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RESEARCH ON THE CONVERSION OF FOOD WASTE INTO BIOGAS

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Abstract. Every year, approximately 1.3 million tonnes of municipal waste are generated in Lithuania, of which about 50% is biodegradable waste. This includes food, garden and park waste, etc. Most biodegradable waste is disposed of in landfills, but this is not the only way to manage this waste. Waste can be useful, and its recycling can create added value. This encourages waste recycling and opens up opportunities for companies to invest in the waste recycling sector. The most effective and promising method of waste treatment for converting organic waste into alternative energy, reducing the amount of organic waste going to landfills and obtaining fertiliser is anaerobic waste decomposition in bioreactors. This article presents a study of biogas production opportunities conducted by Kasmonta, a company engaged in the collection of biodegradable waste.

Keywords: biodegradable waste, alternative energy, bioreactor, biogas

INTRODUCTION

Food waste accounts for a significant proportion of municipal waste and is one of the fastest growing types of organic waste in modern consumer societies. With increasing food waste, population growth and urbanisation, sustainable management of biodegradable waste is becoming a key environmental, economic and energy policy challenge. Conventional methods of food waste disposal, such as landfilling or incineration, have significant negative consequences: landfills generate large amounts of methane, which contributes to the greenhouse effect, while thermal waste treatment requires high energy consumption and does not ensure the principles of a circular economy. Therefore, alternative technologies are being sought that not only reduce environmental pollution but also create added value from secondary raw materials.

Two processing methods are most suitable for the recycling of food industry wastewater and biodegradable waste: composting food industry waste to produce valuable compost and extracting biogas in bioreactors. This article evaluates the method of biogas production in bioreactors and its efficiency for companies that provide biodegradable waste collection services.

Anaerobic digestion of food waste in bioreactors is one of the most promising technologies for converting food waste into renewable energy – biogas, consisting mainly of methane and carbon dioxide. This process takes place without oxygen, involving various groups of microorganisms that break down complex organic materials into simpler compounds in stages. Anaerobic digestion is considered an effective technology not only because of the possibility of obtaining energy, but also because of the reduction in waste, the stabilised residual product and the use of residues in agriculture.

Food waste is characterised by high moisture content and easily degradable organic matter, making it particularly suitable for biogas production. However, the processing of this stream in bioreactors also presents technological challenges: high fat content can cause the process to slow down or stop, rapid hydrolysis leads to a risk of acidification, and the heterogeneous composition of the waste makes it difficult to manage the process consistently. In recent years, intensive research has been conducted on how to optimise bioreactor performance, improve microbial activity, regulate process parameters (pH, temperature) and implement advanced technologies such as dry waste fermentation, two-stage anaerobic digestion, etc. (Khan, M. A., Ngo, H. H 2021)

Sustainable waste management policies in Lithuania and other European Union countries increasingly emphasise the development of biodegradable waste collection and recycling in order to reduce the amount of waste disposed of in landfills and increase renewable energy production. The conversion of food waste into biogas is in line with the principles of the circular economy, contributes to the reduction of greenhouse gas emissions and creates the conditions for the development of decentralised energy production models. It is therefore important to develop research that would allow a fundamental understanding of the mechanisms of anaerobic digestion of food waste, evaluate the efficiency of different bioreactor configurations, and create conditions for large-scale practical application of the technology. The article presents a study of the maintenance options for wastewater treatment plants and an assessment of waste processing technologies in companies that provide biodegradable waste collection services. Kasmonta presented an assessment and best recommendations for the processing of collected waste.

FOOD WASTE RECYCLING INTO BIOGAS

One of the best ways to recycle food industry wastewater containing large amounts of fat is to extract biogas in bioreactors. This method of recycling is particularly effective when the wastewater is mixed with water or other impurities, as it does not require significant costs for separation. Companies that collect and transport food industry wastewater transport it mixed with water.

