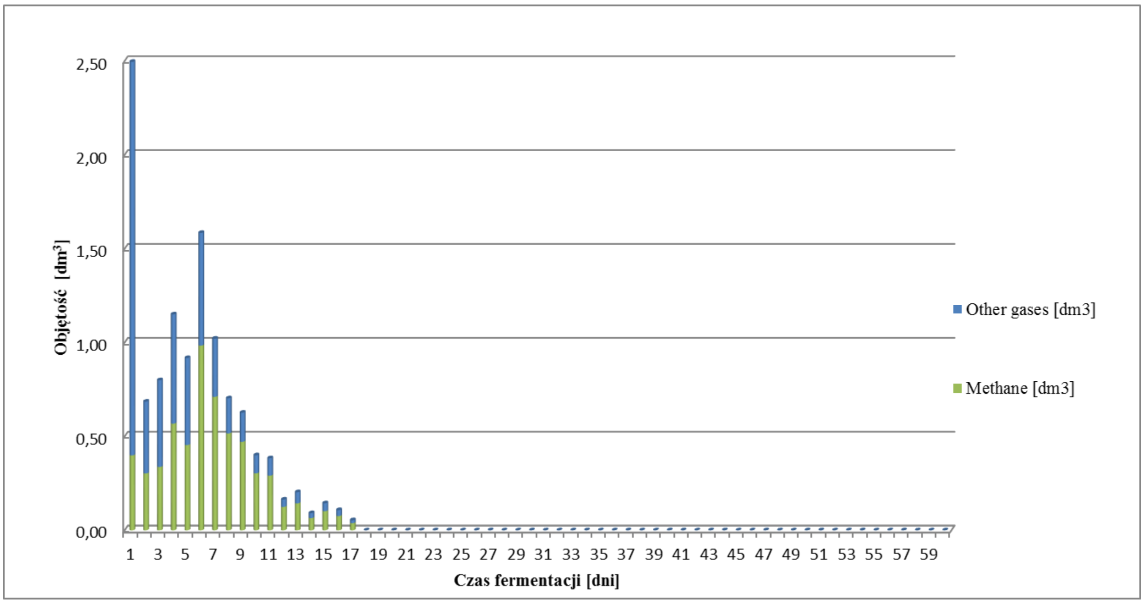

Fig 3.6. Daily thermophilic fermentation of maize silage.

Observing those numbers, it can be deduced that the fermentation process is much more efficient for maize silage than for sewage sludge, but an addition of a little amount of maize silage to the sewage sludge can fix the low efficiency. In the figures 3.7, 3.8, 3.9 and 3.10 can be observed the cumulated biogas and methane production which is more useful than the daily production because it shows the total production of a substrate which is the most important parameter for biogas plants. All the cumulative productions are in terms of organic dry matter, which is the most objective parameter for biogas production.

