Project: WasteMan

Report on kitchen waste fermentation, composting/(EM treatment) and fertilizer formation activities

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Contents

Introduction

1. The use of effective microorganisms

As part of the work, research was carried out on the possibility of using aerobic and anaerobic effective microorganisms (EM) for stabilization of organic fractions of municipal waste. The process was carried out directly in collection containers and in traditional way – in the compost pile. The influence of EM on mesophilic methane fermentation of selected organic substrates was also investigated.

1.1 The use of effective microorganisms for the stabilization of organic fraction of municipal solid wastes

During the research, anaerobic strains of microorganisms provided by Greendland EM® Technology (Fig. 1) were used. The agent contains naturally occurring microorganisms in the environment (including lactic acid bacteria, yeast, phototrophic bacteria) in various proportions, which show a synergistic effect.

The aim of the research was to determine the effect of EM on organic waste including inhibition of odor generation. Parallel to the laboratory tests, field tests were carried out at Waste Management Treatment Plant - Eco Dolina sp.z o.o. – Project Partner.

Fig. 1 Effective microorganisms provided by Greenland

Two types of substrates were used in this research: wheat straw and organic kitchen waste. Each of the substrates was pre-crushed and then placed in two clean, equal volume jars with a tight lid. The EM solution (1 ml of microorganism suspension per 100 ml of water) was spread in the first jar, while the second one was the reference sample (only 100 ml of water was added).

The jars were closed and kept at room temperature for 2 months. During the test, they were opened and sensory analyzed. Figure 2 shows jars with wheat straw, while Figure 3 shows kitchen waste.

Wheat straw

Sample mass: 120g

Reference sample | **Sample with EM**

Fig. 2 Wheat straw without (left side) and with effective microorganisms (right side)

For the EM-treated sample, intense carbon dioxide production was noted during the first two weeks. After about two months, the production of CO_2 decreased. At the beginning of the experiment, both straw samples smelled similar - there was a sour and fruity smell. After two months, the EM treated straw was observed to have a more intense, sour smell. There were no clear differences in straw structure or color between the samples with with and without the addition of EM.

Kitchen/food wastes

Sample mass: 800g

Reference sample ***Sample with EM***

Fig. 3 Source sorted kitchen wastes without (left side) and with EM addition

Similar observations as in the case of straw were observed during the studies on kitchen waste (Fig. 3). At the beginning of the experiment, intensive CO_2 production was noticed in the sample with the addition of EM. A similar phenomenon was noticed in the case of the reference sample however, the production of CO_2 was less intense and prolonged. After two months of testing, the intensity of the smell in both trials was similar (sour smell was dominant), however the smell intensity in the case of kitchen waste with EM was more acidic and a little bit fruity. It is worth adding that in the waste treated with EM more intensive mold and fungal growth was noticed compared to the control sample. The EM treated waste has been applied as fertilizer – see Report "Poland: Municipal Solid Waste"

On site-research

The next stage of the research was to determine the impact of effective microbes on waste under real conditions, the studies were conducted on site at Eco Dolina Waste Management Plan. The observations were carried out in order to increase the intensity of the composting process and to reduce the odors emitted already at the stage of waste collection.

Standard waste containers were used for the tests (Fig. 4), in which two types of organic waste were placed: green wastes and fraction of mixed municipal solid wastes (MSW) after separation on a 20-80 mm sieve. Each type of waste was divided into two samples - one with EM suspension, the other was the reference sample (only with water). Water was added to reference sample to ensure the same substrate moisture. The waste in the containers was stacked in layers. After laying the waste layer, the water solution with EM was spread, then another layer of waste was added to evenly distribute the microorganisms. Detailed parameters of the studies are presented in Table 1.

Fig. 4 Containers with treated wastes

Tab. 1 Sample characterization

Symbol	Type of waste	Sample mass [kg]	Pretreatment
Z.0	Reference green	49.6	Water sprayed (10L)
Z.1	Green with EM	51.8	EM solution sprayed (1L EM + 9L water)
O.0	Reference fraction 20-80 of MSW	52.4	Water sprayed (10L)
O.1	Fraction 20-80 of MSW	52.2	EM solution sprayed (1L EM + 9L water)

Compost pile research

Parallel to the container tests, the tests were carried out on composting piles at Eco Dolina Municipal Waste Treatment Plant, which aimed at acceleration of composting process and reduction of odor emissions by applying aerobic EM. A solution of an aerobic microorganisms was applied to the prepared pile, which was delivered by representatives of CleanBacter Ltd (Fig. 6). In the hall of the indoor composting plant, a pile of source sorted biodegradable fraction of municipal waste (about 20 tons) was prepared (Fig. 5 and 6).

Fig. 5 Composting pile of source sorted fraction of municipal solid wastes

Fig. 6 Composting pile pretreatment – spraying with EM solution

In order to determine the influence of aerobic EM on the decomposition of organic matter in the composting process, a second pile was prepared (without EM addition, spraying with water only), which was the reference test.

