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A Possibility of Functioning Biogas Plant at a Poultry Farm

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ABSTRACT

The biogas production constitutes one of renewable energy sources (RES) . In addition, wastes are preferred for energy production. In the case of some wastes, e.g. poultry manure, it is difficult to conduct anaerobic digestion in monofermentation. The aim of this work was to plan the biogas plant, in which the main substrate is the waste from a poultry farm. The scope of work included: preparation of a biogas plant technological project, determining the amount of biogas and methane that can be produced annually on the example of the selected poultry farm, performing the energy and financial calculations for the current conditions prevailing on the renewable energy market in Poland. The installation project assumed the location of a biogas plant at an existing poultry farm – the source of the substrate. The micro-biogas plant includes a fermentation tank with a capacity of 500 m^3 and storage of digestate pulp with a capacity of 700 m^3. The assumed power biogas plant will generate 112 kW of electricity and 120 kW of heat. The installation will operate in a single-stage mesophilic technology (39 ºC), which will avoid incurring additional costs related to heating and the construction of additional fermentation tanks. The use of poultry manure by anaerobic digestion provides benefits through biogas technology. It is necessary to examine the technology in terms of biogas production, which is carried out under better sanitary and environmental conditions. This work was undertaken to investigate the environmentally friendly removal of poultry manure through biogas technology to obtain the best economic effect, and employ it further, e.g. as a fertilizer.

Keywords: poultry waste, biogas, renewable energy, environmental protection, sustainable development, animal production

INTRODUCTION

Poultry farms are becoming increasingly popular worldwide due to the relatively cheap and fast meat production. However, such a large production is directly related to the amount of waste (e.g. manure) that requires proper management (Chaump et al. 2018, Çoban et al. 2016, Anaswara 2015, Wang et al. 2014).

One of the possibilities is to use the manure as a fertilizer (Czekała et al. 2015). There are different types of poultry manure, e.g. high rise manure, cage manure, broiler manure and deep litter manure (Amanullah et al. 2010). Regardless of the type, such an organic waste contains various amounts of water, mineral nutrients, organic matter (Duan et al. 2018).

The application of such an organic fertilizer improves the physical condition of the soil, increasing the soil porosity and reducing the bulk density, which allows for smooth root penetration and growth in the soil (Czekała et al. 2019). A chemical fertilizer, used together with organic fertilizer, supports the plant growth and contributes to higher productivity (Wolna-Maruwka et al. 2015). Among the various organic fertilizers, poultry manure helps to improve the condition of the soil, increase the water retention capacity in the soil and provide.

Poultry manure can provide all 13 types of soil micronutrients in a significant amount that inorganic fertilizer cannot (Subedi et al. 2018). The above-mentioned waste from poultry farms is rich in: nitrogen, phosphorous, iron, potassium, calcium, magnesium, sulphur, copper, manganese, zinc, molybdenum, chlorine, boron. However, the content of these components varies, depending on the moisture content and age of the manure, as well as on the age of the poultry (Amanullah et al. 2010, Nahm 2007).

The poultry manure may exhibit highly variable nutrient characteristic, depending on their processing conditions. The litter to manure ratio and the moisture content are among the factors causing the greatest variation in manures from different houses. The poultry manure is composed of ca. 3–5% nitrogen, 1.5–3% phosphorous and 1.5–3.0% potassium as well as significant amounts of micro-nutrients (Amanullah et al. 2010).

Direct soil spreading of the poultry manure for crop fertilization is a traditional and still the most applied method. However, the contemporary rearing poultry methods have made the issue more complicated. The majority of poultry manufactured these days is litter-free. Litter is not used in the case of birds bred in cages or slots (Duan et al. 2018, Amanullah et al. 2010).

The litter used in manure absorbs moisture and facilitates keeping the manure friable, resulting in the atmospheric exposure of a large surface. In turn, the manure without litter contains 60–70% moisture, complicating the application process. Meanwhile, in the event of storage aimed at reducing the moisture content, nutrient losses appear and the process is less cost-effective (Amanullah et al. 2010, Duan et al. 2018). Another issue pertaining to this type of manure is the very quick release of N, so in the event of negligence in its application, burning may occur.

The poultry manure handling, storage and direct application involve numerous problems including the emission of ammonia, nitrate pollution, contamination of surface and underground water, attracting and breeding flies as well as public nuisance (Amanullah et al. 2010, Harremoes 1991).In order to apply the manure quickly and prevent nutrient loss and environmental pollution, it can be used as follows: soil fertilization for crops, activator for button mushroom cultivation, feed for fish and livestock, energy generation – biogas, electricity (Amanullah et al. 2010).