Domestic biodegradable waste can be a cheap source of non-traditional energy**.** Biogas is produced when any organic material decomposes in an oxygen-free environment. Biogas is a unique mixture of gaseous components that is formed as a result of anaerobic microbiological fermentation of the organic part of waste or chemical reactions between decomposed waste components. Different raw materials yield different amounts of biogas. Most of it is produced from **fatty and oil waste – 400-600** m^3 /t, from corn – 200, grass – 110, beet –75, pig manure – 35 m^3 /t of biogas.

Biogas production is not a completely simple process, as organic materials are affected by different types of bacteria. Figure 1 shows which bacteria are involved in the biogas production process.

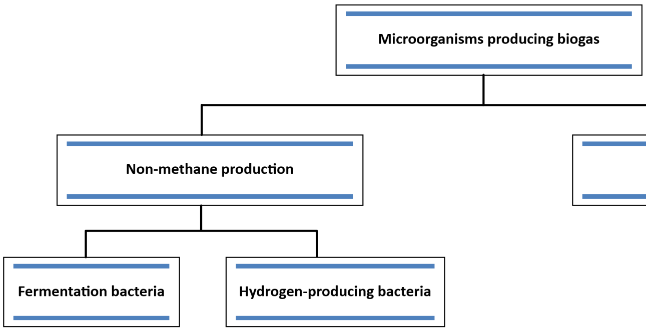

Figure 1. **Bacteria involved in the biogas production process (Kvasauskas, M. 2009)**

Under the action of anaerobic bacteria, the conversion of organic matter into biogas takes place in three stages: hydrolysis (Fig. 2), acetogenesis (Fig. 3) and methanogenesis (Fig. 4). Each stage involves a specific group of microorganisms with different functions and characteristics (Bailey, J. E. 1991), (Guo Guo, L. 2010.).

During hydrolysis, bacteria break down complex compounds into sugars, carbon dioxide and acetates (Jørgensen, H.; Kristensen, J. B.; Felby, C. 2007), (Xu, F., Li, Y...2020).

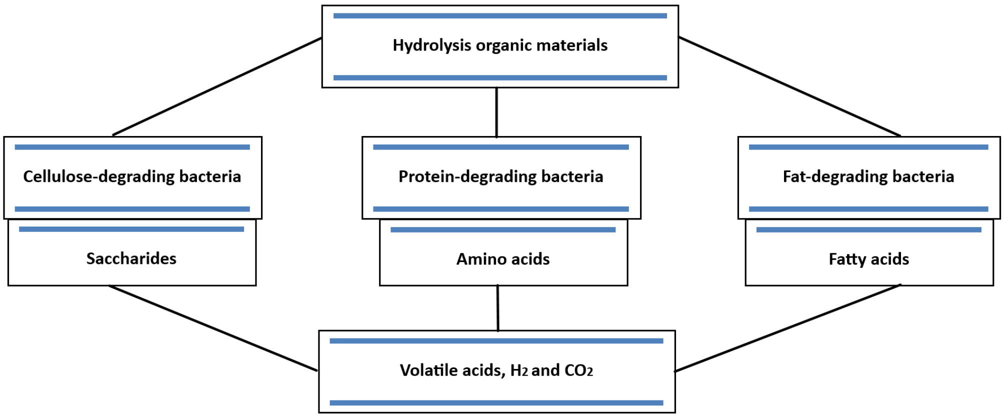

Figure 2. **Hydrolysis process**

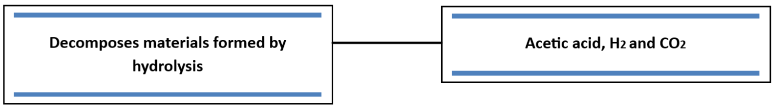

Figure 3. **The process of acetogenesis**

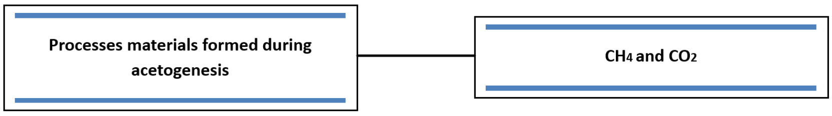

Figure 4. **The process of methanogenesis**

During the methanogenesis stage, methane-producing bacteria can use hydrogen, carbon dioxide and acetate as substrates to obtain methane through metabolic processes. About 70% of methane is produced from acetates and 30% from hydrogen and carbon dioxide (Ghose, T. K. 2023), (Koven, B. 2009).