It was established that the piles would be thrown twice a week to ensure optimal conditions for the development and life of the applied microorganisms. It was assumed that the trial would be conducted for two months.

During the composting process, the temperature was measured using wireless thermometers placed in different places of the piles.

During the composting process, samples of the compost (Fig. 7) were taken to determine the degree of organic matter decomposition (Fig. 8). This parameter was determined on the basis of organic and total carbon analyzes which were carried out in the laboratory EcoDolina Municipal Waste Management Plant.

Fig. 7 Compost sample

Fig. 8 Dried compost samples from compost piles (left side) and sample prepared for TOC analysis.

1.2 Effective microorganism for enhance methane fermentation process

Effective anaerobic microorganisms were also used in research on the pre-treatment of selected organic waste intended as substrates for methane fermentation. Wheat straw (WS) and kitchen waste (KW) described in Subchapter 1.1 were used in the research.

Materials and methods

The substrates used in the research were wheat straw and kitchen wastes presented in Subchapter 1.1. Both substrates were subjected to anaerobic EM treatment, 100 ml of bacterial suspension (1 ml of EM solution: 100 ml of water) were applied per 1 kg of fresh substrate.

After EM application, the substrates were placed in jars and kept at room temperature for 2 months. After two months, the substrates were used for biogas potential tests. A detailed description of the methodology used is described in more detail in Subchapter 2.1.

In order to determine the effect of EM on the efficiency of methane fermentation, a series of fermentation tests of substrates without EM treatment, with only 100 ml of water was also carried out.

Results and discussion

Figure 9 shows the daily production of biogas and methane from selectively collected model organic wastes treated with EM (1) and a reference sample (without EM) (2). Figure 10 shows the daily production of biogas and methane of wheat straw (1) and reference sample (2).

Based on the analysis of the daily efficiency of biogas production from selectively collected municipal waste, it was found that, regardless of the use of EM, the fermentation kinetics of both substrates are similar.

In the initial phase of fermentation, a significant share of CO_2 in the biogas was recorded. After about 7 days, half of the biogas volume was made up of CH_4. Its content in biogas increased with each subsequent day until the end of the 21-day fermentation.

Similar observations were made in the case of wheat straw. Regardless of whether the straw was treated with EM or not, the kinetics of the 25-day fermentation were similar.

In the first days of fermentation, the share of CH_4 was small, its average highest content was recorded after about a week of fermentation.

There was no significant increase in the proportion of CH_4 in the biogas during the fermentation. The longer fermentation time for the wheat straw samples was due to a different composition of the substrate and a more complex structure than in the case of municipal waste.

It was observed that in the substrate samples treated with EM, the total yield of biomethane production was lower than in the case of substrates without EM. – see Table 2.

Tab. 2 Cumulative production of biogas and methane in the tested substrates

Sample	Biogas yield [m^3/t VS]	Methane yield [m^3/t VS]	Methane content [%]
Kitchen waste	987.96	554.56	56
Kitchen waste + EM	740.92	408.49	55
Wheat straw	80.66	163.93	49
Wheat straw + EM	69.26	153.34	45

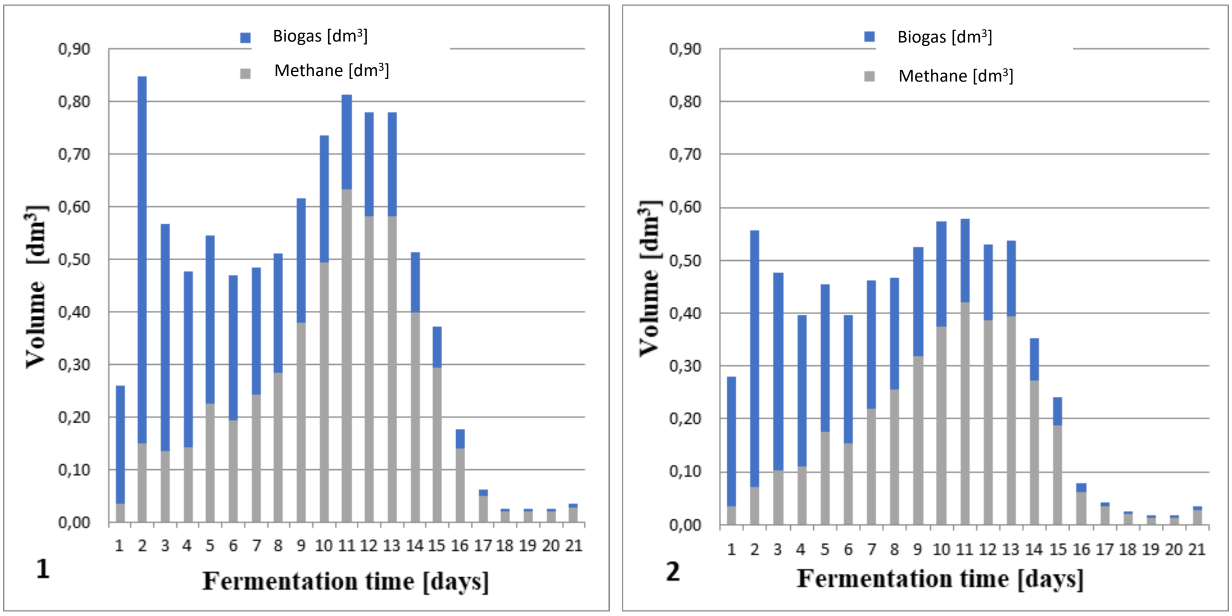

Fig. 9 Daily biogas and methane production from organic fraction of municipal solid wastes (without EM – 1, with EM – 2)

