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New Trends in Substrates and Biogas Systems in Poland

Stanisław Marks[1], Jacek Dach[1], Francisco Jesus Fernandez Morales[2], Jakub Mazurkiewicz[1], Patrycja Pochwatka[3], Łukasz Gierz[4]

[1] Poznan University of Life Sciences, Institute of Biosystems Engineering, Wojska Polskiego 28, 60-637 Poznan, Poland

[2] University Castilla-La Mancha, Chemical Engineering Department, Avda. Camilo Jose Cela S/N 13071, Ciudad Real, Spain

[3] University of Life Sciences in Lublin, Department of Environmental Engineering and Geodesy, Leszczyńskiego 7, 20-069 Lublin, Poland

[4] Poznan University of Technology, Faculty of Civil and Transport Engineering, Piotrowo 3, 60-965 Poznan, Poland

* Corresponding author's e-mail: stanislaw_marks@o2.pl

ABSTRACT

The amendment to the Polish Renewable Energy Act creates great opportunities for the development of the biogas market in Poland. Years of experience in biogas production in Western Europe and the development of biogas installations in Poland indicate the requirement to look for alternative substrates to those produced from dedicated crop production (mainly maize silage). Feasible solutions include the use of biodegradable waste from agriculture or industry as well as municipal landfill sites. The usage of these substrates in the methane fermentation process offers low cost, high biogas production and the safe management of biowaste. The arguments for using them in biogas installations are persuasive. This article presents new approaches of biogas plant installation solutions which allows for the effective fermentation of biowaste from animal and vegetable production, from the agro-food industry and from municipal waste.

Keywords: biogas plant, biowaste, agriculture, industry, biogas, methane, new trends in substrates, new technologies

THE STATE OF THE BIOGAS MARKET IN POLAND

Economic development, and the subsequent dependence on mechanization and technology, brings an increased demand for energy and any higher consumption of conventional fuels leads to environmental degradation and pollutant emissions. Therefore, alternative solutions are sought, including wind turbines and solar panels [Furlan and Mortarino, 2018]. Despite the technological advancement of the abovementioned installations, their efficiency depends to a large extent on geographical and climatic conditions. Biogas installations, however, allow for the effective production of biomethane as a source of heat and electricity, and the efficiency of this production is independent of external factors [Scarlat et al., 2018]. However, it should be emphasized that the anaerobic decomposition of organic matter requires a properly designed installation suitably adapted to methane fermentation technology and maintaining appropriate process parameters with the appropriate selection of the substrates for biogas production. Most important factors that have influence on good functionality of biogas plats are: cheap but efficient substrates, large spectrum for substrates usage, more efficient fermentation and installation working hours [Wandera et al., 2018].

The amendment to the Renewable Energy Sources Act [2017] has introduced great optimism for the development of alternative energy production technologies in Poland. The changes are designed to allow the rebirth of the biogas market, which, until now, has been slowly dying with insufficient funding and support from the government. Existing or emerging installations, despite the efficient methane fermentation process, have become unprofitable investments. The rescue plan for existing installations is based on the use of low cost industrial substrates that demonstrate high biogas yields [Czekała et al., 2020].

SUBSTRATES USED IN BIOGAS INSTALLATIONS

Agricultural products

In Poland, agricultural based biogas plant installations have the biggest potential (comparing to municipal using urban waste and sewage sludge), mainly due to the availability of substrates suitable for methane fermentation [Piwowar et al., 2016; Igliński et al., 2015]. The basic idea of the operation of biogas plants is the use of biowaste-based substrates that are problematic in their management. During livestock breeding, especially in the case of intensive livestock production, huge amounts of manures are created. Contrary to Western Europe biogas plant where slurry in an agricultural installations is very often the basic substrate of the fermentation mixture [Vega et al., 2014]. Animal excrements are the source of the bacteria necessary for the anaerobic digestion process and is used as an inoculum source in the fermentation chamber. These animal faeces also exhibit buffering properties, thanks to which the proper pH of the fermentation mixture is maintained, which is important, for example, in the case of using silage. In addition, manure usually shows high hydration, which allows its use in biogas plants as a co-substrate for diluting the fermentation mixture. It is possible to subject the slurry to separation, thanks to which dry fraction fermentation is a much more efficient process [Deng et al., 2014]. Manure is the substrate that feeds the fermentation mixture due to the high content of dry matter. It should be noted that the use of substrates derived from animal production in biogas installations is more environmentally friendly than the storage of animal waste or its use for fertilization as both allow for the emission of greenhouse and odoric gases directly into the atmosphere, posing a threat to the environment, and to human and animal health [Czekała et al., 2018a]. For example, in the poultry industry, in which Poland is the EU's leading producer, manure is a major by product. These droppings are not only a serious threat to the environment, but also present a high organoleptic nuisance, which is why using them as a co-substrate in biogas plants offers the best solution [Li et al., 2017]. The high nitrogen content means that the manure can be used as a co-substrate for the methane fermentation process together with low-N materials like straw[Mazurkiewicz et al., 2019]. The release of nitrogen in the form of ammonia during manure monofermentation has an inhibitory effect on the kinetics of anaerobic digestion.