During the biological degradation of organic matter in the reactor, all groups of microorganisms coordinate their activities so that the intermediate products secreted by one group are consumed by other groups of microorganisms. Microorganisms that produce biogas need a suitable environment to sustain their vital activities. Methanogenic bacteria are very sensitive to anaerobic processes, so when the amount of oxygen or nitrogen (ammonia) in the environment increases, their activity and, consequently, biogas production is disrupted. Temperature, acidity and alkalinity, oxidation-reduction potential and other environmental factors must meet their requirements. Metabolic activity and methane production depend on the following factors: the composition of the substrate being processed, the temperature maintained and its fluctuations, the duration of storage, acidity and inhibitory factors. As already mentioned, various raw materials can be used for biogas production: livestock manure, plant residues, food industry and agricultural waste, sewage sludge, organic municipal waste.

Table 1

Biogas yield and methane content

Composition of biodegradable waste	Methane gas content in biogas, perc.
Fats	80
Protein	75
Carbohydrates	50

As we can see from the statistical data presented, the yield of biogas is highest from fat. The study found that when collecting biodegradable wastewater, the company should adjust its collection routes in order to collect the purest possible single-type wastewater containing fat.

BIOREACTOR TECHNOLOGIES

Various types of bioreactors are used for anaerobic digestion. The most commonly used are:

- Continuous stirred tank reactors (CSTR) – suitable for various types of waste, characterised by process stability;
- Plug-flow bioreactors – used for substrates with a high dry matter content;
- Two-stage reactors – the hydrolysis and methanogenesis phases are separated, allowing for more precise control of the processes.

The choice of bioreactor type depends on the composition of the food waste, moisture content and desired biogas yield. The operation of a bioreactor is determined by three main parameters: temperature, substrate retention time and load.

Temperature

In order to maintain a uniform temperature throughout the bioreactor and ensure good contact between microorganisms and organic matter, the bioreactor must have a substrate mixing system. Mixing also prevents the formation of a crust on top of the load, which prevents the biogas formed from escaping from the raw material being processed. The bioreactor must also have a substrate loading and unloading system. It must be designed to ensure the smallest possible changes in temperature and concentration in the load.

Retention time

Retention time is the time the substrate remains in the bioreactor, measured in days. In continuous bioreactors, the retention time is obtained by dividing the working volume of the bioreactor (the volume filled with substrate) by the amount of feed supplied to the reactor per day:

$$\mathrm{MP} = \frac{\text{reactor working volume } \mathrm{m}^3}{\text{maintenance period } \mathrm{m}^3/\text{per day}} \tag{1}$$

MP – maintenance period, per day.

The total volume of the bioreactor is usually assumed to be 10 per cent greater than the working volume.

Load

Another important parameter of a bioreactor is the load. The load describes the amount of dry organic matter or purified organic matter loaded into the bioreactor per day, per cubic metre of the bioreactor's working volume. If the load is low, the bacteria lack food, their activity is not intense, and therefore biogas production slows down. If the load is too high, a large amount of volatile fatty acids begin to accumulate in the bioreactor. The amount of biogas produced decreases, and the CO2 concentration in it increases. The pH value falls below 6, which inhibits the activity of methanogenic bacteria. It is therefore important to select the correct reactor load in order to optimise biogas production from biodegradable waste. The required dry organic matter volume per unit of time is calculated as follows:

$$B_R = \frac{mc}{V_R} \tag{2}$$

B_R – organic load [kg/d·m^3];
m – required substrate amount per day (kg/d);
c – organic matter concentration (perc.);
V_R - organic matter concentration [m^3].

A mini bioreactor for biogas production from fat was created in the laboratory and the main characteristics influencing biogas production from fat were determined, Figure 5.