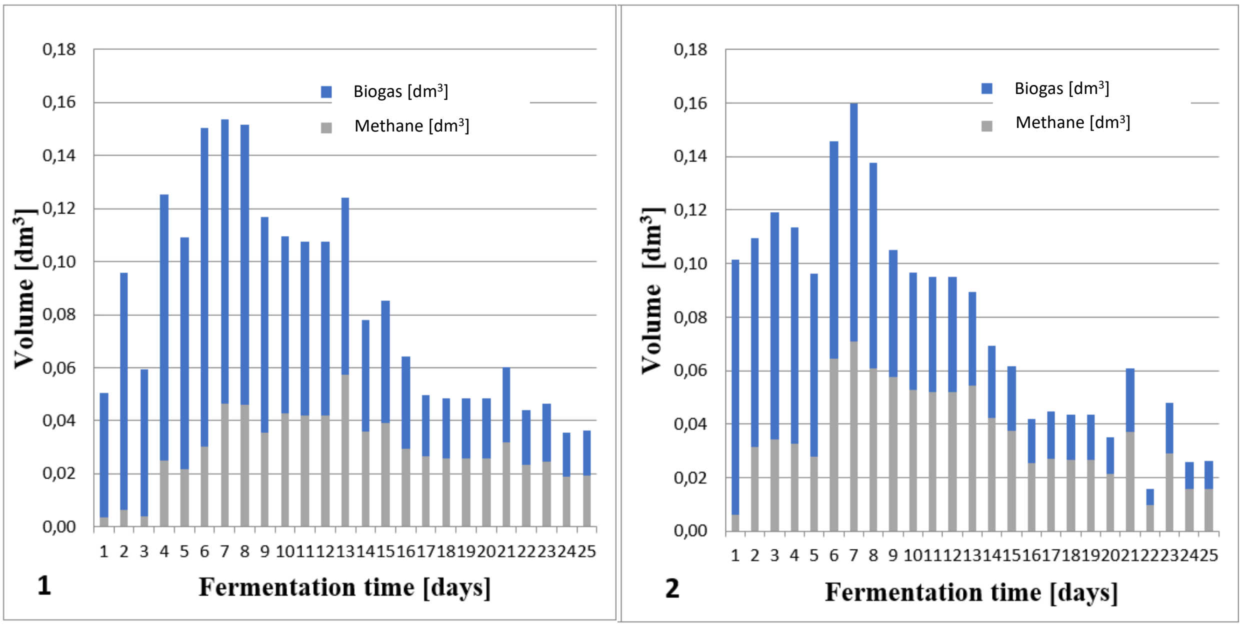

Fig. 10 Daily biogas and methane production from wheat straw (without EM – 1, with EM – 2)

Detailed data on the biogas production efficiency from all substrates along with CH_4 content are presented in Table 2. Based on the analysis of the cumulative yields of biogas and methane from the tested substrates, it was found that the EM treatment did not have a positive effect on the efficiency of methane fermentation.

Both in the samples of food waste and wheat straw, it was found that the production of methane was limited when using EM.

Apart from the decrease in biogas production efficiency, there was also a slight decrease in the methane content in the biogas. The possible cause of the reduction in production efficiency is the partial decomposition of readily biodegradable substances during pre-treatment.

2. Management of selected organic waste streams

As part of the tasks assumed in the project, research was carried out on methane fermentation of municipal organic waste. During the research, physicochemical methods of substrate processing/pretreatment were also used in order to intensify the production of biogas and methane. Samples of selected waste streams used in the research were collected from Eko Dolina Waste Management Treatment Plant.

2.1 Methane fermentation of model substrate and physicochemical treatment

The first stage of the research was to develop a model waste - to determine a specific morphological composition. Contrary to the organic fraction of waste from the landfill, the model waste was characterized by the same composition and characteristics, which significantly facilitated the research and interpretation of the results.

In addition, the problem with microbiological risk was reduced, which is the case with research work with real waste. In order to intensify the production of biogas, the model waste was also subjected to thermal, chemical and combined treatment.

Materials and methods

Fig. 11 Model waste components (left side) and grinded model substrate (right side)

The composition of the model waste used in fermentation studies and its physicochemical characteristics are presented in Table 3.

