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Monosubstrate agricultural micro-biogas plant for liquid manure as a complement to the technological line in large-scale animal husbandry — practical verification

Abstract
The micro-biogas technologies using liquid manure, which eliminates harmful compounds for the environment and maintains high fertilizing parameters of digestate, are already available in Poland. The effectiveness of these technologies together with a summary of previous experience have been presented and discussed in this paper. The presented conclusions are based on analysis of dozen BIOLECTRIC* micro-scale biogas plants with installed power from 11 to 40 kWe working in Poland and more than one hundred and eighty of such installations in Europe. They overcome the paradigm of the lack of profitability of these installations in a microscale.

Keywords: micro-biogas plant, liquid manure, cogeneration, animal husbandry.

1. Introduction

Functioning of highly specialized, large-scale farms effects its high production concentration combined with the increase of productivity. This is caused not only by the economic profitability threshold, but also by the response to the nowadays rising feeding needs of the growing human population and its consumerism. However, this phenomenon has a second, unfortunately negative side, visible especially in mass cattle breeding, in industrialized and territorially small European countries. It is a very large accumulation and concentration of manure, burdensome for the environment; this includes dairy cattle manure, which generates: excessive nitrogen emission to soil and water, uncontrolled emission of methane into the atmosphere, whose impact on the greenhouse effect is more than 28 times higher than CO_2, and onerous odour of other biogas components (Podkówka, & Podkówka, 2011; Orzech, 2015).

In Poland, which has a relatively large territory, this problem is not as severe as in the Netherlands or Belgium so far, nevertheless, the undesirable symptoms are already appearing in Podlasie and Warmia and Mazury, where Polish dairy farming is concentrated. Examples from countries with intensive agricultural production, show however, that large and highly efficient farms do not necessarily pose any threat to the natural environment. Farms often clean up and utilizing waste at the place of their creation. It should be stressed that micro-biogas technologies using liquid manure, which eliminates harmful compounds for the environment and maintains high fertilizing parameters of digestate, are already available in Poland.

The effectiveness of these technologies together with a summary of previous experience have been presented and discussed in this study. The presented conclusions are based on analysis of dozen BIOLECTRIC® micro-scale biogas plants with installed power from 11 to 40 kWe working in Poland and more than one hundred and eighty of such installations in Europe.

2. The experience of the Benelux countries

The development of technologies enabling efficient use of manure for methane fermentation processes has gained the greatest dynamics in Belgium and the Netherlands. It is where the high concentration of cattle breeding in small spaces effects environment negatively with exceptional intensity. Moreover, very limited cultivated area, in many cases its lack, prevents use of plants (which, at the same time, may be use as a feed for livestock) as a substrate for biogas production. The initiating step, and at the same time the accelerator of the entire process, was the obligation introduced in the Benelux countries to cover lagoons and slurry tanks by a tight coating to reduces odour and methane emission. The first attempts to use the biogas accumulated in such type of construction, consisted in using it as a fuel in adapted gas boilers or cogeneration systems. However, it was a very unstable energy source, dependent on external atmospheric conditions. Therefore, it was necessary to develop technologies improving the efficiency of methane fermentation, by ensuring appropriate process conditions, including controlling its critical parameters. Additional requirements, which turned out to be essentially important under polish conditions, were adjustments of the scale of biogas installations to the size of existing herds in Belgium (from 50 to a few hundred dairy cattle) and maintaining attractive profitability of micro-biogas plants without financial support in forms of investment subsidies or subsidies to sold energy.

The author's comparative analysis of the European market for micro-biogas manufacturers carried out in 2013 showed more than 50 producers offering their products in the Benelux countries as well as in Germany and Switzerland. Some of them have significantly developed their technologies, although the price of these micro-biogas systems has become far too high (well above EUR 20,000/1 kW_e). In addition, to achieve the expected energy parameters, it was necessary to use co-substrates in the form of silage or green fodder. Over 60% of producers from the analyzed group remained however at the prototype stage or several units sold, and then, withdrew from the market. Special attention of the team has been focused on the product of the Belgian producer BIOLECTRIC NV, because its microbiogas plant turned out to be the only one, realistically working only on liquid manure and at the same time maintaining the attractiveness of prices, and started series production. In 2018 more than 180 installations of this type exist: in Belgium, the Netherlands, Italy, France, Sweden, Turkey and Poland.