Another option for managing the manure is to use it for energy production. The availability of sufficient, inexpensive and environmentally-friendly energy is one of the greatest challenges in the world (Çoban et al. 2016, Miah et al. 2016). Renewable energy sources are of interest to the world due to the climate change and unavoidable depletion of limited resources, such as coal and oil (Arshad et al. 2018, Kian Heng 2017).

The biogas is an environmentally friendly and one of the most efficient and effective renewable energy options. The biogas can be produced using the chicken manure, although it is not easy due to the very high nitrogen content of the droppings (Duan et al. 2018, Miah et al. 2016). The biogas is produced in the fermentation process; fermentation digestate sludge is rich in essential nutrients that can be used as a very good fertilizer (Czekała et al. 2017). The anaerobic digestion is a process of organic materials degradation by microorganisms without oxygen. It is a multi-stage biological process in which organic carbon is mainly converted to carbon dioxide and methane (Miah et al. 2016).

The biogas production by anaerobic digestion is considered an attractive and efficient technology for processing animal waste (Bayrakdar et al. 2017), with the exception of the main objective – removal of matter and control of environmental pollution, while producing the biogas for the needs of local energy. The poultry manure with an original dry matter of 20–25% or more has a high content biodegradable organic matter. Therefore, the conversion of this organic matter to renewable energy in the anaerobic digestion process will not only reduce the negative impact on the environment, but will also significantly contribute to the energy supply (Duan et al. 2018, Anaswara 2015).

Although the technology of methane fermentation in the processing of animal manure for biogas production is very mature and intensive research has been intensively carried out, limited studies can be found on anaerobic digestion of poultry manure, especially mono-digestion (Chaump et al. 2018).

The process of poultry manure fermentation, with a low carbon/nitrogen (C/N) ratio of 5–10, usually ends with reactor instability or even failure due to its inactive enzymes that affect the material transport and inhibit methanogenic microflora as a result of ammonia accumulation (Duan et al. 2018, Lewicki et al. 2016, Wang et al. 2014, Pokój 2014). Several attempts have been proposed to avoid the accumulation of ammonia during that process. Co-fermentation with various carbon-rich types of biomass was studied to obtain a favorable C/N ratio, such as with pork waste, municipal solid waste and other biowaste, in particular the biomass from agricultural production (Chaump et al. 2018, Duan et al. 2018, Brown and Li 2013).

The amount of waste from the agro-food industry and poultry manure in Poland is still increasing in parallel. One of the most advantageous solutions of processing these wastes together is anaerobic co-digestion (Çoban et al. 2016, Kian Heng 2017, Amanullah et al. 2010, Çoban et al. 2016, Sądej et al. 2016, Pokój 2014.

At present, there are 96 agricultural biogas installations in Poland (AMA 2018); with total power about 100 MW, but the potential of the biogas market from bio-waste, according to our estimates is 3000–4500 MW. Poland is the leader in poultry production in Europe (nearly 1 billion a year). Currently, the poultry waste is processed into mink feed. When the mink farms are closed, there will be a great problem with waste management. 80–100 million Mg of animal waste per year are created in Poland; for comparison: in India 12.1 million Mg (Amanullah et al. 2010), in Iran ca. 2 million Mg (Çoban et al. 2016). The stored droppings generate 0.3–0.5 million Mg CH_4 per year. The storage of the waste from poultry farms is an increasing environmental and social problem (e.g. strong odor emissions) in Poland and similar problems are encountered in other countries too (Çoban et al. 2016, Kian Heng 2017, Amanullah et al. 2010). The aim of this work was to plan a biogas plant, in which the main substrate is the waste from poultry farms.

MATERIALS AND METHODS

The study examined the biogas yield of the following substrates: chicken manure, post-slaughter waste, barley straw and grass silage. All materials came from two poultry farms located in the West Pomeranian Voivodeship.

The samples collected for testing were stored under refrigeration conditions at 4°C until the start of the experiment. The research on the anaerobic digestion process was carried out at the university laboratory based on the commonly used German standards DIN 38 414/S8 and VDI 4630. The biogas efficiency tests were conducted in reactors with a capacity of 2 dm^3 placed in a water bath at a temperature of 39 (± 1)°C (Fig. 2).

The scope of work included:

- determining the amount of biogas and methane that can be produced annually on the example of the selected poultry farm,
- preparation of a biogas plant technological project,
- performing the energy and financial calculations for the current conditions prevailing on the renewable energy market in Poland.