Tab. 3 Composition of model organic waste used for fermentation test

Component	Part [%]	Dry matter (TS) [%]	Dry organic matter (VSS) [%TS]	Nitrogen [gN/kg TS]
Apple	5			
Lemon	5			
Bread	5			
Butter	5			
Cream	5			
Milk	5			
White cheese	5			
Yogurt	5			
Eggs	5			
Meat with bones	5	53.9	33.8	4.0
Sousages, cold cuts	5			
Fish	5			
Potatoes	5			
Bananas	5			
Tomatoes	5			
Lettuce	5			
Juice	5			
Buns	5			
Flowers and papers	10			

All components of the model waste were grinded to a particle size below 3mm using a mincer and then mixed well to obtain a homogeneous paste. Figure 11 shows the used components and the prepared substrate. Substrate was then placed in airtight containers and kept at 4°C until the tests were carried out.

The model substrate was subjected to fermentation tests after:

- acidic pretreatment,
- thermo-acidic pretreatment,
- untreated.

Table 4 shows the values of TS and VSS and the type of applied model substrate treatment.

Tab. 4 Model substrate pretreatment conditions and TS and VSS content

Pretreatment	Conditions	TS [%]	VS [% TS]
Acidic	pH=4 for 24h	49.7	34.3
Thermal-acidic	pH=4, 100°C for 1h	61.0	30.3
without	-	53.9	33.8

The acid treatment consisted in lowering the pH of the substrate to a value of approx. 4 and maintaining it for 24 hours. After that, the substrate was neutralized using 30% NaOH solution.

In the case of the thermo-acid treatment, the model waste was acidified to pH = 4 and then heated in the reactor, the temperature was kept at 100 °C for 1 hour. After cooling, it was neutralized with 30% NaOH solution.

Due to changes in the content of water and minerals as a result of the pre-treatment, the dry matter (SM) and dry organic matter (SMO) content was re-determined before the fermentation tests in the substrate.

The amount of substrate required for tests was calculated on the basis of the substrate TS and VSS content in order to further comparison of the obtained results.

Biogas test

The fermentation system of the "batch-test" type, presented in Figure 12 was used for the methane fermentation studies.

Determination of biogas and methane potential (BMP - Biomethane Potential Test) is a procedure that allows to determine the production of biogas and methane obtained from an organic substrate by anaerobic methane fermentation (anaerobic decomposition).

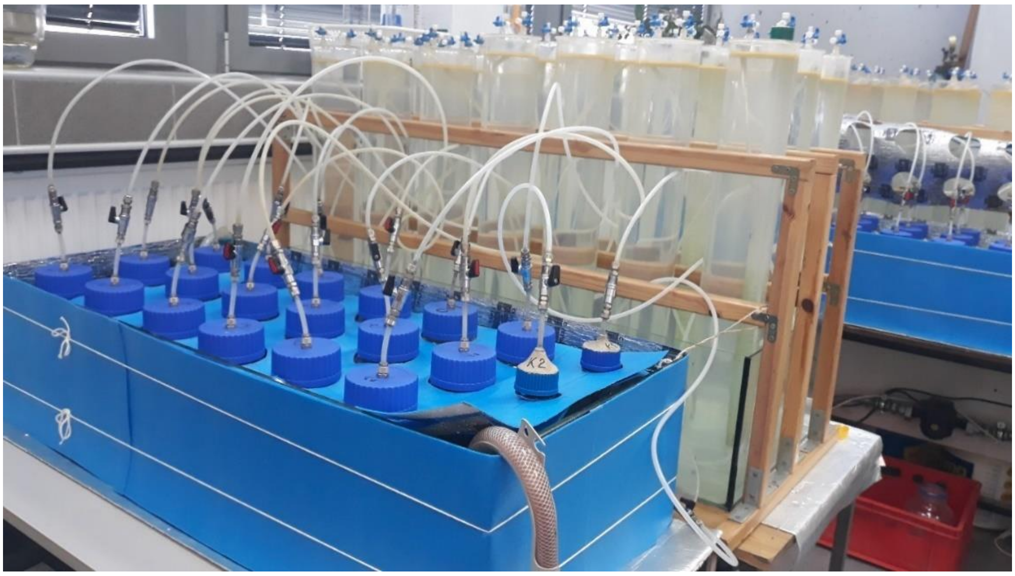

Fig. 12 „Batch“ fermentation setup

The analysis of data obtained with BMP tests provides a lot of valuable information especially needed when biogas plant is designed. It is possible to verify the technological assumptions, determine the influence of time and method of fermented substrate processing as well as the influence of co-substrate on the obtained amount of biogas.

The laboratory methane fermentation set in “batch” system consists of:

- 21 reactors with a capacity of 2000 cm^3,
- a water heater with a thermostat ensuring a constant temperature of the reactors,
- water circulation pump,
- 21 biogas collection vessels,
- gas and liquid sampling system.

The determination of biogas profitability consisted in placing a calculated amount of substrate and inoculum (fermented wastewater sludge) in the reactor. The reactors were then purged with nitrogen and placed in a water bath with controlled water temperature (38 ± 2 ° C) in order to create the most optimal conditions for the life and growth of anaerobic microorganisms.

