Relevant biogas substrate – maize silage vs slaughterhouse waste

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Abstract. The lack of support for construction and operation of installation of biogas plants in Poland makes looking for cheap and efficient substrates. The most commonly used substrate is maize silage. This is related to the high biogas efficiency and the advanced technology of its extraction. The problem, however, is the cost of buying the silage by the biogas plants, which has grown considerably in recent years, due to its wide use. It finds food applications, is a rich nutrition source for animals but is also the most commonly used substrate in the production of renewable energy for production of bioethanol as well as in biogas fermentation. As a result, maize is a desirable substrate on the market. This paper indicates the possibility of using of post-slaughter waste in biogas plants. The methane fermentation of these waste materials allows them to be safely disposed of, so that these substrates can be obtained for a small fee or even for free. Slaughterhouse waste materials have also shown high biogas and methane efficiency and are therefore the substrates desired in the anaerobic biodegradation process. It should be noted, however, that these substrates require additional thermal treatment prior to application into the fermentation chamber, which reduces the potential income for the biogas plant..

Keywords: biogas, maize silage, slaughterhouse waste, methane efficiency

1 Introduction

In a biogas plant, the right choice of the substrates is a key element influencing the kinetics of overcoming methane fermentation. The basic factor is the content of dry matter and dry organic matter. An important issue is the purity of the substrate, i.e. lack of foreign bodies in the form of stones or sand. The bacterial microflora plays very important role in the methane fermentation process, so selected substrates should be free from bactericidal and pathogenic organisms or chemicals that prevent the functioning of anaerobic bacteria. An important issue in the selection of substrates for biogas plants is the cost of their acquisition, availability and location of the source of their acquisition. (Kozlowski et al., 2016; Wiecek and Tys, 2015).
Basic substrate used in biogas plants are waste materials from animal husbandry. These are faeces of livestock in the form of manure and slurry. An application of the

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manure is to feed the fermentation mixture with dry matter and dry organic matter. In turn, the slurry, despite its low energy value, has a number of functions in the methane fermentation process. It is a diluting fermentation mixture substrate, consisting of the materials with higher dry matter content, which are the source of biogenic substances for microorganisms responsible for the production of methane. Rich bacterial microflora of the slurry makes it also an inoculant, especially for methanogenic bacteria. Slurry has buffering properties, which make it possible to manage many hazardous substances in the environment, allowing for the stability of the process in progress (Smurzyńska et al. 2016). Moreover, the management of animal waste in the methane fermentation process enables their safe disposal, which allows the protection of soils, waters and against uncontrolled and dangerous gaseous emissions (Smurzyńska et al. 2015, Smurzyńska et al. 2016a, Smurzyńska et al. 2016b, Smurzyńska et al. 2016c).

Further, most commonly used substrates in biogas plants are the materials of plant origin. The most commonly used plant is maize, and its silage. In 2012, 241590.19 megagrammes of this substrate (ARR 2014) were used for biogas purposes. Szlachta and Fugol (2009) highlight the efficiency of methane fermentation process based on slurry and maize silage. In the fermentation process, vegetable and fruit residues and their pulp are also commonly used. The use of these vegetable products is due to the properties they exhibit during the anaerobic process and biogas and methane efficiency.

Methane fermentation also makes it possible to efficiently dispose the substrates that are potentially hazardous to the environment. Many of the biodegradable byproducts from industry and agri-food sector may be successfully used in biogas plants, which will also allow for safe manure production (Czekała et al., 2012). Among these products, sewage sludge should be mentioned (Carmona and Dach 2015), banned for storage since 2016 and therefore requiring proper management. Other burdensome substrates are slaughter waste, the number of which increases with the development of farm holdings. The use of these dangerous substrates in biogas plant is increasingly used not only because of the increasing amount of hazardous substrates, but also because of the potential for safe disposal while achieving economic profitability.

This article has compared the use of maize silage in biogas plant as the substrate most commonly used with the substrate that pose a threat to the environment.

1.1 Maize silage characteristic

Maize is an important and most productive crop in the world. Both in Europe and Poland, the economic importance of maize is high and growing (Michalski 2004, Szmigiel et al., 2012). In Poland, maize cultivation is widespread throughout the country and the cultivated area is more than 1.2 million hectares (Central Statistical Office, 2016).

It is possible to distinguish two main directions of cultivation of this plant: grain and silage. Maize is used for consumption and industrial purposes and for the feeding of farm animals. In recent decades, along with the development of renewable energy, both grain (bioethanol) and silage (methane fermentation) have been used for bioenergetic purposes (Fugol and Prask, 2011). It should be noted that while the area devoted to maize cultivation in Poland in order to obtain maize silage is over 555 thousand, in case of Germany it amounts to 900 thousand. ha.