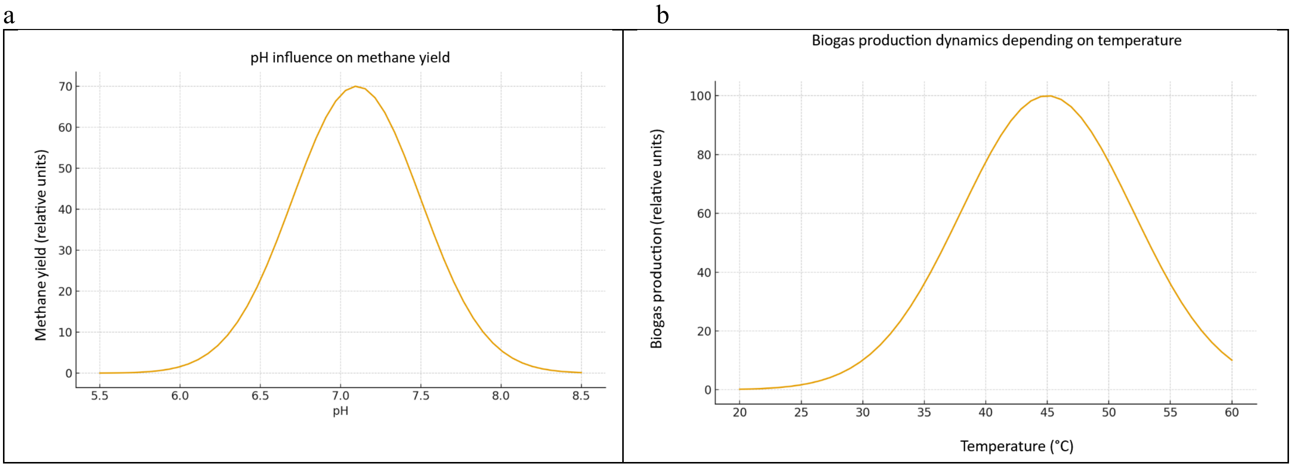

Figure 5. (a) **pH influence on the biogas production process; (b) temperature influence on the biogas production process**

The graph shows the dependence of biogas production intensity on temperature. It can be seen that biogas production increases as the temperature approaches the optimal mesophilic and thermophilic temperature range. Maximum production rates are observed at 45 °C, while at lower or higher temperatures, biogas synthesis decreases due to the inhibition of microbial activity.

Graph b shows how different pH values determine the amount of methane in biogas. The optimal pH range (approximately 6.8–7.4) ensures maximum methanogenesis efficiency. Lower pH values cause acidification and a drop in methane synthesis, while higher pH values can cause ammonia toxicity, which also reduces the methane content.

CALCULATION OF BIOGAS VOLUME AND BIOREACTOR PARAMETERS

This section presents calculations that allow us to estimate how much biogas can be produced with bioreactors of various sizes. Calculations Bioreactor calculation methodology (Kvasauskas, M. 2009), (Mao, C., Feng, Y. 2015).

From the point of view of anaerobic digestion, biomass is evaluated according to its fat, protein and carbohydrate content. Knowing the amounts of these organic components, it is possible to determine the biogas yield from the processed biomass. The average theoretical amount of biogas and methane produced can be calculated using the results of experimental studies. Knowing the average organic composition of waste (Table 1) and the stoichiometric biogas yield, it is possible to estimate the biogas yield from the organic composition of biomass: carbohydrates, proteins and fats. The amount of biogas from biodegradable carbohydrates:

$$Q_A = 0{,}75\, M_B \left(\frac{q_A}{100}\right) \tag{3}$$

Here, *0.75* is the average stoichiometric biogas yield, m^3 /kg of dry carbohydrate mass;
QA – amount of biogas released from biodegradable carbohydrates;
MB – biomass content, kg;
qA – amount of carbohydrates in biomass, % of dry mass.

Amount of biogas from biodegradable **proteins**:

$$Q_B = 0{,}75\, M_B \left(\frac{q_B}{100}\right) \tag{4}$$

Here, *0.75* is the average stoichiometric biogas yield, m^3 /kg of dry protein mass;
Q_B is the amount of biogas released by biodegradable proteins;
q_B is the amount of protein in the biomass, as a percentage of dry mass.