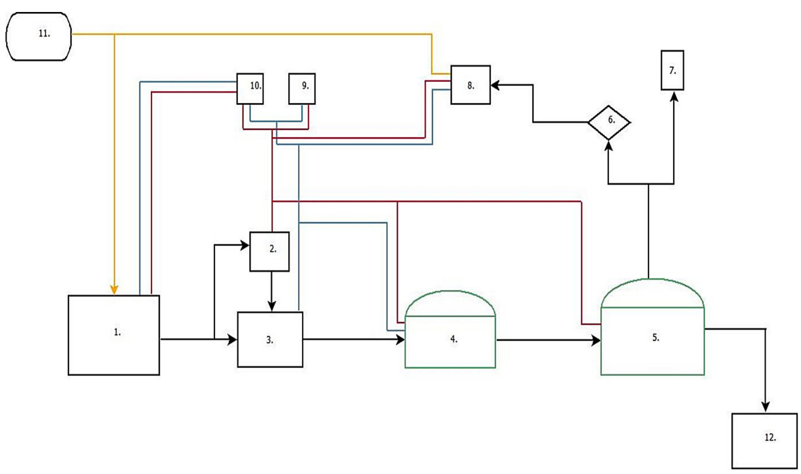

Fig. 1. Diagram of the planed biogas plant

1 – Poultry farm, 2 – Substrate hygienization, 3 – Substrate warehouse, 4 – Anaereobic digestion tank, 5 – Post-fermentation pulp tank, 6 – Biogas desulphurisation station, 7 – Torch, 8 – CHP unit, 9 – Emergency cooling, 10 – Heat exchanger, 11 – Energy network, 12 – Organic fertilization of cultivated areas

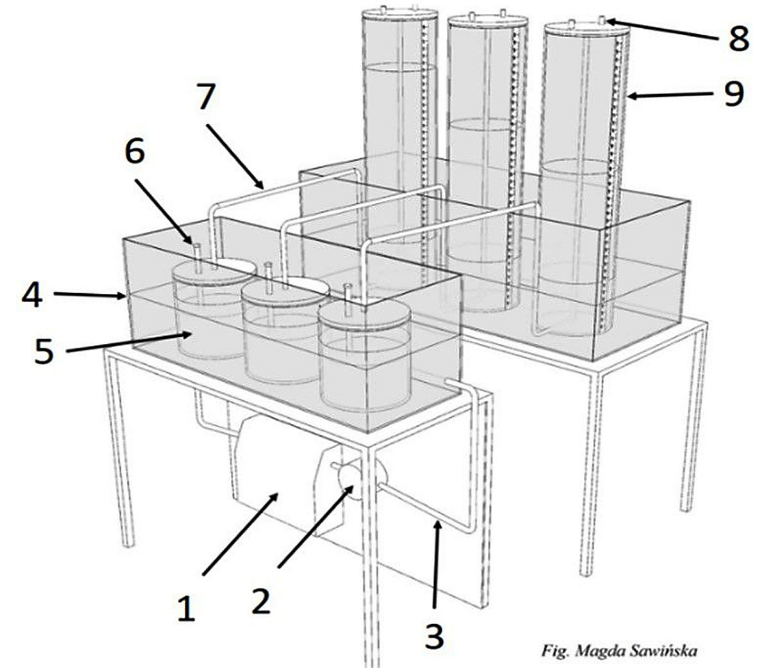

Fig. 2. Scheme of biofermenter for biogas production research (3-chamber section)

1 – water heater with temperature regulator, 2 – water pump, 3 – insulated conductors of calefaction liquid, 4 – water coat, 5 – biofermenter with charge capacity 2 dm^3, 6 – sampling tubes, 7 – biogas transporting tube, 8 – gas sampling valve, 9 – biogas volume-scale reservoir (Cieślik et al. 2016)

The installation project assumed the location of a biogas plant at an existing poultry farm, the source of the substrate. The owner has a second farm in another location, about 5 km away, from which the waste will be regularly collected and transported to the biogas plant. The location of the installation close to the plant reduces the transport costs.

The main research tasks – qualitative and quantitative analysis of the gases produced (CH_4, CO_2, NH_3, O_2, H_2S) was carried out daily using Geotech GA5000 gas analyzer.

Financial and energy calculation methodology

In order to determine the potential energy potential and calculate the revenue resulting from the production of electricity and heat, mathematic formulas described by Kozlowski were used (Kozłowski et al. 2017).

RESULTS

Due to the high nitrogen content in chicken manure, the best way to obtain a more proper C:N ratio for effective fermentation purposes the co-fermentation is necessary. As additional substrates, post-slaughter waste, straw and silage from grasses will be used. In the table below (Table 1), the available substrates and their characteristics were presented together with the biogas efficiency and methane content.

On the basis of the biogas yields of the supplied substrates and their annual deliveries, basic energy parameters were calculated (Table 1–3).

The production capacity of biogas produced as a result of methane fermentation of the chicken manure was about 188 m^3·Mg^{-1} (fresh mass), with an average methane content of about 56%.