The reactors are connected to the biogas collection vessels, thanks to which the producing biogas pushes liquid out of it. The amount of produced gas is calculated by the graduation on collecting vessel. In order to limit the dissolution of gases in the liquid a special liquid barrier was used. The qualitative analysis of the generated biogas was carried out using the GA5000 Geotech biogas analyzer. The volume of produced biogas and methane was converted to normal conditions and the final results were presented as m^3 of gas per ton of VSS. According to DIN 38 414 8S, fermentation was carried out until the daily production of biogas is less than 1% of its total production.

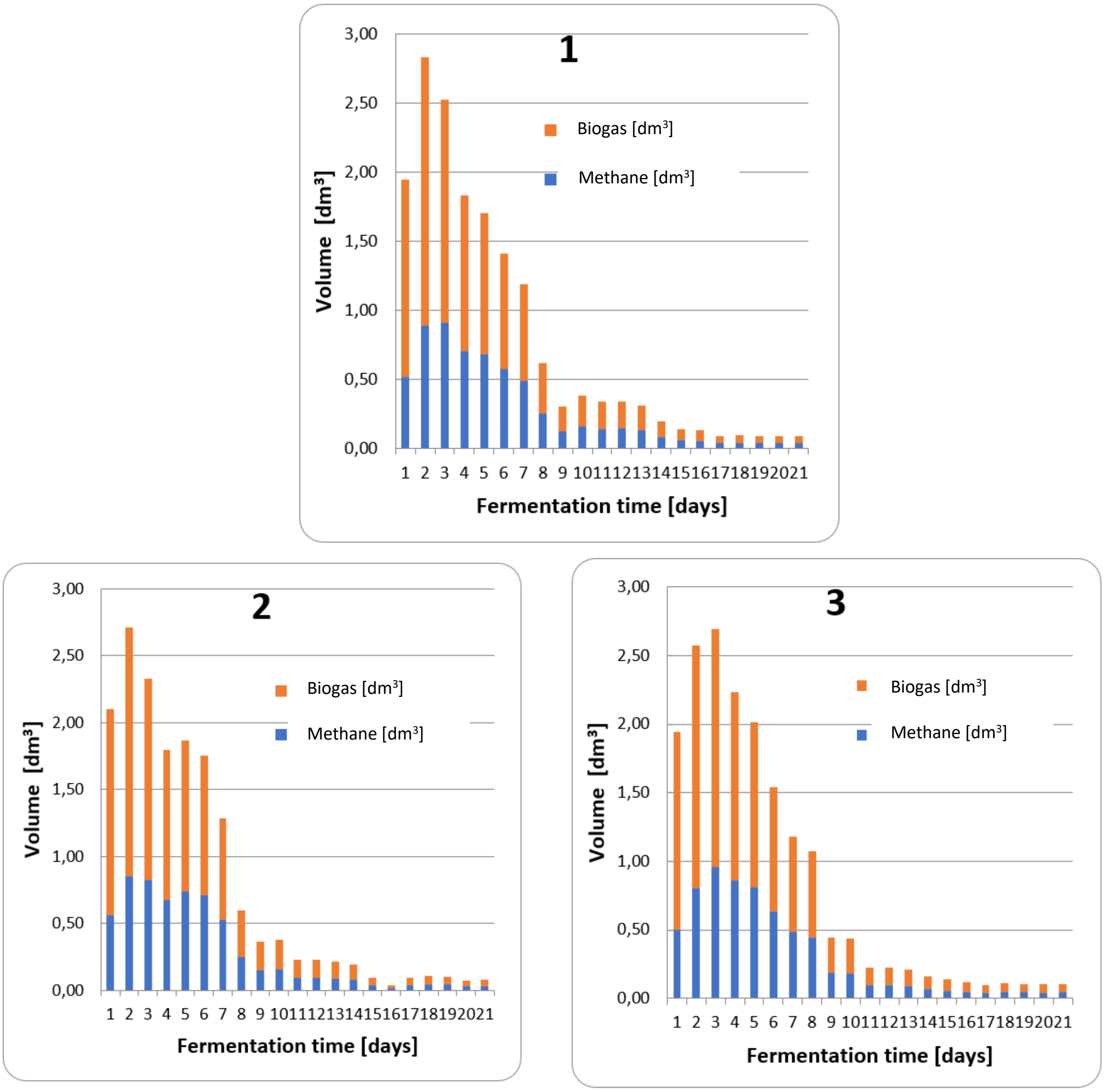

Fig. 13 Methane fermentation dynamics: 1 – without pretreatment, 2 – after acidic pretreatment, 3 – after thermal-acidic pretreatment

Results and discussion

Figure 13 shows the daily production of biogas and methane of the substrate after acid, thermal-acid and the substrate without treatment. Table 5 summarizes the cumulative yields of biogas and methane from all tested substrates.

