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ANALYSIS OF THE POSSIBILITIES OF USING A HYBRID HEATING SYSTEM IN THE PROCESS OF ANAEROBIC BIOMASS DECOMPOSITION IN A CONTAINER FERMENTER

Summary

The subject of the work concerns the design of a hybrid solar system to maintain mesophilic conditions in the process of anaerobic biomass decomposition. The main purpose of the work was to design a hybrid heating installation for a biomass utilizer. It was assumed to simulate the use of three energy sources: photovoltaic panels, solar collector and heat from biogas combustion. It was assumed that the results of the analysis will be supported by evaluation of biogas yield for waste consisting food. The quasi-continuous and periodic operation of the rendering chamber was tested in relation to the energy demand for maintaining the mesophilic conditions in the fermentation process. As a result of the objective of the work, biogas productivity tests of the selected substrate mixture were carried out. A general design of the utilization plant (micro-biogas plant) was also carried out, including thermal insulation and the design of the heating system. In order to determine the heat losses of the digester, the methodology based on the heat transfer coefficient by individual partitions was used. The level of biogas production was determined using a test stand complying with the requirements of DIN 38 414 S.8. On the basis of the volume of biogas production, thermal deficiencies resulting from its combustion were determined. Biogas deficiencies constituted more than 30% in the worst computing conditions for the periodic system and about 6% for the quasi-continuous system. The designed heating installation, which uses additional solar energy, in the case of a periodic system, allowed to cover 100% of the summer heat demand. In winter, the coverage of heat demand was around 90% for average monthly temperatures in December and January and 80% for the worst computing conditions. Identified energy shortages can be limited by optimizing the control of the biological process and optimizing the parameters of thermally insulating layers.

***Key words**: methane fermentation, waste processing, container utilizer, hybrid heating system*

ANALIZA MOŻLIWOŚCI WYKORZYSTANIA HYBRYDOWEGO SYSTEMU GRZEWCZEGO W PROCESIE BEZTLENOWEGO ROZKŁADU BIOMASY W FERMENTORZE KONTENEROWYM

Streszczenie

Tematem pracy jest projekt hybrydowego systemu solarnego w celu utrzymania warunków mezofilnych w procesie beztlenowego rozkładu biomasy. Głównym celem pracy było zaprojektowanie hybrydowej instalacji grzewczej dla utylizatora biomasy. Założono symulację wykorzystania trzech źródeł energii: paneli fotowoltaicznych, kolektorów słonecznych i ciepła ze spalania biogazu. Wskazano, iż wyniki analizy będą poparte oceną wydajności biogazowej dla substratów zawierających składniki żywności i paszy. Quasi-ciągłe i okresowe działanie komory utylizacyjnej badano w odniesieniu do zapotrzebowania na energię do utrzymywania warunków mezofilnych w procesie fermentacji. W wyniku realizacji celu pracy wykonano biogazowe testy wydajności wybranej mieszaniny substratów. Wykonano również ogólny projekt instalacji utylizacyjnej (instalacji mikrobiogazowej), obejmującej izolację termiczną i projekt systemu grzewczego. W celu określenia strat ciepła komory fermentacyjnej zastosowano metodę opartą na współczynniku przenikania ciepła poszczególnych elementów konstrukcji. Poziom produkcji biogazu określono za pomocą stanowiska testowego zgodnego z wymaganiami normy DIN 38 414 S.8. Na podstawie wielkości produkcji biogazu określono niedobory termiczne wynikające z jego spalania. Niedobory biogazu stanowiły ponad 30% w najgorszych warunkach obliczeniowych układu okresowego i około 6% w systemie quasi-ciągłym. Zaprojektowana instalacja grzewcza, w której wykorzystywana jest dodatkowa energia słoneczna, będzie w przypadku układu okresowego bilansowała się na poziomie 100% letniego zapotrzebowania na ciepło. Zimą pokrycie zapotrzebowania na ciepło wynosiło około 90% w przypadku średnich temperatur miesięcznych w grudniu i styczniu oraz 80% dla najgorszych warunków obliczeniowych. Zidentyfikowane niedobory energii można ograniczyć, optymalizując kontrolę procesu biologicznego i optymalizując parametry warstw termoizolacyjnych.

Słowa kluczowe: *fermentacja metanowa, przetwarzanie odpadów, utylizator kontenerowy, hybrydowy system grzewczy*

1. Introduction

According to Laskowski and others [2015] biomass can be characterized as waste generated as a result of agricultural and forestry activities, as well as substances originating from industrial activity, constituting a link in the processing of biodegradable waste from other sources. The definition formulated in this way is close to the form in force in national and EU legislation. The solution that affects the reduction of energy needs of the utilization process consists in the use of various renewable energy sources, including adequately cooperating technical devices that create the so-called hybrid systems.

The biomass consists mainly of carbon, oxygen and hydrogen, and arises due to the ability of plant organisms to accumulate solar energy as a result of their biochemical photosynthesis process. The photosynthesis process leads to the production of carbohydrates from carbon dioxide and water under the influence of solar radiation. Biomass is therefore an organic mass that is a part of plants and animals [Ciechanowicz and Szczukowski 2015, Jastrzębska 2017].