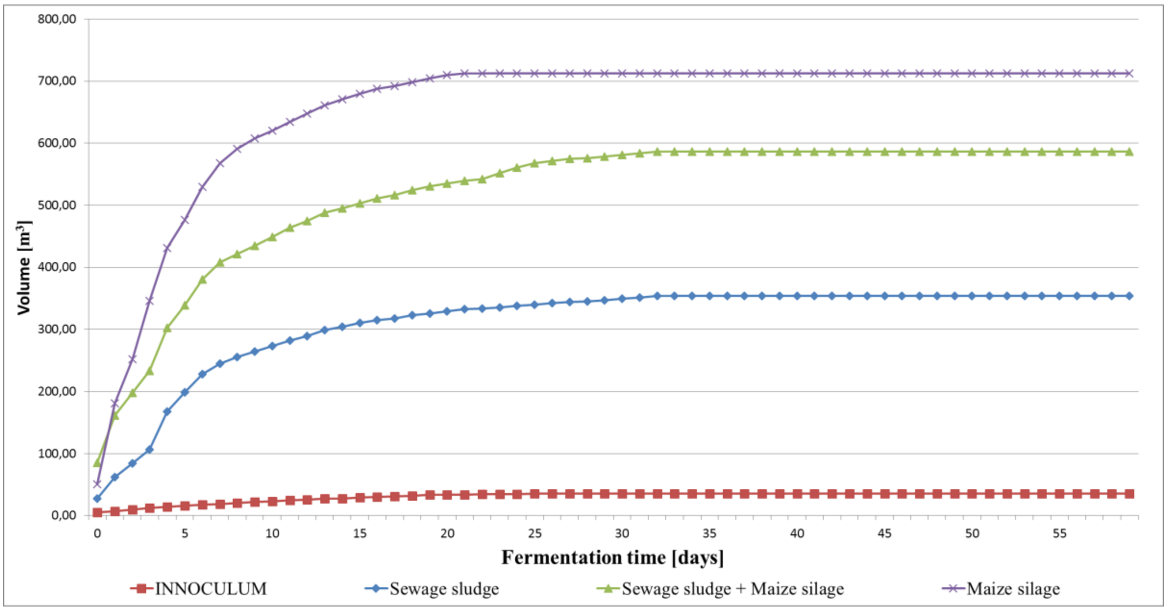

Fig 3.7. Cumulative biogas production for mesophilic fermentation in m^3/tons of organic dry matter.

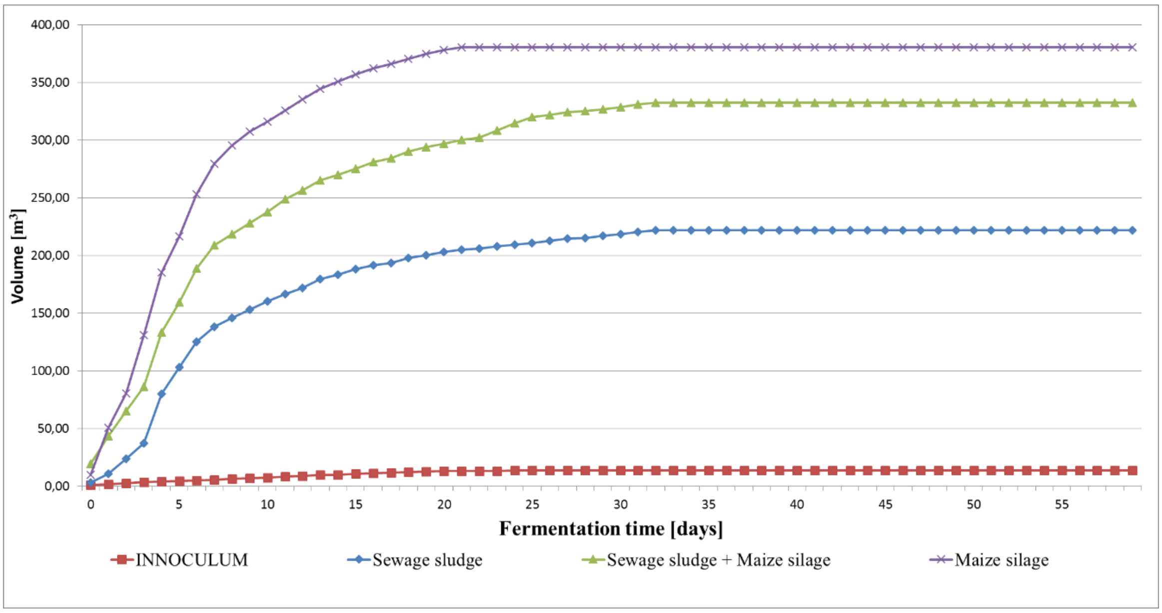

Fig 3.8. Cumulative methane production for mesophilic fermentation in m^3/tons of organic dry matter.