Tab. 5 Total yield of biogas and methane production depending on the type of pretreatment

Pretreatment	Biogas yield [m^3/t VSS]	Methane yield [m^3/t VSS]	Methane content [%]
Acid	800,27	475,69	59
Thermal-acid	794,92	468,72	58
Untreated	861,79	524,30	60

Based on the analysis of the obtained results, it was found that neither the acid treatment nor the thermo-acid treatment result in a significant effect on the dynamics of fermentation. Moreover, it was found that the (cumulative) biogas production efficiencies in the case of fermentation of the tested substrates do not differ significantly – see Table 5.

However, high biogas yields, as well as a significant share of methane in the gas (more than 50%) confirms that the selectively collected fraction of kitchen waste is effective substrate for methane fermentation. In addition, the lack of influence of physicochemical treatment on the fermentation efficiency of this substrate suggest its neglecting in real systems, which significantly reduces the costs of substrate preparation (apart from grinding).

2.2 Leachate fermentation

Taking into account the fact that selectively collected organic waste contains approx. 50% water content (model waste 53.9% DM), part of the water is released during composting. Mentioned leachate constitutes an additional stream which management is necessary. The effluent from the composting plant contains approx. 6% DM. The organic matter consists of pre-decomposed organic substances and microorganisms, also pathogenic.

High hydration, as well as the content of easily degradable organic substances, make such a leachate a very good substrate for methane fermentation.

Materials and methods

The leachate from the composting plant generated on the premises of Eko Dolina sp.z o.o. was used in the research. Due to the high nitrogen content, it was also checked whether its removal before fermentation would have a positive effect on digestion process. Nitrogen removal was performed using thermal-vacuum stripping.

The basic parameters of the substrates used in the research are presented in Table 6. Methane fermentation of the prepared substrates was performed similarly to that described in Section 2.1.

Tab. 6 Characterization of leachate from composting hall

Substrate	TS [%]	VSS [%TS]	Nitrogen [gN/L]
Leachate	4.95	65.0	1.02
Leachate after stripping	6.42	55.4	0.31

Results and discussion

Figure 14 shows the dynamics of the methane fermentation process of the composting effluent. Table 7 summarizes the cumulative yields of biogas and methane. It was observed that during the 19-day fermentation, the dynamics of fermentation was similar regardless of the substrate. Intensive biogas production was registered from the first days of the process, and after two days of fermentation, methane accounted for the majority share in biogas. The cumulative volume of biogas and methane, calculated on the fresh mass of the leachate, amounted to: 28.8 and 17.4 m^3/t TS, respectively, which is about 60.3% of methane in biogas. The cumulative volume of biogas and methane for the effluent after ammonia stripping was: 16.5 and 26.5 m3/t TS, respectively (62.1% methane in biogas).

Based on the analysis of the conducted research, it was found that the nitrogen content in the leachate coming directly from the composting plant is at the optimal level. Its removal by thermal-vacuum stripping reduces the efficiency of biogas production by approx. 8%.

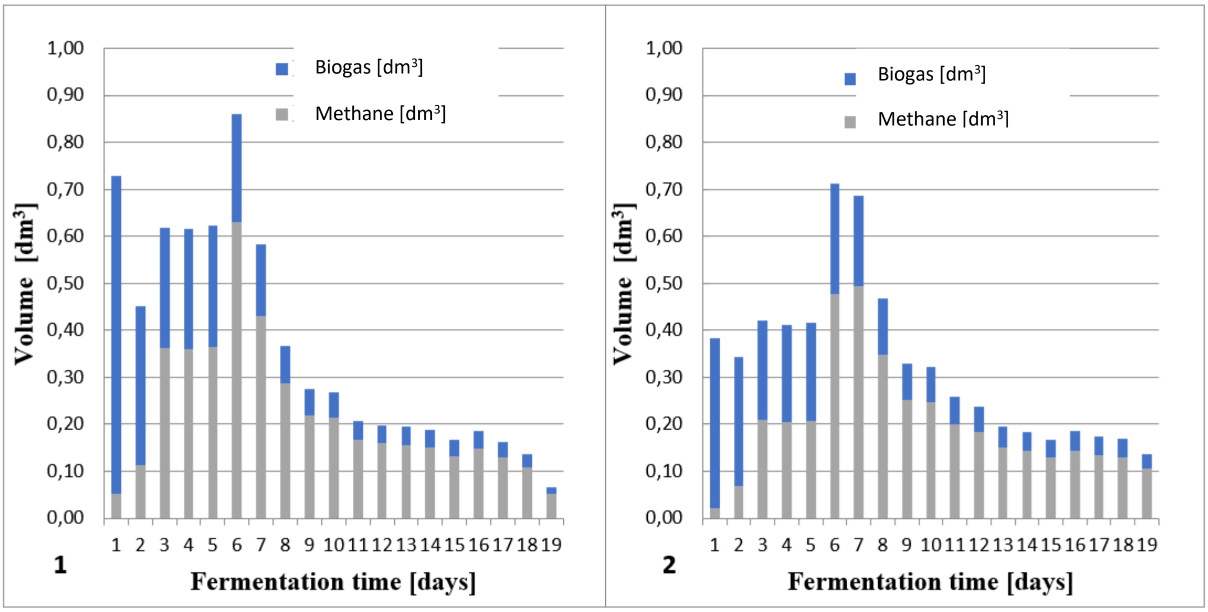

Fig. 14 Dynamics of methane fermentation for leachate (left side) and leachate after ammonia stripping

2.3 Methane fermentation of selected fractions of organic wastes

Analyzing the results obtained earlier, concerning the methane fermentation of model organic waste, research was started on the fermentation of real samples - waste from the landfill.