Biomass can be utilized in the following processes: aerobic stabilization, anaerobic stabilization, thermal decomposition and storage [Jędrczak 2007, Niedziółka and Szpryngiel 2014, Banach et al. 2011, Bilitewski et al. 2003, Neugebauer et al. 2010].

Storage of waste biomass includes storage in places designed for this purpose in an organized and safe manner [Rosik-Dulewska 2010]. As part of the current EU policy, storage should be the final form of waste management applied in cases where there was no possibility of rational use of waste or disposal [Lipińska 2016].

In the deposited wastes, there is a phenomenon of spontaneous methane fermentation, which leads to the formation of landfill gas. The individual stages of this process may take place under anaerobic conditions due to the compact structure of the repository, which prevents the access of oxygen [Lemański 1993].

Waste management, which can lead to the production of biofuels and organic fertilizer is an argument. This solution offers methane fermentation.

Methane fermentation is the biochemical process under the influence of anaerobic microorganisms (fermentation bacteria), during which organic substances with a multimolecular structure (carbohydrates, proteins and fats) are reduced to simple chemical compounds: methane, alcohols, carbon dioxide and water [Buraczewski 1989, Krakowiak 2009, Curkowski et al. 2011, Kołodziejczyk and Myczko 2011, Biskupska and Romaniuk 2014].

Substrates with high moisture content and crude fiber, polysaccharides such as cellulose and hemicellulose, and monomers like lignin are difficult to digest for anaerobic bacteria. For processes that improve the enzymatic hydrolysis may include alcaline leaching or alcaline pretreatment [Adamski et al. 2018, Durczak et al. 2018].

Competent methane fermentation process can be divided into four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis [Tys and Wiącek 2015].

So far, the fermentation process is associated with the scale of the process, which defines the profitability of the investment. Micro biogas installations (micro biogas plants) characterize the barrier of non-mobile installations. This fact results from each preparation of the installation for a known amount of waste subjected to the process of development.

Fermentation in discontinuous (periodic) mode is particularly useful during dry fermentation [Curkowski et al. 2011].

Periodic fermentation (Fig. 1) is also characterized by significant fluctuations in biogas production. The largest amount of biogas is achieved at the beginning of fermentation, while the lowest is at the end. Consequently, this process shows little stability in terms of both quantity and quality [Steppa 1988, Buczkowski et al. 2009, Burczyk 2011].

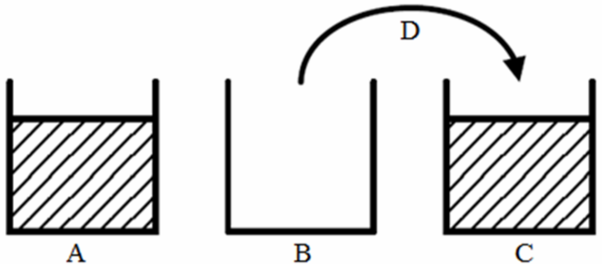

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Fig. 1. Discontinuous (periodical) mode of cooperation between fermentation chambers (A - pre-tank, B - fermentation chamber, C - digestate tank, D - emptying direction) [Gattermann et al. 2006]

Rys. 1. Nieciągły (okresowy) tryb współpracy komór fermentacyjnych (A - zbiornik wstępny, B - komora fermentacyjna, C - komora pofermentacyjna, D - kierunek opróżniania) [Gattermann et al. 2006]

In the case of discontinuous, periodic (Fig. 1) bioreactor, [Gattermann et al. 2006, Buczkowski et al. 2009], is filled with a new substrate and sealed.

Before the end of the retention time, the fresh substrate is not added to the tank, while the material which has been fermented is not emptied from the fermenter.

After fermentation the mass of the digestate is removed from the tank so that a small amount remains on the bottom. This allows the fermentation to be initiated after refilling the tank with fresh substrate [Gattermann et al. 2006, Buczkowski et al. 2009].

The semi-continuous (quasi-continuous) (Fig. 2) mode contributes to increasing the steady production of biogas, which is important, in this mode the bioreactor is filled with fresh material at least once a day [Gattermann et al. 2006, Bartoszek and Buraczewski 1990, Biskupska and Romaniuk 2014].

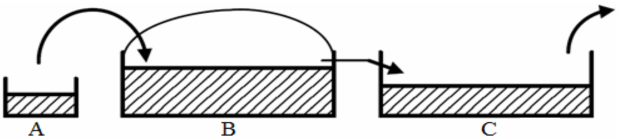

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Fig. 2. Continuous mode of cooperation between fermentation chambers, flow-storage method (A - pre-tank, B - fermentation chamber, C - digestate tank) [Gattermann et al. 2006]

Rys. 2. Tryb pracy ciągłej współpracy komór fermentacyjnych, metoda przepływowa (A - zbiornik wstępny, B - komora fermentacyjna, C - komora pofermentacyjna) [Gattermann et al. 2006]

The quasi-continuous mode will most closely approximate the system of the chamber stabilizing organic waste to the function of a biogas plant. The periodic mode is similar to composting technologies. In the periodic mode, the waste is decomposed with the separation of biogas, however, the energy needs of the system should prevail over energy self-sufficiency [Bartoszek and Buraczewski 1990, Gattermann et al. 2006, Buczkowski et. al. 2009].

