Processing Digestate from Agricultural Biogas Plant to Obtain Financial and Environmental Benefits

Wojciech Czekała[1]

[1]Institute of Biosystems Engineering, Poznan University of Life Sciences, Poznań, Poland e-mail: wojciech@up.poznan.pl

Abstract. At European Union, as well in Poland, renewable energy sources (RES) are an important alternative to fossil fuels. Solid biomass is mainly used for the production of renewable energy. The anaerobic digestion process creates biogas, and digestate. The latter is a residue from the fermentation process, consisting mainly of non-digested organic and mineral components. The market offers many devices for the management of the digestate. Among them the most important are the separators that separate the raw material into solid and liquid fractions. The aim of the research was to discuss the possibility of improving the management efficiency of biogas plant by using the digested pulp and its fractions. For a designed 1 MW_{el} biogas plant installation, modern technological solutions have been proposed. It can be concluded that a proper digested pulp economy can bring additional profits to the biogas plant.

Keywords: digestate, digested pulp, biogas production, waste management.

1 Introduction

With the increase in energy demand, it is necessary to seek new technologies for its production. It should be cheap, efficient and what is most important, safe for the environment. Biofuels are renewable energy sources that are produced from biomass. Agricultural biogas is produced in biogas plants that use agricultural substrates to produce energy (Budzianowski, 2016). It is a mixture of gases with high methane content, so it can be used for energy production (Cieślik et al., 2016). Another product, often overlooked substrate from the anaerobic digestion process of agricultural products is digested pulp (Börjesson and Berglund, 2007). Its composition consists mainly of non-digested organic substances, minerals and microbial biomass.

The most common way to use the digested pulp is use it directly as fertilizer (Tampio et al., 2016). This is due to the ease and high efficiency of its application in the soil. In many countries in Europe and for example in China digestate is perceived as a valuable fertilizer. This is a desirable substrate and apparently presents no environment concerning related to its management. In Poland, there is some resistance about the use of digestes as fertilizers mostly due a misperception and understanding about the biogas and the use of digested pulp. Nowadays, biogas

Proceedings of the 8th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2017), Chania, Greece, 21-24 September, 2017.

plants often have problems for selling the digestes, even for free. However, slowly, with the understand of the benefits of digestate, the perception of its application as fertilizer by farmers is favorably shifting, and digestate started to be treated as a valuable fertilizer.

One possible solution for this problem is the separation (dehydration) of the digestate (Wu et al., 2017). The effect of such action is to obtain a minimum of two significantly differentiated fractions. This will allow easier management of the product after fermentation process. Another advantage will be the possibility of increase the revenue of the biogas plant. The technology which can even increase the fertilizing value of digestate solid fraction is composting. Because of intensive temperature growth during composting, the obtained material is characterized by high fertilizing value, sanitary safety, lack of odor and chemical stability (Waszkielis et al., 2013; Wolna-Maruwka and Dach, 2009;). Another possibility of digestate management is to use it as feeding medium for algae production as the substrate for biogas plant (Cerbin et al., 2012). The experimental installation (greenhouse of 3000 m^2) for algae production with usage of digestate solution for microalgae nutrition was built in Central Poland in 2015. However, the real scale investment has shown much lower microalgae production (mainly because of colder climate and technical problems) than promising results obtained in laboratory scale (Lewicki et al., 2013).

The aim of the research was to discuss the possibility of improving the management and economic revenue of biogas plant by further use the digested pulp. During the implementation of the work, an apparatus for drying and a separation of digestate was utilized.

2 Production of the Digestate, Essence of separation and Digestate Drying

The biogas plant is an installation that produces energy in a recovery process, while manage waste (Dach et al., 2016; Kozłowski et al., 2016). The most common criteria for division of an installation is the substrate used. Therefore, one may distinguish biogas plants in: agricultural, landfills or municipal waste and sewage treatment plants. Agricultural biogas plants are safer from the environmental perspective because the substrates are from agricultural origin, often undergo through high sanitation standard procedures as it is designed for human consumption (Czekala et al., 2015).

The substrate used in the agricultural biogas plant is subject to numerous transformations. The most important is distribution of particles into more easily accessible compounds. Regarding elemental composition, the greatest changes occur in relation to carbon. Organic compounds are degraded, consequently the amount of organic matter decreases (Neugebauer and Sołowiej, 2017). The result of the process, among others, is methane generation. In relation to macroelements, another relevant aspect is the conversion of organic matter into mineral compounds. Minerals are then, available for plants, so that digestates are characterized by better parameters than the unprocessed substrate e.g. slurry.