The research aimed to determine the possibilities of managing the main organic waste streams by fermentation and their mixtures.

Materials and methods

The test material was sampled at the Eco Dolina plant, from selectively collected kitchen waste, leachate from landfill plots and leachate from the composting plant.

The basic physicochemical parameters of the tested substrates are presented in Table 7.

Tab. 7 Physicochemical characteristics of tested substrates

Substrate	Dry mass TS [%]	VSS [%]	Nitrogen [gN/L]
Landfill leachate #1	0.84	23.07	1.4
Landfill leachate #2	1.1	19.1	3.1
Composting hall leachate	6.0	69.4	1.7
Source separated kitchen wastes	18.4	73.3	5.2*

*-gN/kg fresh mass

Selectively collected kitchen waste was shredded prior to fermentation. Figure 15 shows separately collected waste before and after grinding.

Fig. 15 Source separated kitchen waste – before (left) and after (right) grinding

The following substrate mixes were prepared for the fermentation studies:

- Mixture of leachate from landfill 1: 1 (by mass),
- Leachate from the composting plant,
- Source separated kitchen waste,
- Source separated kitchen waste + 1: 1 composting effluent (bulk),
- Source separated kitchen waste + composting plant leachate + landfill leachate 1: 1: 1 (bulk).

The fermentation tests were carried out in accordance with the methodology described in subchapter 2.1. The fermented sludge from the sewage treatment plant was used as the inoculum.

Results and discussion

Table 8 presents cumulative biogas and methane production from fermentation substrates and mixtures.

Tab. 8 Cumulative methane and biogas production from municipal substrates

Substrate	Biogas yield [m3/t VSS]	Methane yield [m^3/t VSS]	Methane content [%]
Landfill leachate	< control	< control	-
Composting hall leachate	660.78	403.33	61.0
Source separated kitchen wastes	681.07	344.63	50.6
MODEL source separated kitchen wastes	861.79	524.30	60.0
Source separated kitchen wastes + composting hall leachate	684.64	369.01	53.9
Source separated kitchen wastes + composting hall leachate + landfill leachate	641.30	324.66	50.7

Based on the analysis of the results presented in Table 8, it was found that there is a possibility of managing selected waste streams or mixtures. In the case of fermentation of the leachate from landfills, inhibition of fermentation was observed. The phenomenon was not observed in the case of co-fermentation of leachate from landfill with selectively collected waste and leachate from composting plants.

The highest yield of biogas and methane was found for the mixture of source separated kitchen wastes in co-fermentation with leachate from the composting plant. This phenomenon is probably due to the presence of partially hydrolyzed bioavailable organic substances in both waste and the effluent. It is worth to mention that the biogas yield is lower compared to the model waste, probably due to some waste decomposition after collection and further logistic processes. Finally, substrates such as: source separated kitchen wastes or their mixtures with leachate may be a valuable substrate for methane fermentation due to significant methane yields (above 300 m^3 CH_4/t TS).

However, taking into account the comprehensive management of organic waste, the fermentation of a mixture of three different types of waste seems to be the most advantageous. The efficiency of biogas and methane production in terms of VSS is similar to the efficiency of individual substrates making up the mixture, at the same time the inhibition effect of the process is not observed.

2.4 Reduction of chemical oxygen demand (COD) after fermentation

A significant problem at the Eko Dolina plant is the treatment of leachate generated in the landfills and composting plants. These leachates are characterized by a significant load of organic carbon, which is removed biologically (anaerobic decomposition). The conducted research investigated the influence of methane fermentation on the organic carbon content of selected waste streams.

Materials and methods

Chemical oxygen demand (COD) was determined in mixtures samples obtained after fermentation tests described in subsection 2.3.

Approximately 30 ml of reactor fermentation medium sample were taken prior to the start of fermentation. The digestate samples for testing were also taken after the end of fermentation.

The COD parameter was determined in three repetitions in each of the samples using the modified dichromate method described in detail in the paper: "*Assessment of a modified and optimized method for determining chemical oxygen demand of solid substrates and solutions with high suspended solid content*" by F. Raposo and others .

Results and discussion

Figure 16 summarizes the results of COD analyzes for the mixtures before and after the fermentation process. Error bars denote the standard deviation of 3 measurements of a given sample. For each of the fermented substrates the percent of COD reduction was also calculated.