For many years, the basic substrate used in agricultural biogas plants has been maize silage [Cieślik et al., 2016]. Despite the high production of biogas and methane, this substrate has contributed to a significant reduction in the profitability of many installations [Smurzyńska et al., 2017]. This situation has been caused by a sudden rise in the price for maize silage because of competition between animal production feeding and biogas plants sector needs.

The use of cereals grown specifically for biogas production has not been effective, perhaps mainly due to the ecological and ethical issues of energy crop monoculture [Maj et al., 2017]. Consequently, waste generated during the cultivation of maize and other cereals, i.e. straw, is more and more often used in agricultural biogas plants. Hay substrate is also often used for the methane fermentation process. However, it should be emphasized that the presence of lignocellulosic compounds in the plant material makes the anaerobic decomposition process difficult and requires, above all, a longer HRT time. High yields in biogas production are demonstrated by plant substrates such as forage, which are quickly and efficiently decomposed [Prochnow et al., 2009]. Grass cuttings are used for energy purposes when they do not have any other use (animal feed). However, their use in biogas installations is associated with the need to ensure adequate storage conditions due to the progressing decomposition / biodegradation time. Therefore, after mowing the field, the best solution is the direct transport of the material to the digester so that the material does not lose its value and the highest level of biogas production is ensured [Czekała et al., 2018b].

For many years, sugar beets have been known as a high-energy source of biogas production in the methane fermentation process. However, the cost of supply, as in the case of silage maize discussed above, has made them an unprofitable substrate despite the high yield from field and good production of methane [Rajaeifar et al., 2019].

Other waste substrates

The utilization of biogas plants also allows for the effective management of food industry waste such as whey and distillery residues. These substrates require proper management. For example, whey is characterized by a very high level of COD and low pH, both of which indicate the possibility of significant environmental contamination. Therefore, manufacturing companies are required to recycle these substrates and this offers the possibility of using this free biodegradable waste from the food industry in the fermentation process. However, these substrates also offer a good solution for animal feed producers [Zhang et al., 2014].

Selected municipal waste – food leftovers from households, restaurant waste and out of date food (ReFood), can also be successfully used in biogas plants [Borowski et al., 2018; Nghiem et al., 2017; Wu et al., 2016]. These biodegradable substrates show high biomethane production and their utilization is not a major problem for the kinetics of the methane fermentation process. Therefore, transferring them from local markets and food wholesalers, as well as catering facilities, may provide additional energy for the fermentation mixture.

Post-slaughter waste is one of the most difficult organic waste products to manage. It poses a serious threat to the environment, in the form of soil and water pollution, as well as a danger to public health. In view of the existing threat, enterprises producing post-slaughter waste are obliged to quickly transfer it to plants dealing with the utilization of problematic substrates. It is possible to deal with this waste in incineration plants, to subject it to oxygen treatment, to treat it using alkaline hydrolysis or to use it in methane fermentation (except waste category I). Category II and III animal waste can be used in biogas plants. However, the methane fermentation does require proper preparation. Post-mortem category II waste requires sterilization at 133°C and 3 bar pressure for a minimum of 20 minutes. Category III waste, after defragmentation and mixing, is pasteurized at 70°C for at least 60 minutes. Liquid manure and animal digestive tract content do not require thermal treatment and can be used in a biogas plant without prior hygienization. Research shows that these substrates are a rich source of organic matter. They are characterized by a high content of organic carbon and are rich in lipids and proteins, and thus constitute a valuable source enriching the fermentation mixture [Moukazis et al., 2018]. It should be noted, however, that the high fat content of these substrates means that they require a longer fermentation time, which means larger storage tanks and/or larger digesters. In addition, the use of meat processing waste in the production of biogas imposes on the plant biogas owners not only the requirement of a hygienization process, but also the installation of special macerating equipment. It should be also underlined that ammonia released during anaerobic decomposition may inhibit such processes and therefore it is proposed that post-slaughter waste is used as a cosubstrate in the fermentation mixture [Pagés-Díaz et al., 2014].