The strong position and extensive BIOLECTRIC® experience on the European market is now used by the largest producer of dairy products in Europe, i.e. the Dutch concern Friesland Campina. It started the project with a budget of several hundred million Euros, of which 180 million EUR come from government support in the form of subsidies for energy. The project involves installations in regular milk suppliers,

a total of one thousand biogas installations with installed power from 22 kWe to several hundred kWe. The company's goal is to provide conditions for sustainable development by reducing negative impact of dairy sector on environment. As part of the project, in perspective of 12 years, BIOLECTRIC NV became a supplier of several hundred micro-biogas installations with power from 22 kWe to 44 kWe, using only liquid manure as substrate. Installations with higher powers, using also other substrates, will be provided by the Dutch BiogasPlus and Host. The implementation of this project is a breakthrough in the management of manure at its production source.

3. Description of BIOLECTRIC® technology

BIOLECTRIC NV based its technology on single-silo (Fig. 1) mesophilic fermentation, carried out in a cylindrical vertical reactor, with a biogas buffer located directly above the mirror of the fermentation mass (under the double membrane flexible roof). The cogeneration and control system is installed in a 20 ft DV container, factory-connected to the wall of the digester. It contains the direct control set-up of the supply and outflow system from the reactor, its heating and mixing systems.

Fig. 1. BIOLECTRIC® 33 kWe installation example: Warmian-Masurian Voivodeship (own source)

All basic components of the micro-biogas plant are manufactured and assembled at the manufacturer's headquarters in Belgium, and then, with one transport, they are delivered to the place of its installation (on an investor's farm, on a hardened concrete surface — see Fig. 2). In the next stages, the following is carried out:

– installation, from prefabricated elements, the reactor together with the heating and mixing system,
– installation of a liquid manure pump immersed in the dung channel,
– connection micro-biogas plants using a Ø 160 mm pipeline to the place of liquid manure collection,
– connection micro-biogas plant using a Ø 110 mm pipeline to the storage site,
– connection of the internet system,

– connection micro-biogas plant to the power system operating on the farm,
– connection the heat distributing system from the cogeneration unit,
– connection to a fresh water intake (only for hygienic purposes),
– insertion of a bacteria culture and start-up of the installation.

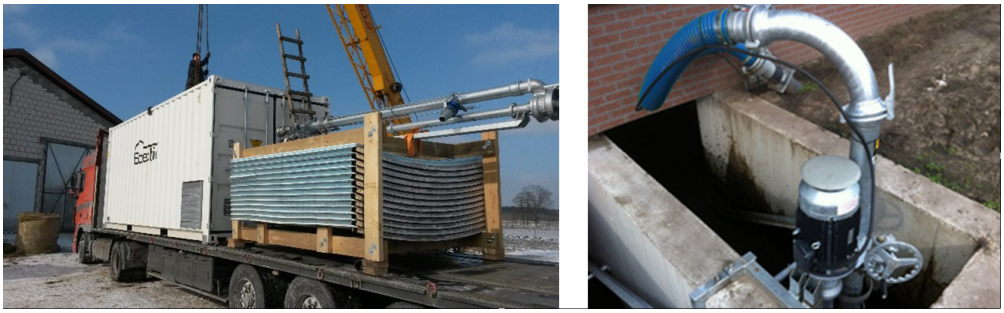

Fig. 2. Delivery of BIOLECTRIC® 11 kWe micro-biogas plant to the place of installation and liquid manure collection from the manure channel (own source)

Fig. 3. The interior of the BIOLECTRIC® cogeneration container (own source)

The construction of the cogeneration container (Fig. 3), assembly of the reactor and realization of connections are carried out by a specialized installation team, and the start-up of the microbial fermentation process is carried out by the monitoring and control centre.

The key of the market success of BIOLECTRIC®, based on achieving serial production and maintaining a reasonable market price of equipment, is the combination of commonly available components (slurry pumps, mixers, engines, generators, roof coatings, H_2S filters, heat exchangers, heating and measuring installations, etc.) with proprietary control and automation systems. They enable optimization of mesophilic methane fermentation of manure and operation of engines and generators with very variable biogas characteristics. Examples of these unique solutions are:

– the use of an electronic controller, called BIOTRONIC®, which regulates the operation of Kubot's engines,

– the use of dedicated control unit and control software that optimizes fermentation processes,
– organization, in each country, a team responsible for current, remote monitoring and control of the fermentation process parameters and, possibly, service intervention.