The intensity of all those transformations depends primarily on the type of substrate used (Czekała et al., 2016a). In addition, the process conditions are an important element, for example the parameters: type of technology used, process temperature, substrate size and type and intensity of the process.

It is estimated that about 90% of the initial substrate matter still remain in the digestate. These values are the assumed values often used in calculation in Poland. Consequently, a typical biogas plant with 1 MW electric power produces, daily, a few tens of tons of digestate. Such a considerable amount of digestate often becomes an liability for biogas plants operating in Poland. Ideally, part of the digestate could be used directly to fertilize the fields that provide substrate to the biogas plant. This will keep the nutrients within the production chain of the biogas plant. Another advantage is related to economic and environmental aspects. The direct use of digestate as fertilize can decreases the cost of crop production. While, the production of mineral fertilizers, in some cases, can pose treat to the environment. Therefore, this alternative is economical and environmentally ideal.

Digestate is characterized by a high degree of hydration, due to hydraulic requirements the pumping operation should take place directly in the agricultural biogas plant. Thus, the dry matter content of the digestate is rather low, about 6%. Dehydration is carried out by means of separation or drying (Kaparaju and Rintala, 2008). In case of separation, solid and liquid fraction are the products which can be used for different purposes. Dry matter content in solid fraction is usually 20-35% while, liquid fraction is about 1.5 to 4%. One advantage of drying is the efficiency of the process because it allows the substrate to be processed to a specific humidity level. However, the drawback is the need to supply a significant amount of energy in the operation. Moreover, in case of use of digestates as fertilizes it is recommended to maintain certain level of humidity that can favor the absorption of nutrients by plants (tab. 1).

Table 1. Averaged composition of solid and liquid fractions of digestate from selected Polish biogas plants [Kowalczyk- Juśko and Szymańska 2015].

Analyzed feature	Solid fraction	Liquid fraction
Dry matter [%]	22 - 27	2,7 - 4,3
Dry organic matter [%]	89 - 94,5	58 – 62
Total nitrogen [%]	0,4 - 0,8	0,2 - 0,75
$N\text{-}NH_4$ [%]	0,08 - 0,52	0,28 - 0,38
P [%]	0,1 - 0,28	0,03 - 0,05
K [%]	0,12 - 0,69	0,5 - 0,62
Ca [%]	0,22 - 0,43	0,05 - 0,07
Mg [%]	0,06 - 0,17	0,01 - 0,02

In Europe, as the market for separators and digestate driers is developed, it is easier to use or improve agricultural biogas installations to include such technologies. For example, separators of slurry, originally used for sewage sludge, were installed in agricultural biogas plants.

3 Digestate Processing

Regarding the process of digestion pulp, the direction of its further use should be carefully considered. If the digestate is used as fertilizer, it is not necessary to further process it. The only requirement is to mix it beforehand, to equalize the nutrient content. However, in case you separate the digestate in liquid and solid fraction, the former, can be either used as fertilizer in the fields or to decrease the dry matter content of the used substrate to align it with the feed hydraulic parameters of the biogas plant, (Sigurnjak et al., 2017). The solid fraction biomass can be used as well as fertilizer or to energy purposes (Czekała et al., 2017; Obidziński, 2012). Direct distribution on the surface of the fields will enrich the organic matter content of the top soil. And, it is also possible to use the solid digestate fraction for compost, both as a stand-alone substrate or as an additive in combination with other ingredients.

Generally, the selection of elements required for waste management should be preceded by:

1. analysis of the scientific literature and legislation in force in the country,
2. industry market analysis of available equipment and technologies,
3. calculating the amount of digestate available,
4. determining the preferred directions of using the digestate,
5. development of a biogas effluent processing plant that is compatible with the biogas plant.

In the present study case, the energetic use of digestate was the objective. The production of solid biofuels, i.e. briquettes and pellets was considered. Both, briquettes and pellets are widely used in Poland for heat production (Szmigielski et al., 2014; Kowalczyk-Jusko et al., 2015a) The design of the agricultural biogas plant with power 1MW will use the substrates shown in table 2. The presented data are from studies conducted in Laboratory of Ecotechnologies in the Poznań University of Life Sciences (PULS). The research was carried out according to the modified German standard DIN 38 414 – S8.