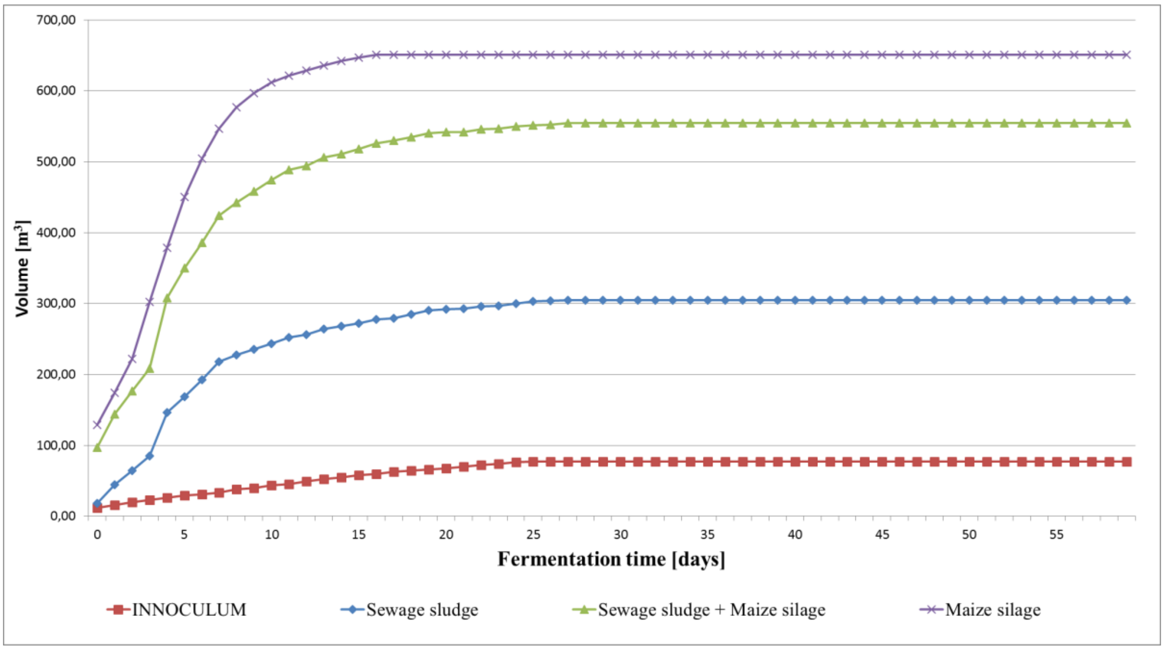

Fig 3.9. Cumulative biogas production for thermophilic fermentation in m^3/tons of organic dry matter.