Fermentation modes (periodic and quasi-continuous) require mixing of fermenting substrates. Among the main available mixing methods (mechanical, hydraulic, pneumatic, hybrid), mechanical mixing was selected. Mechanical mixing, most often carried out by helical stirrers (propellers), is the most prevalent among biogas installations [Mitkowski et al. 2016, Mitkowski et al. 2018].

2. Purpose and scope of work

The aim of the work was to analyze the possibilities of using a hybrid heating system that uses biogas energy and solar energy to sustain the process of waste biomass decomposition in mesophilic conditions on a micro-scale.

For the realization of the work the following range of activities was performed:

- implementation of a functional waste biomass utilization project and determination of the system's efficiency (scale),
- selection of waste substrates,
- testing of biogas yield of organic waste mix,
- indication of thermal losses and energy efficiency of the container system,
- energy balance - indication of energy shortages of the hybrid heating system.

3. Material and methods

Methane fermentation. Biogas efficiency tests (biogas productivity) were carried out in accordance with DIN 38 414-S8 in a multi-chamber fermenter (Fig. 3). The capacity of a single fermentation chamber is 1000 ml. The produced biogas is stored in eudiometer tanks. The capacity of each biogas tank is 1200 ml [KTBL-Heft-84 2009].

Measurement of methane, carbon dioxide, hydrogen sulphide, oxygen, ammonia, nitric oxide and nitrogen dioxide concentrations was performed with the tester of concentration of constituent gases in biogas, Alter Bio MSMR 16.

For the preparation of inoculum was used methanogenic thermostated biostat with a capacity of 1650 ml.

Source: own work / Źródło: opracowanie własne

Fig. 3. Research stand for the study of biogas productivity of substrates according to DIN 38414 s.8 (on the left), inoculum station for quasi continuous fermentation work (on the right)

Rys. 3. Stanowisko badawcze do oznaczania produktywności biogazowej zgodne z normą DIN 38414 s.8 (po lewej), stanowisko inokulantu dla utrzymania trybu quasi-ciągłego fermentacji

The fermentation test stand has been equipped with a thermostated tank that maintains the assumed thermal parameters (35^0C) of the process in the fermentation chambers. Biogas storage tanks are equipped with valves and connectors. This enables the removal of stored biogas and the transfer to the analyzer, Alter Bio MSMR 16 [DIN 38414 S.8]. The measurements of the concentration of constituent gases and the volume of produced biogas were carried out at 24-hour intervals. Mixtures with an identical substrate composition were in each case in three fermenters to confirm the validity of the results.

To measure the concentrations of constituent gases of biogas, measuring heads MG-72 and MG-73 has been used, with a measuring range of 0-100% by volume and the measurement resolution of the order 0,1 ppm to 1% by volume.

Based on laboratory tests and analysis of the literature [Jędrczak 2007, Myczko et al., 2011, Steppa 1988] indicated the critical factors which characterize the methane fermentation process. Factors that can have a significant impact on the biogas production process are primarily: the dry substance content, organic matter content, sample mass, reaction speed, percentage of individual components in the fermenting mix, and time of the experiment.

The following standards were used: [PN-74/C-04540/00, PN-75/C-04616/01 - 04, PN-90 C-04540/01].

Visualization of the digester and hydraulic and electric scheme. In order to visualize the components of the digester AutoCAD 2017 and AutoCAD Plant 3D 2017 were used. The components of the container utilizer have been included in the determination of its thermal parameters. CAD programs have also been used for creating the hydraulic and electric diagrams.

Methodological guidelines for determining the thermal parameters of a container utilizer. To calculate the heat losses, the following factors were used: heat transfer coefficient through structural partitions, material constants and indicators concerning construction materials of the digester, indicators of insulating materials and external housing of the designed container system. The values of thermal parameters were obtained from the technical guide [Dylla 2015]. The work uses selected principles for calculating the design heat load in accordance with PN-EN 12831. The calculation methods used relate to the heat transfer coefficient of the partitions. The ambient temperature range typical for the temperate zone of Central-Eastern Europe was used in the calculations.

Methodology of selecting elements of a hybrid installation. The calculations related to the selection of individual components of the hydraulic system and the appropriate safeguards were used: information from the Office of Technical Inspection along with the methods developed by Immergas [2014] and thematic publications [Bazzocchi and Croci 2015, Kędzierski 2009, Strzeszewski 2010, Zawadzki 2003, Kłos et al. 2010].

In the case of a photovoltaic installation, in order to select individual system components and to optimize system operation, the calculations were carried out according to published guidelines for the design of photovoltaic installations [Klugmann-Radziemska 2010, Klein et al. 2014, Szymański 2017].

This methodology is based on current requirements, contained in the following standards: PN-EN 62109-2: 2011E, PN-EN 61724: 2002P, PN-EN 50438: 2014-02, PN-EN 60269-6: 2011E, PN -HD 60364-6: 2016-07, PN-EN 61173: 2002, PN-HD 60364-7-712: 2016-05, PN-EN 62305-3: 2011, PN-EN 62305-1: 2011, IEC 61215, IEC 61646, VDE V 0126-1-1: 2013-08.