With a quantity of the above-mentioned available annual supplies of substrate quantities, the volumes of fermentation tank with a capacity

Table 1. Available substrates and their characteristics

Substrate	Mass of substrate (Mg·year^{-1})	Biogas efficiency (m^3·Mg^{-1})	Methane content (%)
Chicken manure	1620.00	188.53	56.00
Post-slaughter waste	25.80	245.21	70.00
Barley straw	76.80	442.54	52.00
Grass silage	396.00	224.61	55.00

Table 2. Energetic potential of the substrates

Parameters	Value	Unit
Hydraulic retention time	86	day
Dry mass of the mixture	44	%
The capacity of the methane fermentation tank	502.79 ≈ 500	m^3
The capacity of the digestate storage tank	690 m^3 ≈ 700	m^3
The weight of the used substrate	2 118	$Mg·year^{-1}$

Table 3. Energetic (electrical and thermal) potential of the substrates

Parameters	Value	Unit
The volume of produced biogas	434 677	m^3
The volume of methane produced	242 054	m^3
The amount of electricity produced	965	$MWh·year^{-1}$
The amount of heat produced	1 037	$MWh·year^{-1}$
The amount of heat produced	3 786	$GJ·year^{-1}$
Electrical power of the installation	112	kW
Thermal power	120	kW

of 500 m^3 and a storage of digestate pulp with a capacity of 700 m^3 ware calculated (Table 2). The nominal volumetric load of the fermentation tank was adopted as 4.5 kg of dry organic matter $m^{-3}·d^{-1}$.

The amount of substrates available in a selected poultry farm allows for the production of 112 kW of electricity and 120 kW of heat.

Input data for calculation:

- coefficient of energy efficiency of methane – 0.009968 $MWh·m^{-3}$,
- electrical efficiency of a cogeneration 0.40 [-],
- thermal efficiency of a cogeneration 0.43 [-],
- cogeneration unit operating time during the year – 8,600 h.

The amount of electricity generated in the designed installation will be approx. 965 $MWh·year^{-1}$ and 1,037 $MWh·year^{-1}$ heat (Table 3).

In order to properly calculate the profitability of the investment, which is the construction of an agricultural microbiogas plant, it is necessary to identify and calculate the costs of substrates, transport, exploitation, etc.

Input data for calculation:

- cost of technical service – 5% of investing cost
- cost of technical service – 7 $PLN·MWh^{-1}$
- min. 10 years amortization
- transport cost – 0.40 $PLN·km^{-1}·Mg^{-1}$

A list with outputs and the characteristics of individual costs are given in Table 4.

The operating costs will amount to approximately 288 374 $PLN·year^{-1}$, and the revenue from the sale of electricity and heat approx. 711 020 $PLN·year^{-1}$. Such a balance of profits and losses will generate the income of approximately about 423 646 $PLN·year^{-1}$ (Table 5). Similar effects using the co-substrates from poultry farm and farm waste or by-products were used in other countries with very high poultry production (Cucui et al. 2018, Mia et al. 2016, Çoban et al. 2016, Anaswara 2015), even in a very large industrial scale (Kian Heng 2017).

CONCLUSIONS

The use of poultry manure by anaerobic digestion provides benefits through the biogas technology. It is necessary to examine the technology in terms of the biogas production, which is carried out under better sanitary and environmental conditions. This work was undertaken to investigate the environmentally friendly removal of poultry manure through biogas technology to obtain the

Table 4. Outputs and the characteristics of individual costs of the micro – biogas plant

Costs	Value (PLN)
The cost of the substrate	2 618
The cost of the transport	2 618
The cost of technical service	77 000
The cost of technological service	6 755
The cost of the service	83 755
Depreciation cost	154 000
Staff cost	48 000
Exploitation cost	288 374

Table 5. Economic balance of the biogas plant

Financial data	Value	Unit
Price of electricity energy	595	PLN·MWh^{-1}
Revenue from the sale of electricity	579 852	PLN
Price of thermal energy	127	PLN·MWh^{-1}
Revenue from the sale of thermal energy	132 167	PLN
Total revenue	712 020	PLN
Profit	423 646	PLN

best economic effect, and employ it further, e.g. as a fertilizer.

The implemented biogas plant project will reduce the costs associated with the disposal of problematic waste from a poultry farm, and the energy generated by the investor can be used to cover the farm energy demand or be sold to the local power grid.

From an economic and organizational point of view, the waste from a poultry farm, together with straw and silage from grass, are favorable substrates for agricultural biogas plants. The possibility of effective management of nuisance waste and neutralization of unpleasant odors are the advantages of the agricultural biogas plant based on co-substrates with poultry farm and farm by-products.

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