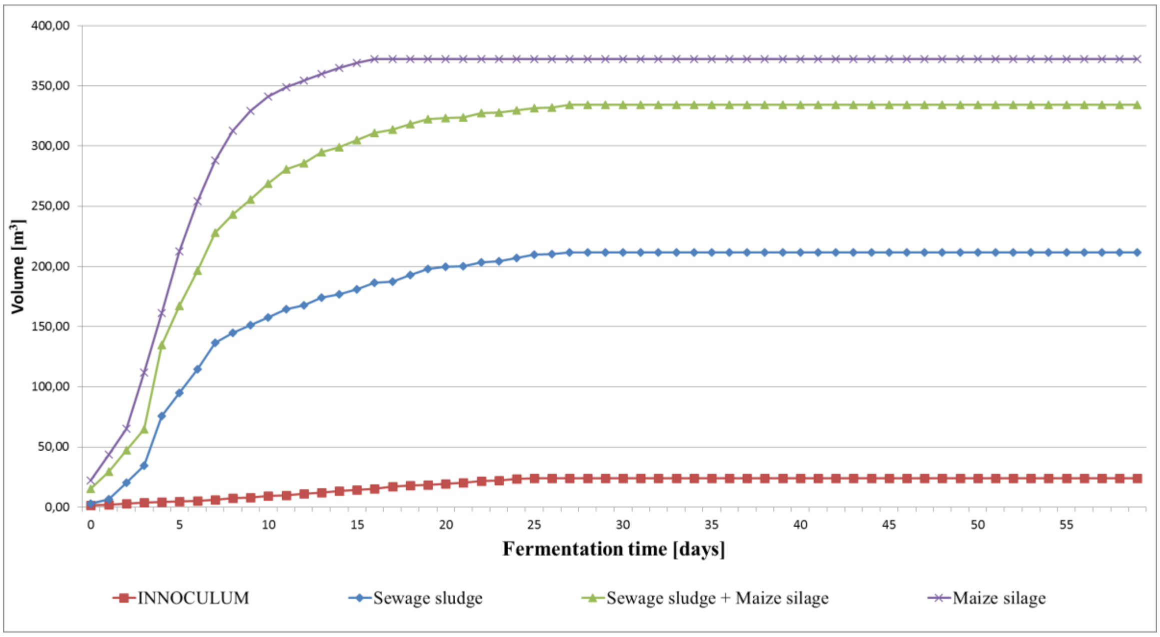

Fig 3.10. Cumulative methane production for thermophilic fermentation in m^3/tons of organic dry matter.

Table 3.1. Cumulated biogas and methane production of the samples from mesophilic fermentation in freshand organic dry matter.

		Average results including the control sample			
		Fresh matter		Organic dry matter	
Sample	Methane content (%)	Cumulated methane [m^3 · ton^{-1} V.S.]	Cumulated biogas [m^3 · ton^{-1} V.S.]	Cumulated methane [m^3 · ton^{-1} V.S.]	Cumulated biogas [m^3 · ton^{-1} V.S.]
Inoculum	39,85	0,45	1,12	14,14	35,49
Sewage sludge	62,74	6,08	9,69	221,79	353,51
Maize silage + Sewage sludge	56,70	37,36	65,90	332,64	586,65
Maize silage	53,38	139,81	261,93	380,33	712,55

Table 3.2. Cumulated biogas and methane production of the samples from thermophilic fermentation in freshand organic dry matter.

		Average results including the control sample			
		Fresh matter		**Organic dry matter**	
Sample	**Methane content (%)**	**Cumulated methane [m^3 · ton^{-1} V.S.]**	**Cumulated biogas [m^3 · ton^{-1} V.S.]**	**Cumulated methane [m^3 · ton^{-1} V.S.]**	**Cumulated biogas [m^3 · ton^{-1} V.S.]**
Inoculum	30,82	0,41	1,33	23,80	77,23
Sewage sludge	69,39	5,79	8,35	211,42	304,66
Maize silage + Sewage sludge	60,23	37,43	62,14	334,06	554,67
Maize silage	57,16	136,84	239,39	372,25	651,22

As can be seen in those tables, the maize silage is twice more efficient than sewage sludge, but the mix of the two substrates is overwhelmingly efficient, because using half of the portion used in maize silage fermentation and sewage sludge which is a very available waste, the achieved biogas production is very close to the production from maize silage, both in thermophilic and mesophilic conditions. Also, it has to be noticed that the methane content of the thermophilic samples is higher for thermophilic fermentation (besides inoculum, which is not so important).

4. Conclusions

Sewage sludge is not the best substrate for biogas fermentation, neither mesophilic nor thermophilic. But the addition of a small amount of maize silage increase significantly the produced biogas. It is important to remark that this amount of maize silage is half of the amount commonly used for methane fermentations. Also, it is very important to notice that the difference of the produced biogas mixing the maize silage with sewage sludge and fermenting the maize silage alone is very small. In huge scale, it means that a huge amount of maize silage could be saved for alimentary purpose instead of being used for energetic purpose. Also, it would help to save much money, because a biogas plant would pay half of the money for maize silage, and no much money for sewage sludge because it is a waste, the hypothetical biogas plant just should pay for the transport of the sewage sludge.

Choosing between thermophilic or mesophilic fermentation of these substrates, mesophilic would be the most sensible selection. The difference in fermentation days is insignificant, mesophilic fermentation generates more biogas, but thermophilic fermentation generates higher quality biogas. But, in mesophilic fermentation the temperature is around 39ºC, and 55ºC for thermophilic, so the difference of energy that should be used for a suitable fermentation is just too big. It would not be profitable for biogas plants to use thermophilic fermentation taking into account that there is almost no difference between mesophilic and thermophilic fermentation. Also, in thermophilic fermentation, it was noticed a considerable amount of hydrogen sulphide during fermentation, so the biogas plant should implement air purification machinery, which a consequent increase of costs. In mesophilic fermentation the amount of hydrogen sulphide was insignificant.

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