4. Results

To analyze the hybrid heating system of the digester, the following assumptions regarding the utilizer were specified:

- the size of the fermentation chamber 9.5 m^3,

- cylindrical shape of the fermentation chamber,
- use of thermal insulation materials,
- building the fermentation chamber with a hook container of typical dimensions.

In order to determine the biogas productivity, and thus the possibility of producing heat from biogas combustion, the following assumptions were made:

- fermentation substrate composed of organic agri-food waste,
- mesophilic conditions of the methane fermentation process,
- operation of the system in a periodic filling system (waste biomass utilization) and quasi-continuous (micro-biogas plant),
- work in a one-stage system.

As a form of building the digester, hooklift roller container EKOPROMET KP 36 was selected according to DIN 30722. The dimensions of the container system are shown in millimetres. The container has been modified to meet the functional and technical requirements that enable the fermentation process to be carried out (Fig. 4).

In the interior of the MK 38 hooklift roller container a cylindrical digester with a heating jacket on the envelope has been positioned (Fig. 5). The chamber and heating jacket are made of stainless steel OH18N9 and thermally insulated using a mineral wool layer. An additional layer of insulation was also planned on the inner walls of the container.

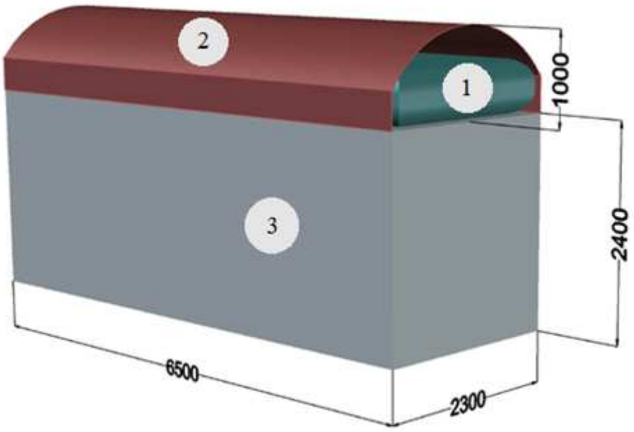

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Fig. 4. View of a mobile utilization chamber on the basis of a hooklift waste container (1 - biogas tank, 2 - roof covering, 3 - hooklift roller container

Rys. 4. Widok mobilnej komory utylizacyjnej na bazie kontenera hakowego (1 - zbiornik biogazu, 2 - osłona górna, 3 - kontener hakowy

Waste substrates biogas yield. In order to determine the heat demand of container micro-installations, in the first stage, tests of the biogas yield of the substrate mixture were carried out. The composition of the mixture is presented in Table 1. The research allowed to determine the level of energy self-sufficiency of the installation.

The subject of the research included a mixture of solid and liquid substrates, subject to anaerobic decomposition. A waste test mix (M4) (Table 2) and a reference sample (M10) (Table 3) were prepared.

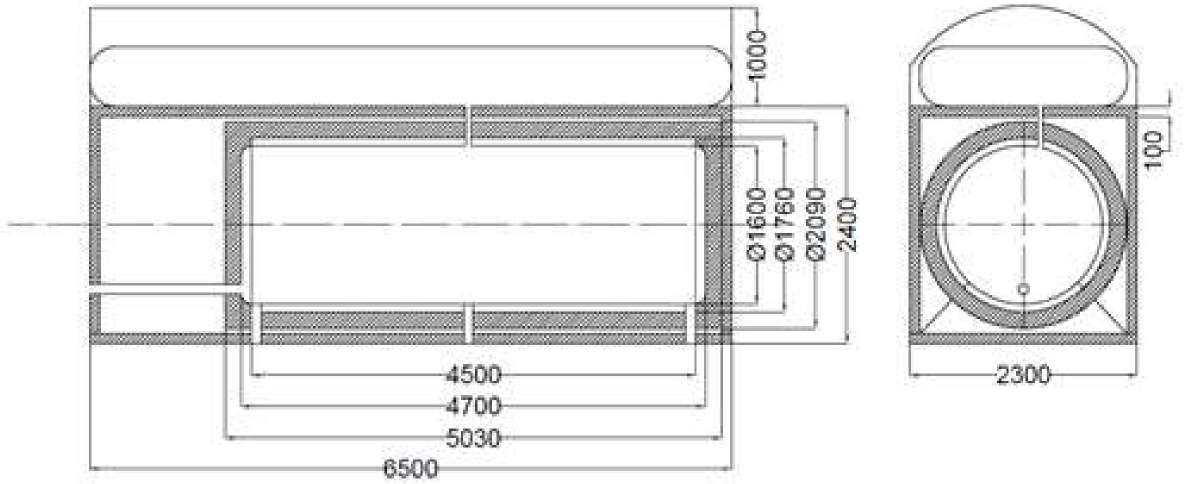

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Fig. 5. View of the cylindrical chamber in a hooklift container, dimensions in millimetres