Fig. 1. The area of cultivation of maize for silage (thousands ha) (Central Statistical Office, 2016)

This is due to the fact that maize silage is a basic substrate used in biogas plants, the number of which in Germany has increased significantly in the last decade. Due to the new possibilities of maize application, special energy varieties have been created which allow for optimum biomass yield (Atletico K 280, Cannavaro K 310, Cassilas K 260, Fernandez K 250, Kaifus K 300, Krabas K 290, Ronaldinio K 260, Touran K 230). Maize varieties used in the methane fermentation process intended for silage contain higher amount of structural polysaccharides. In turn, maize intended for silage in order to obtain valuable feed is characterized by more starch content.

It should be marked that the content of components during the maize development, affects the amount of methane produced. In the early stages of maize vegetation, the parts of plants are formed that contain structural carbohydrates, i.e., raw fiber. In the later period during the grain formation, the starch is stored there. The increase in the amount of starch and lignin-cellulosic compounds during vegetation causes the raw material to be less susceptible to methane fermentation, which results in lower yields on the substrate. Literary sources report that obtaining valuable maize silage for methane fermentation takes place at a dry matter content of 28-35% for the entire plant. The maize in this period is in the phase of making flasks and filling them with the grains. Its biomass is characterized by the most optimal content of raw protein, raw fiber and its components (i.e. cellulose, hemicellulose and lignin as well as starch and sugar) for biogas purposes.

If maize silage is used as a substrate in biogas plants, the costs of maize growing are significantly important. Maize is a plant resistant to temperature fluctuations, so it is suitable for the climate in Poland. However, the decrease in yield during drought is noted. The maize cultivation allows for a very high yield of green mass from 1 ha, which is important due to the high and constant demand for filling the fermenting chambers. This plant is easy to ensilage and is characterized by lower acquisition costs compared to other cultivated plants. The techniques for maize growing and harvesting are also widespread, due to the use of maize for food purposes and to provide cattle feed (Szlachta, 2009).

It is also important to achieve high levels of methane and biogas production from maize silage during anaerobic biodegradation. This results from a high dry matter content (on average 28%) and dry organic matter (on average 90%), so it is considered as an energy crop (Niedziołka and Zuchniarz, 2007). Maize silage is a substrate free of harmful organic substances and heavy metals (Schattauer et al., 2005), which are responsible for the inhibition of the methane fermentation.

In order to use maize silage in biogas plants, it is required to store it properly and it is therefore necessary to provide storage plates for this substrate. This allows the protection of ecosystems and the purity of the substrate, which is important in the fermentation process. Maize silage is stored in prisms under foil cover. In turn, dosing into the fermentation tank is done using a conveyor belt.

In order to use maize silage as a substrate for fermentation mix, the cost of obtaining this substrate should be taken into account. As highlighted, maize is a multi-directional-use crop, so that cultivation for a biogas substrate becomes competitive with respect to silage used for food and feed purposes. This leads, to the gradual increase of the price, which is noted with the development of renewable energy. Studies of Szlachta and Tupiek (2013) show that profitability of maize for silage as a substrate for biogas plants depends on the level of yield and the costs of cultivation, harvesting and silage. Moreover, the authors also highlight the need to ensure competitive prices both for the farmer and the biogas plant. Studies have proved a higher income for maize cultivated for grain.

1.2 Slaughtery waste characteristics

The basic characteristic of slaughterhouse waste is the high content of organic compounds, so that they are naturally biodegradable. These waste materials are the source of carbohydrates, proteins, fats and biogenic substances essential for the development of microorganisms. In view of the above, in case of lack of management, these waste materials constitute a serious threat to the environment. Slaughter waste is a source of serious health hazards, due to potential development of pathogenic microflora. By disposing of decomposition they are responsible for the burdensome odor emissions that arise during storage. Moreover, improper storage may lead to leaching of leachate effluents consisting of biogenic compounds (nitrate, phosphate and potassium) to soil and water, disrupting the ecosystems balance (Sobczak and Błyszczek, 2009).

The slaughter waste indicates high biogas and methane efficiency that result from increased lipid content compared to plant material. Fats are a source of high carbon and hydrogen content, which makes them a high potential for methane production. It should be noted, however, that the presence of fats also contributes to the reduction

of methanogenic activity and biomass adsorption. As a result, lower levels of degradation and longer HRT are observed.
According to the EU law, three categories of slaughter waste are distinguished (Regulation of the European Parliament and the Council (EC) 2009). Category I requires unconditional disposal of waste at the incineration plant and is unsuitable for utilization in methane fermentation. Slaughter waste from category II and III can be processed by anaerobic fermentation in biogas plants, after prior thermal treatment under additional conditions.