Used technical solutions, optimizing the run and efficiency of the fermentation process, do not exclude the need for the initial selection of potential investors. The basic criterion is the quantity and quality of manure available on the farm, which is directly related to the way of breeding, quantity and milk yield of cows. The following is required:
– no-bedding breeding with scrapers, grate or lattice,
– in case of breeding with scrapers, minimum of 60 milked cattle required,
– in case of breeding with lattice, minimum of 100 milked cattle required,
– minimal milk yield for milked cows at 8,000 litres of milk/year.

Under the above conditions (in Poland achievable by the majority of modern breeding farms), the technical and economic parameters of BIOTRONIC® installations are as in the Table 1.

Table 1. Economic and technical parameters of the biogas power-plant using dairy cow liquid manure, for 8,000 hours/year of biogas plant operation (own elaboration)

The size of the micro-biogas plant	Electrical power: Thermal power:	11 kW_e 25.9 kW_{th}	22 kW_e 45.7 kW_{th}	33 kW_e 64.8 kW_{th}	44 kW_e 74 kW_{th}
Investment expenditure	on 1 kW_e [€]	9,500	7,500	5,900	5,300
	total [€]	105,000	165,000	195,000	235,000
Yearly maintenance costs	[€]	6,000	9,000	12,000	15,000
Actual volume of the fermenter chamber	[m^3]	100	200	300	400
Diameter of the fermenter	[m]	7.8	10.9	13	15.6
Necessary building area	[m x m]	18x10	21x13	23x15	26x18
Total efficiency	%	94	94	93	93
Average, indispensable amount of dairy cows	full floor with scrapers [pieces]	60	120	180	240
	floor with grate [pieces]	100	200	300	400
The average daily supply of the manure to the reactor	full floor with scrapers [m^3]	4	6–8	9–12	14–17
	floor with grate [m^3]	8	14-16	21–24	28–34
HRT: Hydraulic retention time [days]	full floor with scrapers	up to 25	25–30	25–30	25–30
	floor with grate	up to 13	12–15	12–15	up to 16
The volume of biogas production/year	biogas [m^3]	45,000	97,000	145,000	180,000
	methane [m^3]	26,100	56,200	84,100	104,400
The volume of energy production/year	generated electric power [kWh_e]	88,000	176,000	264,000	352,000
	usable heat [kWh_{th}]	80,000	210,000	360,000	430,000

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Production/100 tons of manure	full floor with scrapers [kWh_e]	5,870	5,870	5,870	6,000
	floor with grate	3,000	3,450	3,450	3,450
Production of ee/m^3 of manure	full floor with scrapers [kWh_e]	59	59	59	59
	floor with grate [kWh_e]	30	35	35	35

The design concept adopted by BIOLECTRIC NV makes the solution almost maintenance-free from the investor's point of view. The charging and emptying of the reactor is a continuous and automatic process, without the participation of additional equipment or employees. Parameters of the fermentation process are being managed by control system, while the remote monitoring is carried out by a specialized team from the manufacturer or his representative in a given country. On the part of the investor there remains periodic replacement of oil and oil filters in engines, replacement of activated carbon in hydrogen sulphide filters, if necessary, mixing of slurry in a manure pit and, of course, supervision.

4. Experience after 3 years use of the BIOLECTRIC® micro-biogas plant in Poland

At present, 19 BIOLECTRIC® micro-biogas plants operate or are in the start-up and installation phase, of which 9 have already been connected to the power grid. The first user in 2015, was a Dutch breeder running his farm in the West Pomeranian Voivodeship. This was not the fortuity, because he had the opportunity to verify the benefits resulting from the use of micro-biogas in his home country and made the investment decision without any subsidy support. Subsequent installations, but with use of subsidies, as part of voivodeship operational programs, were created in the Warmian-Masurian and Łódź Voivodeships.

The time necessary for assembly of a single biogas plant unit does not exceed two weeks from the moment of delivery to the farm. The period of production of the device and components lasts in Belgium about 6 weeks. In the meantime, the investor is obliged to prepare hardened surface for the foundation of the container and fermentation reactor. In Poland often breeders do not have slurry tanks, hence the need for additional earthworks (embankments), where a flexible tank is installed for periodic storage of digestate. Due to the climate conditions in Poland, relatively cold compared to Belgium and the Netherlands, elements of additional thermal insulation of roofing membranes and piping below the freezing zone are used in Poland and Sweden.

All assembly work is carried out in Poland by a specialized installation team, equipped with the necessary machinery and equipment enabling comprehensive implementation of the task: from excavations, through laying pipelines, conducting connections, to communication configuration with the control centre that control work of the biogas plants. All installation works are carried out within one breeding farm,

and the micro-biogas plant is connected to an existing or extended technological cycle: between the manure channel and the slurry tank. The operation of a biogas plant itself proceeds within the framework of environmental permits held already by the breeder.