Rys. 5. Widok komory cylindrycznej w kontenerze hakowym, wymiary w mm

Table 1. The composition of the fermentation mixture
Tab. 1. Skład mieszanki fermentacyjnej

No.	Type of substrate	Mass share [%]
1.	Roman salad	8,16
2.	Tomato	7,71
3.	Cucumber	6,93
4.	Carrot	11,47
5.	Parsley root	1,98
6.	Parsley	2,63
7.	Leek	4,23
8.	Celery	4,17
9.	Onion	4,12
10.	Potato	4,35
11.	Pear	8,00
12.	Apple	8,50
13.	Plum	1,37
14.	Peach	5,88
15.	Banana	5,93
16.	Rancid butter	0,45
17.	Cream cheese	4,45
18.	Sausage	1,98
19.	Cat food	4,45
20.	Bread roll	2,53
21.	Biscuits	0,71
	Sum (total) [%]	100,00

Source: own work / Źródło: opracowanie własne

Table 2. Output parameters of the M4 substrate mix
Tab. 2. Parametry wyjściowe mieszanki substratu M4

	Mass [g]	Part [%]	DM [%]	DM [g]	ODM [%]	ODM [g]
Cattle slurry	350,800	62,553	1,487	6,705	98,513	6,606
Inoculation	100,000	17,832				
Substrates mix.	110,000	19,615	15,403	16,943	94,025	15,931
Mixture M4	560,800	100,000	4,217	23,649	95,297	22,536

Source: own work / Źródło: opracowanie własne

Table 3. Output parameters of the M10 reference substrate mix
Tab. 3. Parametry wyjściowe referencyjnej mieszanki wzorcowej M10

	Mass [g]	Part [%]	DM [%]	DM [g]	ODM [%]	ODM [g]
Cattle slurry	351,400	77,812	1,487	6,717	98,513	6,617
Inoculation	100,200	22,188				
Mixture M10	451,600	100,00	1,487	6,717	98,513	6,617

Source: own work / Źródło: opracowanie własne

The M4 mixture was compiled as a combination of microbial inoculation, bovine manure and tested waste substrates. The reference sample (M10) was compiled as a combination of bovine slurry and microbial inoculation. As a result of the tests carried out on samples M4 and M10, biogas productivity levels were determined: daily (Fig. 7), cumulative (Fig. 8) and methane concentrations in the produced biogas (Fig. 6) were indicated.

The results of biogas productivity tests of samples M4 and M10 are presented in tabular form (Table 4).

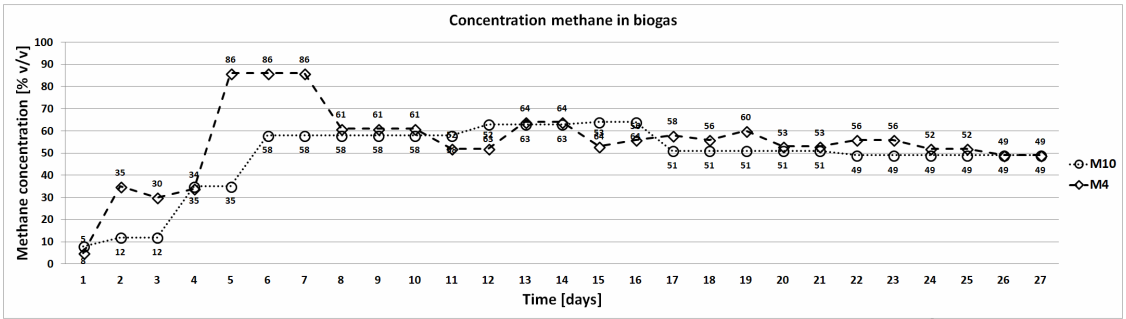

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Fig. 6. Concentration of methane in biogas [% v/v]
Rys. 6. Stężenie metanu w biogazie [% v/v]

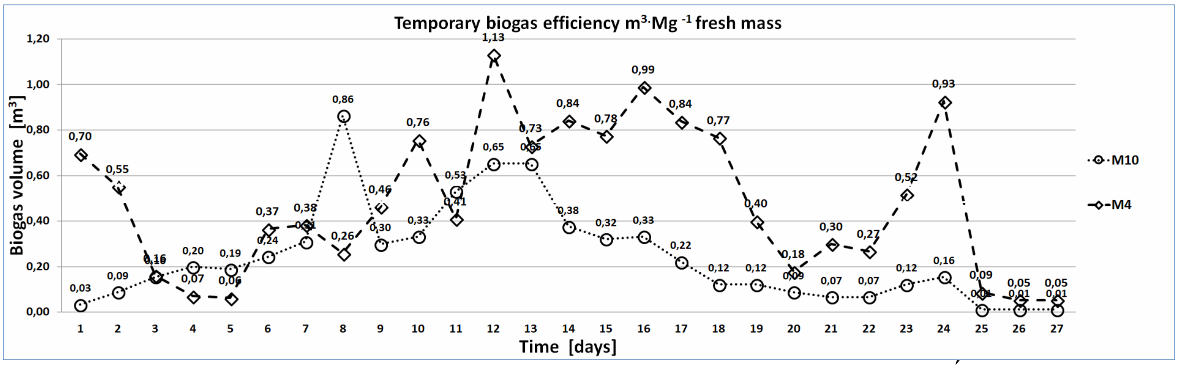

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Fig. 7. Daily biogas efficiency [$m^{3}\cdot Mg^{-1}$ fresh matter]