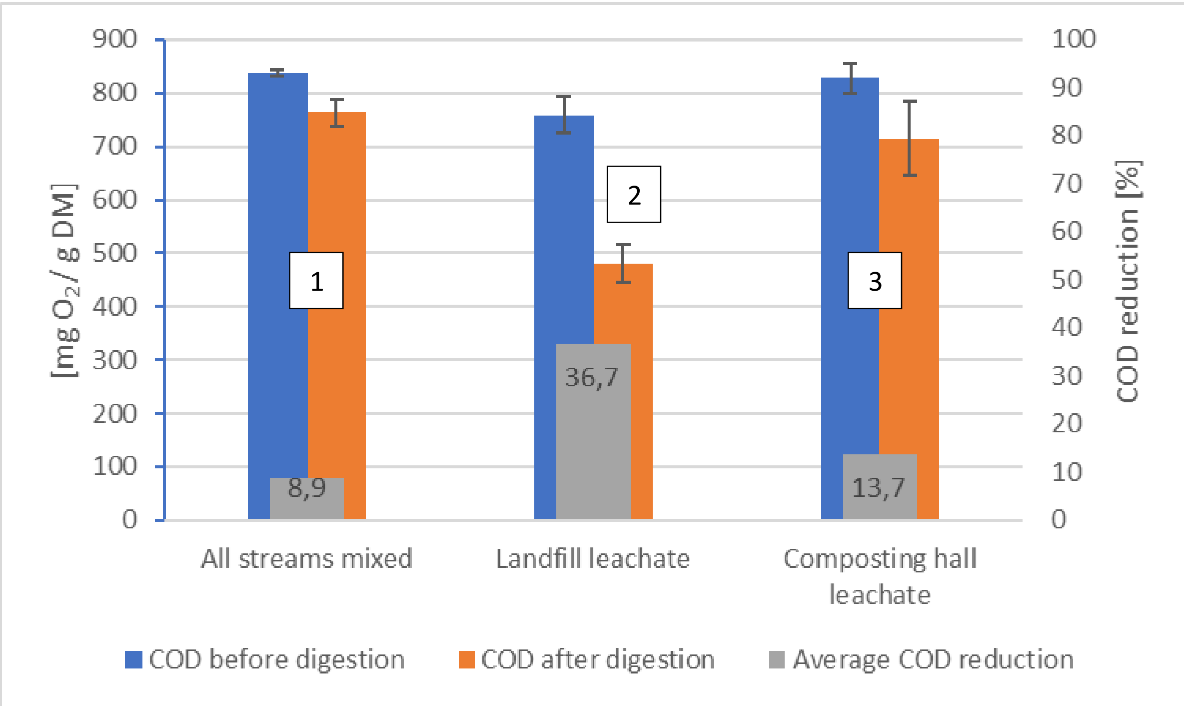

Fig. 16 Chemical oxygen demand for selected mixtures before and after fermentation, 1- all stream mixture, 2 – landfill leachate, 3- composting hall leachate

Based on the analysis of the obtained data, it was shown that the total COD in the samples can be reduced by methane fermentation.

The lowest degree of reduction was recorded for: a mixture of waste (a mixture of leachate from landfill, composting plant and source separated kitchen wastes) and leachate from composting plants. A small degree of reduction may be related to the intensive development of microorganisms during methane fermentation. As mentioned, both substrates are rich in easily degradable organic substances as well as macro and microelements that favor the intensive multiplication of microorganisms. The reduction of COD is probably related only to the conversion of part of the organic carbon to methane.

In the case of leachate from landfill plots, a significant reduction in COD was observed. It is worth adding that in the case of this sample, inhibition of methane fermentation was observed. Despite the low yield of biogas and methane, the organic substances in the leachate were partially mineralized by fermentation, which resulted in a significant reduction of the COD parameter.

3. Preparation of fertilizer for glasshouse experiments

The aim of the research was to prepare selectively collected municipal model waste for the production of organic fertilizer.

3.1 Fertilizer from model wastes with effective microorganisms

In order to carry out the research task, a model waste was prepared, which was initially stabilized with the use of EM (similarly to subsection 1.1), which was aimed at limiting the decomposition of organic matter by microorganisms (mold / rot).

After two months of stabilization, the substrate was dried and granulated using a meat grinder. Figure 17 shows the prepared fertilizer intended for fertilization tests.

Fig. 17 Fertilizer from model kitchen wastes

3.2 Fertilizer from fermented model kitchen wastes

Parallel to the model waste fertilizer, fertilizer was prepared from the fermented model waste. Mesophilic methane fermentation was carried out in a continuous system using a continuous fermentation reactor with a working volume of 15 dm^3 (Figure 18). During approx. 2 weeks of continuous fermentation, a total of approx. 1.5 kg of fresh weight of the model substrate was introduced into the reactor.

After each "feeding" of the reactor, the process parameters were kept constant and the fermentation was carried out until the gas production slowed down (about 5 days). With this approach, the DM content of the fermentation medium gradually increased and the process was not inhibited by the excessive production of volatile fatty acids. The produced digestate was separated with use a laboratory centrifuge, thus obtaining a semi-liquid organic fertilizer with approx. 12% DM content.


Fig. 18 Reactor for semi-continuous fermentation