Amount of biogas from biodegradable fats:

$$Q_R = 0{,}75\, M_B \left(\frac{q_R}{100}\right) \tag{5}$$

Here, *0.75* is the average stoichiometric biogas yield, m^3 /kg of dry protein mass;
Q_R – amount of biogas produced from biodegradable fats;
q_R – fat content in biomass, % of dry mass.

The total biogas yield m^3 from biomass will be equal to the biogas yield from the decomposition of carbohydrates, proteins and fats:

$$Q_D = Q_A + Q_B + Q_R \tag{6}$$

Q_D – Total biogas yield, m^3

Calculation of bioreactor parameters

Biomass remains in the reactor for a set period of time, during which most of it decomposes and turns into biogas. In continuous feed reactors, biomass is kept on average twice as long as it takes for methanogenic bacteria to renew themselves. This period depends on the nature and composition of the biomass. The decomposition of biomass binding substances – cellulose and hemicellulose – takes the longest, while carbohydrates, proteins and fats decompose more easily.

The main criterion for designing the size of an anaerobic reactor is the lifetime of microorganisms. In a traditional bioreactor, it is equivalent to the hydraulic retention time and is directly related to the volume of the bioreactor. Thus, the working volume of the bioreactor depends on the duration of biomass retention in the reactor and the amount of biomass processed per unit of time. The working volume of the bioreactor is calculated using the formula:

$$V_d = 0{,}1\frac{M_{DM}}{B_T}\,T_d \tag{6}$$

Where Vd is the working volume of the bioreactor, m^3;
M_{DM} – dry matter mass, kg;
B_T – biomass density, per cent;
T_d – duration of biomass retention in the reactor, d.

Then the total reactor volume will be:

$$V = 1{,}25\,V_d \tag{7}$$

Here, V is the total volume of the bioreactor, m^3.

Reactor fermentation volume:

$$V_f = 0{,}3142\,D^3 \tag{8}$$

where V_f is the fermentation volume of the bioreactor, m^3;
D is the diameter of the bioreactor, m.

Biodigester storage volume:

$$V_d = 0{,}0827\,D^3 \tag{9}$$

where V_d is the gas collection volume, m^3.

The recommended gas collection volume is 5 per cent of the total reactor volume, then:

$$V_S = 0{,}05\,V \tag{10}$$

where V_S is the gas storage volume, m^3;

The recommended sludge collection volume is 15% of the total reactor volume, then:

$$V_D = 0{,}15\,V \tag{11}$$

where V_D is the sludge collection volume, m^3.

RECOMMENDATIONS FOR BIODEGRADABLE BIOREACTOR PARAMETERS

Based on the presented bioreactor calculation methodology, the parameters of the biogas bioreactor were modelled, taking into account the amounts of biowaste collected by the company, the frequency of collection and the state of the biomass. The modelling results are presented in Figure 6.