Rys. 7. Dobowa wydajność biogazowa [$m^{3}\cdot Mg^{-1}$świeżej masy]

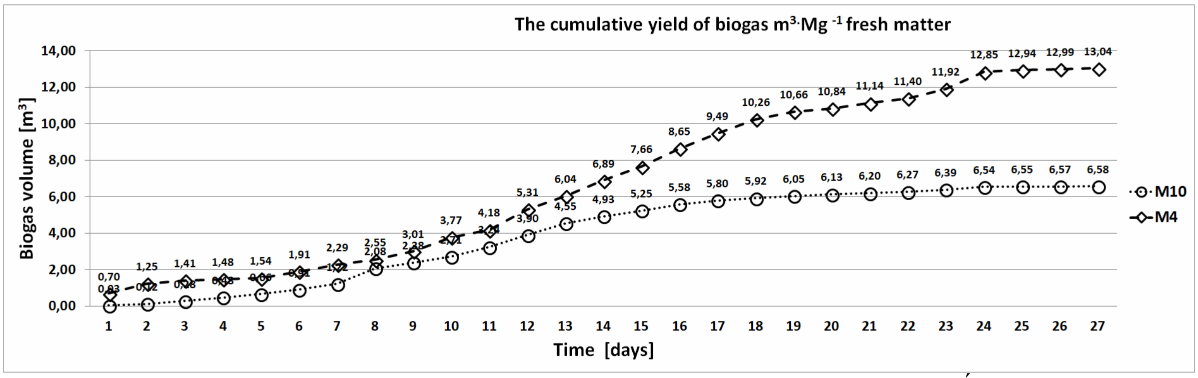

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Fig. 8. The cumulative yield of biogas [$m^{3}\cdot Mg^{-1}$ fresh matter]

Rys. 8. Wydajność skumulowana biogazu [$m^{3}\cdot Mg^{-1}$świeżej masy]

Table 4. Results of biogas productivity tests of samples M4 and M10

Tab. 4. Wyniki badania produktywności biogazowej próbek M4 i M10

Sample	The test parameter	Unit of measure	Result
M4	Average methane concentration in biogas	% v/v	53
M10	Average methane concentration in biogas	% v/v	47
M4	Average daily yield of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	0,48
M10	Average daily yield of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	0,24
M4	Maximum daily productivity of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	1,13
M10	Maximum daily productivity of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	0,99
M4	Cumulative yield of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	13,04
M10	Cumulative yield of biogas	$m^{3}\cdot Mg^{-1}$ fresh mass	6,58

Source: own work / Źródło: opracowanie własne

Thermal losses and energy efficiency. The obtained data from laboratory tests were used to determine the energy possibilities of a container biogas plant. In the created energy balance, the biogas productivity was compared with the needs of the chamber heating system and energy losses through conduction.

The total heat loss was calculated on the basis of heat transfer coefficients by individual walls of the container installation and structural elements of the digester. The design external temperature was adopted according to the II climate zone. It is used in calculating heat load of buildings in accordance with PN-EN 12831.

Thermal properties of individual construction materials were adopted according to material tables. The internal temperature was 45°C (water jacket temperature) or 38°C for the bottoms of the fermentation chamber (no heating jacket).

Calculations of heat loss streams were made, depending on the heat transfer coefficient, barrier surface and temperature difference on both sides of the barrier. The total design heat loss (Q_T) was calculated by summing the heat losses through individual container walls (Q_1 to Q_6) in accordance with the formula 1.

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \tag{1}$$

The total design heat loss (Q_T) after adding losses of all barriers amounted to 1075.65W.

According to the calculations, the power of the heating device should be equivalent or higher than the sum of the heat loss through the barriers. Fig. 9 presents a graphic description of biogas productivity, depending on the selected system of work.

The utilization system (periodic fermentation chamber filling system) and the microbiological system operating mode (quasi-continuous fermentation chamber filling system) were considered.

The average daily biogas productivity (ABP) for the periodic system (PS) was calculated based on the total biogas productivity related to the hydraulic retention time (HRT = 27 days) (ABP-PS = 0,48 $m^{3}\cdot Mg^{-1}$fresh matter).

Based on the results of biogas productivity calculated for the periodic and quasi-continuous system (Fig. 9), the heating power obtained from biogas combustion was determined.

The calculations (for periodic fermentation) were based on: dependence of heat obtained from biogas combustion (Q_U), hourly biogas productivity (W_{HU}) and the average calorific value of biogas (W_B) and efficiency of a gas boiler (η) burning biogas (formula 2).

$$Q_U = W_{HU} \cdot W_B \cdot \left(\frac{\eta}{100} \right) \tag{2}$$

The calculations (for a quasi-continuous system) indicated the dependence of heat obtained from biogas combustion (Q_M), hourly biogas productivity (W_{HM}) and the average calorific value of biogas W_B and the efficiency of a gas boiler (η) burning biogas (formula 3).

$$Q_M = W_{HM} \cdot W_B \cdot \left(\frac{\eta}{100} \right) \tag{3}$$

The results of calculations are presented in Table 5 and Table 6.