The time required for full start-up of a micro-biogas plant fed with liquid manure varies from 3 to 6 months. It depends on the quality of manure, weather conditions (impact on the temperature of fresh manure feed), and also on quantity of the first charge, which is a bacterial inoculation (minimum 1/3 of the reactor's active capacity). In the case of the first installations, this initial charge is a digestate from other, a nearby biogas plant using a substrate with a share, as much as possible, of cows manure. Currently, the digestate from near-placed BIOLECTRIC® micro-biogas plants is already being used. During the start-up period, it is particularly important to select daily, actually hourly, doses of fresh manure, to maintain the optimal fermentation temperature and to avoid excessive hydrogen sulphide concentration. All commissioning activities are performed by a dedicated monitoring and control team located in Wrocław.

The formal conditions for the construction, connection and exploitation of agricultural micro-biogas plants are set out in the building low. The Act of June 7, 2018 amending the act on renewable energy sources and some other acts (Journal of Laws of June 29, 2018, item 1276) introduced a number of changes that do support an application of agricultural micro-biogas plants. For example, in Art. 29, in paragraph 2 of the construction law, undertakings have been listed, including agricultural micro--biogas plants, for which there is no obligation, not only to obtain a building permit, but also a permit for construction works is not required. This means that it is possible to install micro-biogas plants without having to notify the construction authorities about the start of these works.

A separate and complex issue is the connection of the micro-biogas plant installation to the power grid and the definition of the rules for the resale of energy surpluses. BIOLECTRIC® devices are microinstallations (after the amendment of the RES Act to 50 kW), but as agricultural micro-biogas plants they have a special status. They are connected to the network on the basis of the so-called notification, although the user has no prosumer status. This is a beneficial solution for the owner, because after installing a biogas plant operating up to 8,000 hours a year, he has some surplus energy, while its purchase from the network is already marginal. This means that the compensation, according to the coefficient 0.7, would be unfavourable. Due to the lack of experience in this respect, this special status of agricultural micro-scale biogas plant is not yet noticed by all DSO operators and they try to push the breeder into prosumer regulations, which requires a lot of arduous explanations. Before the amendment set up, the user of the micro-biogas plant sold surplus electricity on the basis of a special contract, which meant a income of about 0.16 PLN/kWh. Currently, new rules are being develop, which theoretically give the opportunity to sell surpluses at a price close to the guaranteed prices in URE auctions. Unfortunately, there is still no experience in this matter, both on the part of the Energy Regulatory Office, as well as energy operators and users. This means that under Polish conditions, the determination of the profitability of investments and the operation of a micro-biogas plants fed with manure should be based on the "golden rule". It reads: the size of the biogas

micro-installation must be selected for the amount of energy used in the farm, so that the energy surpluses are as low as possible. If so, the best tariff applies, i.e. the cost of energy purchase and the transmission service are avoided, which often gives a rate of 0.60 PLN/kWh$_e$. On the other hand, the use of generated heat on the farm means avoiding the cost of heating by oil or coal, which aligns the annual operating costs of the micro-biogas plant. Manure is after all a cumbersome, but free, substrate available without the cost of transportation.

Summary

The Polish legislator, who is preparing a package of regulations limiting odour emissions and the outflow of nitrogen from agricultural sources, already sees the negative impact of animal manure on the natural environment. In addition, in the European committees, a draft regulation is being developed which, instead of abolishing the so-called milk quotas, introduce an obligatory purchase of methane emission rights. This is another element that will justify the use of agricultural biogas plants on a much wider scale than is currently the case. The German agriculture has been a leader in this field for over ten years. However, two conflicts related to rational use of the available economic and environmental space were clearly visible. First, the fermentation of silage, green fodder, grains etc. disturbs the efficiency of the feeding cycle, whose sources are, after all, limited. Secondly, with a large unit scale of agricultural biogas plants and its territorial concentration, there is an undesirable effect of competitiveness in the development of agricultural areas. Therefore, a reasonable conclusion for the development of the agricultural biogas plant sector in Poland should be the implementation of micro-biogas plants, located within individual farms, using the waste i.e. onerous manure, at its place of production. It is only necessary to overcome the paradigm of the lack of profitability of these installations in a microscale, and that's what BIOLECTRIC® solutions have done.

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