Another source of substrates used in waste biogas plants is waste from sewage treatment plants, particularly sewage sludge, which according to the applicable norms existing since January 1, 2016 requires a development plan (exempting agricultural waste) [Regulation of the Minister of Economy...2015]. In this situation, the combination of wastewater treatment and biogas production has become an increasingly common solution and this development allows the profitable use of biological material that is effectively stabilized in digesters. Sewage sludge has a high content of biogenic fertilizers, i.e. nitrogen and phosphorus and therefore it is an efficient substrate in the biomethane production process [Sousa et al., 2011]. The methane fermentation of sewage sludge leads to a reduction of organic matter by a minimum of 30% and is a reason why biogas installations are often located in sewage treatment plant facilities.

Landfill waste is another rich source for energy generated in methane fermentation [Frac and Ziemiński, 2012]. The ability to use organic waste in biogas plants is possible due to residential waste segregation. It is necessary, however, to ensure high quality by limiting the decomposition process and storage time should be kept to a minimum. The collected biodegradable waste is mainly fruit and vegetable waste, dairy products, and leftover meals.

Substrate pre-treatment

Nevertheless, in order to digest every substrate in effective way its need a proper pretreatment. Pre-treatment make the material more accessible for microbial degradation by its structure destruction, thereby raising its potential for biogas production [Lindmark et al., 2012]. There are few different types of substrate pre-treatment available at the market. Some of them are: mechanical cutting, thermal pretreatment, micronization, sonification, cavitation (electromagnetic mill) or biological decomposition (i.e. Trichoderma fungi). Optimal treatment selections relies on comparison between the treatment cost and energy gain as extra biogas production [Brunia et al., 2010]. It is inevitable to mention that obtained pre-treatment effects are very often lower then promised by technology suppliers.

BIOGAS PLANT INSTALLATION SOLUTIONS

Fermentation chamber technology

Traditional fermentation chamber technology is based on one fermentation chamber in which all fermentation stages (Hydrolysis, Acidogenesis, Acetogenesis, Methanogenesis) occurs. An example of this technology is solution called “NaWaRo”. An Illustrative draft of such solutions is shown in Figure 1. This type (as well as its clones) dominates in Europe (over 15,000 installations) and it consists in one digestion chamber where all fermentation phases take place. Usually it also has two side mixers with engines located a side of chamber in order to facilitate their service [Eder and Schulz, 2008].

New technology has been recently developed and implement to real scale biogas plant by Dynamic Biogas Company with scientific support of Institute of Biosystems Engineering, Poznan University of Life Sciences (PULS). It is composed of two fermentation chambers. This solution illustrative draft is shown in Fig. 2. First, smaller chamber (named Biotechnological Accelerator) is responsible for first three digestion stages: Hydrolysis, Acidogenesis and Acetogenesis (acid hydrolysis). This compartment is dominate by acid environment. This creates the special conditions for organic matter digestion. Second, larger compartment is mainly responsible for Methanogenesis and has higher pH level approx. 7.2–7.9. The Hydrolysis, Acidogenesis and Acetogenesis also take place it this chamber but at much less scale. This solution abbreviates fermentation time up to 40–50% in comparison with traditional technology. Furthermore low pH level at accelerator allows digesting larger scale of substrates like e.g. post-slaughter waste from food and beverage industry. An additional advantage of acid hydrolysis is sanitary effect as low pH level kills dangerous bacteria and allows for profound decomposition of antibiotics and pesticides. Moreover larger decomposition of dry matter into acids decreases the energy needs for pulp mixing. In October 2019 Dynamic Biogas Company in cooperation with Institute of Biosystems Engineering (PULS) have opened the first real scale biogas plant based on that technology.