Table 2. Substrates use to biogas production*

Substrate	Quantity [Mg•year^{-1}]	DM [%]	ODM [%DM]	Biogas efficiency [m^3•Mg^{-1}FM]	Methane content [%]
Maize silage	11 000	32	95	210	55
Brewers grains	11 000	24	90	140	60
Slurry	22 000	4	70	10	60

*non-published data from Laboratory of Ecotechnologies at PULS

In order to calculate the amount of digestate material produced on a biogas plant it is necessary to estimate the dry matter and water content of the substrates. The following formulas were used (1):

$$M_{dm} = M_{fm} \bullet dm \ [Mg \bullet y^{-1}] \quad \textbf{(1)}$$

where:
M_{dm}- mass of dry substance mass [Mg•y^{-1}]
M_{fm} - mass of fresh mass [Mg•y^{-1}]
dm - dry matter content [%].

The most important parameter when planning a separation installation is the water content of the raw digestate and its fractions. The quantity and characteristics of the substrates are shown in table 2.

The mass of substrates used for biogas production in the analyzed mix was 44000 Mg (table 2). Assuming that the amount of the digestate constitutes 90% of the feed substrate, the annual amount of digestate is calculated (2).

$$M_{dig} = M_s \bullet n \ [Mg \bullet y^{-1}] \quad \textbf{(2)}$$

where:

M_{dig}- digestate mass [Mg•r^{-1}]
M_s- mass of input to biogas plant [Mg•r^{-1}]
n – mass retention coefficient in the fermentation process -0.9 [%].

At the present study case, it is expected an annually production of 39,600 Mg of digestate, which gives about 108 Mg digestate per day. The quantity is relatively large, since half of the load is a slurry characterized by high hydration. The addressed project is planned to use solid fractions for the production of solid biofuels. And, the liquid fraction will be directed to the hydration of new substrates and partly for the production of microorganism-enriched fertilizers. This is an innovative solution that complies with, both, scientific and entrepreneur interest in relation to research on microbial inoculation of the liquid fraction to enhance fertilizer properties. The following assumptions were made for calculations (table 3).

Table 3. Design assumptions

Assumption	Value of assumption
Quantity of digestate production [m^3•y^{-1}]	39600
Mass of 1 m^3 of fermentation pulp [Mg]	1
Dry matter of digestate [%]	8
Amount of liquid fraction after separation [Mg•y^{-1}]	28800
Amount of solid fraction after separation [Mg•y^{-1}]	10800

*non-published data based on real scale biogas plants

The generated solid biofuel from the digestate has a slightly lower calorific value than the wood pellet treated as the standard solid biofuel. The determined calorific value was 16.58 MJ•kg^{-1} (Czekała et al., 2016b). In the analyzed example, it was assumed that the daily production of the solid fraction is 20 Mg with a dry mass of 23%. Generally, water content can affect the strength of materials (Chocyk et al., 2015, Kowalczyk-Jusko et al,. 2015b). Thus, to achieve appropriate level of water in the substrate, a belt dryer will operate in the biogas plant. Then, with the resulted solid fraction, it will be possible to produce about 4 tons of briquettes from the digestate. Produced briquette can be sold to external buyers for 100-130 Euro•Mg^{-1}.

Necessary installations for digestate processing in the biogas plant are as follows:
- separator EUR 44 000
- belt dryer EUR 60 000
- line for the production of briquettes (0,5 Mg•h^{-1}) EUR 14 000.

The cost of installation of above listed separation and treatment devices is 118,000 Euros. However the biogas plant building cost is about 5 million Euros, consequently, the above device cost seems economically acceptable.

4 Conclusion

Lack of specific regulations and social resistance are responsible for limiting the use of digestate at field. Moreover, biogas plant owners often do not have enough farmland to distribute the entire produced digestate. Consequently, this situation creates barriers to the development of the biogas sector in Poland. Additionally, it is recommended to carry out physical, chemical and microbiological analyzes of the digestate before its application in the soil. A better characterization of the fertilizer can increase the trustiness of farmers and favor the utilization of digestate at fields. Investments in an installation for industrial separation and processing of digestate creates opportunities for the use of digestate with additional revenue.

Acknowledgments. The work was carried out as part of the project: "Research on the development of innovative organic-mineral fertilizers from digestate"; co-financed by the European Union under the Operational Program - Intelligent Development (Support for environment and business potential for R & D & I activity), application POIR.02.03.02-30-0002/16.