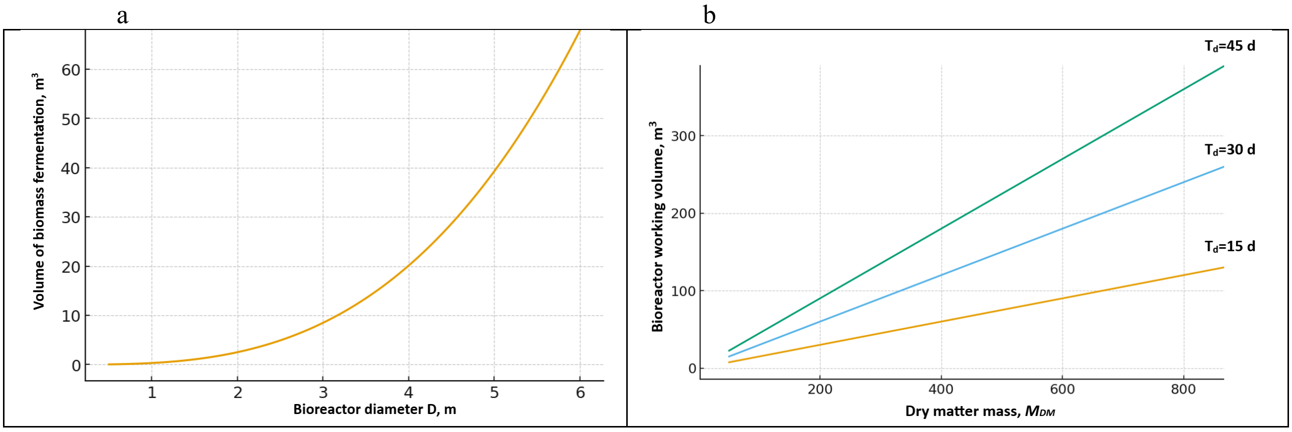

Figure 6. **(a) Dependence of biomass fermentation volume on bioreactor diameter; (b) Dependence of the working bioreactor volume Vd on dry matter mass M_{DM} and retention time Td**.

The graph shows the dependence of the fermentation volume of the bioreactor on the diameter of the reactor. This curve clearly demonstrates the dependence between the diameter of the reactor and the fermentation volume, which determines the extremely rapid increase in volume as the diameter increases. This means that even a slight increase in reactor diameter increases the fermentation volume several times over. This relationship is important in bioreactor design because it allows the influence of geometry on process scale, reactor capacity and structural efficiency to be assessed. Graph b shows how the working volume of the bioreactor changes as the mass of dry matter entering the reactor increases and the retention time of the biomass in the reactor changes. The three curves in the graph show that a longer retention time has a direct impact on the increase in working volume – at higher values, more biomass is stored in the reactor at a time, therefore a larger working volume is required. This relationship is essential from a technological point of view when designing the reactor capacity, as it allows the volume requirement to be estimated based on the planned load and process duration.

Based on the modelling results and an assessment of the number of customers from whom Kasmonta collects biodegradable waste, a continuous-flow bioreactor with a diameter of 4 metres and a capacity of 20 $^{m^3}$was proposed. In continuous bioreactors, the load is changed gradually, in fixed portions: when a portion of fresh substrate is added to the bioreactor, the same amount of degassed substrate is removed. The entire load of the bioreactor is replaced over a period equal to the retention time. The recommended retention time for biomass in the bioreactor is at least 30 days. Taking into account the frequency of collection of biodegradable (fatty) waste by the company, this would allow the company to completely renew the necessary reactor load and have a continuous biogas production process.

CONCLUSIONS

1. After conducting the analysis, it can be concluded that biodegradable waste can be useful and create additional added value for the company, especially for companies such as Kasmonta, one of whose activities is to collect wastewater from food production companies. Currently, the company delivers the collected wastewater to disposal companies and pays for this service. By investing in a bioreactor, the company could earn additional income from the gas produced, or could use the gas for its own needs, for heat or electricity production.
2. The analysis shows that biogas can be produced both by processing sewage sludge and by processing biodegradable food waste. Most biogas is produced from fat and oil waste – 400-600 m^3 /t. The biogas production process in bioreactors is recommended for Kasmonta when processing biodegradable food waste containing fat. This method of fat processing would be particularly suitable if biogas were also produced from sewage sludge, as this would reduce the costs of gas collection, storage and utilisation. In addition, larger quantities of biogas are possible. The company is advised to review its list of customers and retain only the collection of biodegradable food (fat) waste.
3. Before processing biodegradable food waste, it must be cleaned and separated from water. Kasmonta is recommended to install a fully automated grease separation system that is built into the ground. Such a system would be more suitable for separating thicker grease waste. The size of the system would depend on the amount of food waste processed by. The analysis showed that the company collects an average of 50 $m^3$of untreated biodegradable wastewater with water over a 30-day period.
4. Based on the modelling results and an assessment of the number of customers from whom Kasmonta collects biodegradable waste, a 4-metre diameter, 20 m^3capacity continuous operation bioreactor was proposed. In continuous bioreactors, the load is changed gradually, in fixed portions: when a portion of fresh substrate is added to the bioreactor, the same amount of degassed substrate is removed. The entire load of the bioreactor is replaced over a period equal to the retention time. The recommended retention time for biomass in the bioreactor is at least 30 days. This would allow the company to have a continuous biogas production process.

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