Agitation systems

High biogas and methane production efficiency at biogas plant largely dependents on proper mixing system selection for fermentative pulp [Lindmark et al., 2014, Satjaritanun et al., 2016]. Proper agitation ensures adequate bacterial contact with the substrate due to even distribution of substrate and bacteria agglomerates throughout the whole tank volume. It also decreases the risk of different temperatures zones creation which has negative effect on fermentation process [Ward et al., 2008]. There are many different types of agitation systems used at Polish market some of

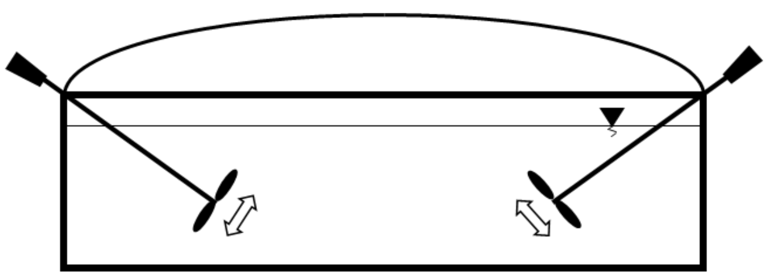

Fig. 1. Illustrative draft of NaWaRo technology fermentation chamber [Marks et al.,2017]

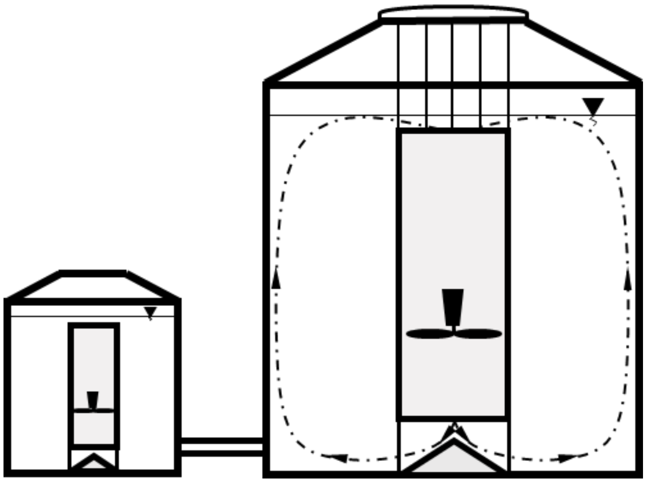

Fig. 2. Illustrative draft of new biogas plant technology. Accelerator on the left side and main fermentation chamber on the right side.

them are: mechanic (side/central), hydraulic or pneumatic. Among others central mechanic mixing system with the tube submerged in fermentation pulp results as highly effective. Central mixing generates the flow of the fermentation liquid directed downwards and recycled upwards at the tank bottom. To reduce energy consumption and increase the flow effect, the mixing paddles are placed in a special steel pipe (Fig. 2). Top inlet of the pipe is located approx. 10–15 cm bellow the pulp mirror in order to create a pulp funnel during agitation which attracts the flotation substrate to it interiors. This solution completely prevents from thicken layer formation which may appear at the top of fermentation chamber. At the bottom outlet the conical structure is positioned in order to evenly distribute the fermentation pulp [Marks et al., 2017].

Biogas plant design and work management

Traditional biogas plants are designed to work continuously. For example biogas plant with 0.5 MW power continuously generate heat and power at constant level. On the other hand our society electricity demand is not stable but varies depending on the time of a day. Therefore Dynamic Biogas Company in cooperation with Institute of Biosystems Engineering has started to design biogas plants as „peak" installations. This type of biogas plant management strives to produce heat and power for 15 hours a day during highest electricity and heat demand (from 6:00 AM to 9:00 PM). Hence biogas plant originally designed for 0.5 MW power may be converted to biogas plant with power of 0.8 MW and produce electricity when is really needed. Afterwards from 9:00 PM to 6:00 AM biogas plant accumulates biomethane in order to feed 0.8 MW power Combined Heat and Power (CHP) unit for next 15 hours. This solution allows relieving power plants during high electricity demand peaks. Furthermore electricity cost during high demand peaks is grater what improves the financial economy of biogas plant business plan [Dach et al., 2019].

CONCLUSION

This paper indicates the high potential of biodegradable wastes that allow for the effective production of biomethane from substrates obtained for free or for a small fee. The utilization of biogas plants has now become an alternative to traditional agricultural biogas plants, where the use of plant cultivation dedicated for biogas plant has become an unprofitable venture. New biogas plants designs which take in to account fermentation phase's separation, proper agitation system and peak working hours let to increase biogas plant efficiency and allows for the effective production of biomethane, as well as the safe management of organic waste from sewage treatment plants, landfills and by-products from agricultural and food production.

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