2 Materials and methods

2.1 Substrates used in experiment

The research material was maize silage. The slaughter waste was also used for the study. These were homogenized waste materials from category II and category III.
In order to investigate the biogas and methane efficiency, a fermentation inoculum containing the desired groups of organisms was required. Inoculum, which is the separated liquid fraction of the fermentation pulp from one properly functioning agricultural biogas plant, was used in the performed experiment. The following methodology was used according to the Polish Standards: PN-90 C-04540/01 for pH determination, PN-EN 27888: 1999 for conductivity, PN-75 C-04616/01 for dry matter and PN- Z-15011-3 in case of organic dry matter.

2.2 Experimental set-up

The research on methane efficiency of the substrates in batch culture technology was carried out in the Laboratory of Ecotechnology at the Institute of Biosystems Engineering (PULS) on the basis of internal procedures, based on adapted standards: DIN 38 414-S8 and VDI 4630, commonly used in Europe. Detailed methodology of performed research was presented by Cieślik et al. (2016)

3 Results and discussion

At the beginning of the experiment the basic physicochemical parameters of the investigated substrates were defined in order to determine the proportion of individual components in the fermentation mixtures. Table 1 shows the dry matter content and dry matter content of the substrates. Both silage and slaughter waste show a high dry matter content and thus require an application of additional dilution substrate (Owczuk et al. 2014).

Table 1. Parameters of analyzed substrates

Substrates	D.M. [%]	O.D.M. [%]
Maize silage	31.74	95.92
Slaughtery waste, cathegory II	49.85	98.12
Slaughtery waste, cathegory III	36.59	96.50

Table 2 represents the methane and biogas efficiency of investigated substrates. A high biogas yield is noted in case of slaughter waste. The highest production of methane and biogas was noted in particular when using category II waste, which was at the level of 407.27 m^3·Mg F.M. and 586.48 m^3·Mg F.M..

In turn, the least efficient substrate turned out to be maize silage, which is the most commonly used co-substrate in biogas plants, among others, in Poland. For maize silage, over 5 times lower methane production and more than 4 times lower biogas production has been noted, compared to waste from category II, in calculation for fresh matter. In contrast, waste from category III have been reported to account for almost 4-fold lower methane production and 3-fold lower biogas production, also in calculation for fresh matter.

Comparing the biogas and methane efficiency of the tested substrates calculated on dry matter, the higher methane efficiency of slaughterhouse waste has been noted, more than 3 times, as well as twice higher the biogas efficiency in relation to maize silage.

Table 2. Methane and biogas efficiency of tested substrates

	Methane content [%]	**Cumulated methane [m^3·Mg^{-1} F.M.]**	**Cumulated biogas [m^3·Mg^{-1} F.M.]**	**Cumulated methane [m^3·Mg^{-1} D.M.]**	**Cumulated biogas [m^3·Mg^{-1} D.M.]**
Maize silage	53.40	75.92	142.18	261.50	489.74
Slaughter waste - category II	69.45	407.27	586.48	816.99	1176.49
Slaughter waste - category III	69.10	294.67	426.30	805.33	1165.08

In case of investigated substrates, the price of maize silage is 25-35 €/Mg, whereas slaughter waste materials are the substrates for disposal, so the biogas plant receives a recycling fee of 5-100 €/Mg (depending on the waste type). Consequently, the possibility of utilizing of slaughter waste in biogas plants is of mutual benefit. For a meat factory that transfers waste to environmentally safe disposal without incurring costs. And in turn, the biogas plant adopts a burdensome substrate, which is also a valuable source of energy production.

The biogas and methane efficiency shown by slaughter waste represents the potential for high energy production in biogas plant. If maize silage is used which shows significantly lower biogas and methane efficiency, it should also be marked that the cost of this substrate purchasing should be taken into account, which considerably decreases the income of the planned investment. Therefore, it is proposed to use maize straw silage to maintain the viability of the plant (Cieslik et al., 2016).

4 Conclusions

In many biogas plants the primary substrate except the slurry is corn silage. This is due to the biogas and methane efficiency of the substrate and methane fermentation run, which is devoid of the inhibitor of the process. The development of biogas energetics has forced cultivation of maize with higher content of dry matter and reduced starch content. Moreover, maize is a high yielding plant with resistance to temperature changes, which makes it one of the main crops in Poland. The wide range of maize applications makes the growing and harvesting techniques also widespread. However, use of maize in food industry and the possibility of energetic support of biogas plants, causes that the purchase price of this substrate entails less and less interest in using it for energy purposes. As a result, other substrates are being sought that will allow the profitability of the biogas plant, especially in case of such low subsidies for investments in renewable energy installations in Poland. It is proposed to use biodegradable waste materials from industry and agriculture. This article proves very high biogas and methane efficiency of slaughterhouse waste. However, it should be highlighted that despite the free substrate acquisition by the biogas plants, they also require additional thermal treatment, resulting in higher investment and operating costs of biogas plants.

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