Calculations showed (Table 5) that the periodic fermentation system would not be able to cover the total heat requirement (716.19 W).

The quasi-continuous fermentation system is characterized by a higher heat production (Table 6), which means that such a system can be regarded as self-sufficient in terms of energy (1008.38 W). The calculations were made for the fermentation chamber fill factor of 82%.

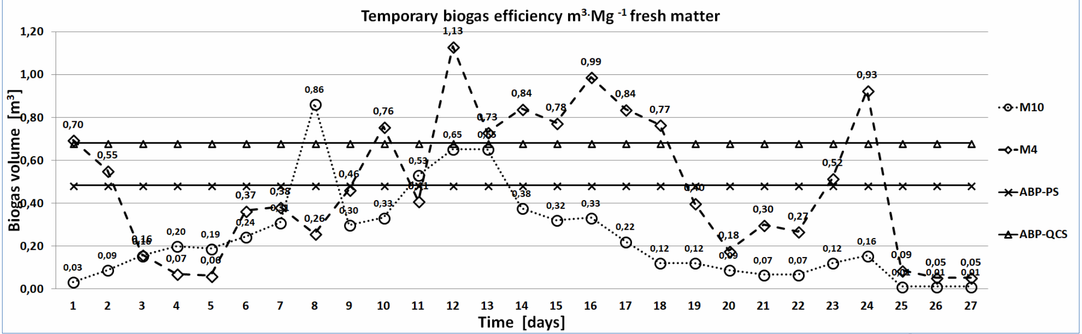

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Fig. 9. Average daily biogas productivity for the periodic and quasi-continuous system

Rys. 9. Średnia dobowa produkcja biogazu dla systemu okresowego i quasi-ciągłego

Table 5. Production of biogas heat for periodic fermentation

Tab. 5. Produkcja ciepła z biogazu w przypadku fermentacji okresowej

Parameter	Symbol	Value	Quantity
The efficiency of a gas boiler and internal installation	η	96	%
Average calorific value of biogas	W_B	17	$MJ \cdot m^{-3}$
Cumulative productivity of biogas	W_{CAL}	13,04	$m^3 \cdot Mg^{-1}$ fresh matter
The duration of the process	t	27	days
Average daily productivity of biogas	W_0	0,48	$m^3 \cdot Mg^{-1}$ fresh matter
The fermenting mass	m	7,85	t
Daily biogas yield of the utilizer	W_{DU}	3,79	$m^3 \cdot d^{-1}$
Hourly biogas yield of the utilizer	W_{HU}	0,16	$m^3 \cdot h^{-1}$
Heat from biogas combustion	Q_U	2,58	MJ
Heating power from the combustion of biogas	P_{HWM}	716,19	W

Source: own work / Źródło: opracowanie własne

Table 6. Production of biogas heat for quasi-continuous fermentation

Tab. 6. Produkcja ciepła z biogazu w przypadku fermentacji quasi-ciągłej

Parameter	Symbol	Value	Quantity
The efficiency of a gas boiler and internal installation	η	96	%
Average calorific value of biogas	W_B	17	$MJ \cdot m^{-3}$
Average daily productivity of biogas	W_{QC}	0,68	$m^3 \cdot Mg^{-1}$ fresh matter
The fermenting mass	M	7,85	t
Daily biogas efficiency of micro biogas plants	W_{DM}	5,34	$m^3 \cdot d^{-1}$
Hourly biogas efficiency of micro biogas plants	W_{HM}	0,22	$m^3 \cdot h^{-1}$
Heat from biogas combustion	Q_M	3,63	MJ
Heating power from the combustion of biogas	P_{HWM}	1008,38	W

Source: own work / Źródło: opracowanie własne

The installation space on the side wall of the container (15.6 m^2) was used and the photovoltaic installation and solar collector were proposed. The hybrid heating system can support the operation of two fermentation systems: periodic and quasi-continuous. The power of solar devices was determined as the real power of PV panels (solar collectors) and expressed in watts [W] [Tytko 2016]. The number of photovoltaic panels (4 pcs) and solar collectors (1 item) for the side surface of the container has been determined. For the calculations were adopted: the unit surface area of the PV panel (1.474 m^2) and the active surface of the solar collector (2.130 m^2). The power of solar devices was calculated in accordance with the published methodology [Tytko 2016] on the basis of the following formula 4:

$$P_{SOL} = M_E \cdot S \cdot \frac{\eta}{100} \cdot n \tag{4}$$

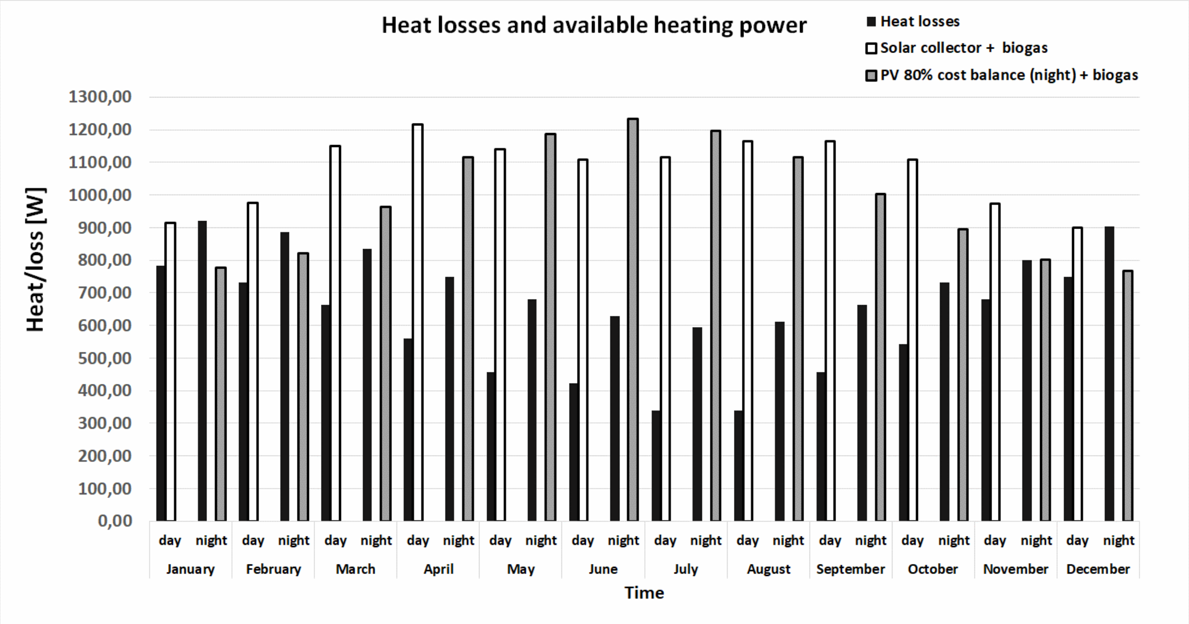
where:
P_{SOL} - real power of PV panels / solar collectors [W],
M_E - solar radiation power [Wm^{-2}],
S - active surface of the PV panel / solar collector [m^2],
η - efficiency of PV panel / solar collector [%],
n - number of PV panels / solar collectors.

It was assumed that the efficiency of the PV panel is 18% and the efficiency of the solar collector is 69%. Calculation results, comparing heat losses with potential heating power, were presented in two cases. The first case involves the cooperation of a gas boiler with a solar collector. The second case involves the cooperation of a gas boiler with a photovoltaic installation. In the case of a hybrid system with a PV installation, a discount system was included in the calculation, which in 80% balances the use of electricity from the power grid (Fig. 10).

Heating power and balances between sources, used in the analyzed system (Fig. 10). Heat sources were used: solar collector Hewalex Thermomax HP 400-20, 4 solar panels WINAICO feeding the electric heater and gas boiler VITODENS 200-W.

Heat losses were calculated on the basis of heat transfer coefficients by individual walls and structural elements, using in this case average monthly temperatures in the day / night system for their comparison with the operation of the solar and biogas systems (Fig. 10).

Despite the use of an additional solar system, calculations showed that in 3 months (January, February and December) the system operates on the edge of the energy needs of the fermenter.



Source: own work / Źródło: opracowanie własne

Fig. 10. Comparison of heat losses and heating power obtained from the solar system and gas boiler
Rys. 10. Porównanie strat ciepła i ciepła uzyskanego z systemu solarnego i ogrzewacza gazowego

5. Summary and conclusions

The research showed that the cumulated biogas productivity reached the level of over 13 m^3 from a Mg of fresh mass. The obtained results of biogas efficiency levels can be improved by increasing the digestibility of the mixture and better balancing macronutrients and the C / N ratio. A mixture of wastes with possibly varied composition was tested to approximate the real problems of waste disposal.
The highly diversified composition of the mixture showed inhibitory qualities, thanks to which the level of biogas productivity was deliberately lowered.

It has been shown that the change of chamber operation mode (periodic system to quasi continuous system) intensively increases the energy capacity of the fermenter, with a constant level of heat losses through the partitions.

Obtained average daily biogas yields indicated that from the waste mix, productivity can be expected at 0.48 m^3 of biogas from a tonne of fresh mass in the case of a periodic system and 0.68 m^3 of biogas from a tonne of fresh mass in the case of a quasi-continuous system.

Both biogas productivity results were used to analyze the energy efficiency of the digester in a periodic and quasi-continuous system.

The considered systems (periodic and quasi-continuous) refer to the use of the proposed fermenter as a utilization or microbiogas plant. Identified energy shortages can be limited by optimizing the control of the biological process and optimizing the parameters of thermally insulating layers. The element of support may also be in multiplication of chambers or additionally their mutual phase shift of daily biogas efficiency (biogas yield in periodic system).

Identified energy shortages can be limited by optimizing the control of the biological process and optimizing the parameters of thermally insulating layers. The element of support may also be in multiplication of chambers or additionally their mutual phase shift of daily efficiency.

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