References

1. Börjesson, P. and Berglund, M. (2007) Environmental system analysis of biogas system - Part II: The environmental impact of replacing various systems. Biomass and Bioenergy, 31, p.326-44.
2. Budzianowski, M. (2016) A review of potential innovations for production, conditioning and utilization of biogas with multiple-criteria assessment. Renewable and Sustainable Energy Reviews, 54, p.1148-71.

3. Chocyk, D., Gładyszewska, B., Ciupak, A., obiczuk, T., Mościcki, L. and Rejak, A. (2015) Influence of water addition on mechanical properties of thermoplastic starch foils. International Agrophysics, 29, p.267-75.
4. Cerbin, S., Nowakowski, K., Dach, J., Pilarski, K., Boniecki, P., Przybyl, J. and Lewicki, A. (2012) Possibilities of neural image analysis implementation in monitoring of microalgae production as a substrate for biogas plant. 4th International Conference On Digital Image Processing (ICDIP 2012). Proceedings of SPIE. Vol.: 8334 Article Number: 83342A Doi: 10.1117/12.954164
5. Cieślik, M., Dach, J., Lewicki, A., Smurzyńska, A., Janczak, D., Pawlicka-Kaczorowska, J., Boniecki, P., Cyplik, P., Czekała, W. and Jóźwiakowski, K. (2016) Methane fermentation of the maize straw silage under meso- and thermophilic conditions. Energy, 115, p.1495-1502.
6. Czekała, W., Dach, J. and Czekała J. (2015) Operational possibilities of a biogas plant at the brewery under polish conditions. Proceedings of the 2nd International Conference on Energy & Environment: Bringing Together Engineering and Economics: p.520-525.
7. Czekała, W., Smurzyńska, A., Cieślik, M., Boniecki, P. and Kozłowski, K. (2016a) Biogas efficiency of selected fresh fruit covered by the Russian embargo. Energy And Clean Technologies Conference Proceedings, SGEM 2016, VOL III: p.227-33.
8. Czekała, W., Bartnikowska, S., Lewicka, A., Bugała, A., Zbytek, Z. and Lewicki, A. (2016b) Economic and energy efficiency of the solid biofuels produced from digested pulp. MATEC Web of Conferences 60, 04005 ICCBS 2016. DOI: 10.1051/ matecconf/20166004005
9. Czekała, W., Dach, J., Dong, R., Janczak, D., Malińska, K., Jóźwiakowski, K., Smurzyńska, A. and Cieślik, M. (2017) Composting potential of the solid fraction of digested pulp produced by a biogas plant. Biosystems Engineering, 160, p.25-9.
10. Dach, J., Jozwiakowski, K., Kowalczyk-Jusko, A., Kozlowski, K. and Neugebauer, M. (2016) Biogas plant exploitation under the low-substides market conditions: maize silage versus biowaste scenarios. Energy And Clean Technologies Conference Proceedings, SGEM 2016, VOL III: p.221-226.
11. Kaparaju, P.L.N. and Rintala, J.A. (2008) Effects of solid-liquid separation on recovering residual methane and nitrogen from digested dairy cow manure. Bioresource Technology, 99, p.120-27,
12. Kowalczyk-Juśko, A. and Szymańska, M. (2015) Poferment nawozem dla rolnictwa. http://ksow.pl/uploads/tx_library/files/Poferment_nawozem_dla_rolnictwa_01.pdf
13. Kowalczyk-Jusko, A., Kowalczuk, J., Szmigielski, M., Marczuk, A., Jozwiakowski, K., Zarajczyk, K., Maslowski, A., Slaska-Grzywna, B., Sagan, A. and Zarajczyk, J. (2015a) Quality of biomass pellets used as fuel or raw material for syngas production. Przemysl Chemiczny, 94, p.1835-37.

14. Kowalczyk-Jusko, A., Koscik, B., Jozwiakowski, K., Marczuk, A., Zarajczyk, J., Kowalczuk, J., Szmigielski, M. and Sagan, A. (2015b) Effects of biochemical and thermochemical conversion of sorghum biomass to usable energy. Przemysl Chemiczny, 94, p.1838-40.
15. Kozlowski, K., Lewicki, A., Solowiej, P. Neugebauer, P. adn Smurzynska, A. (2016) Usage of waste whey as mono-substrate in continuous fermentation process. Energy And Clean Technologies Conference Proceedings, SGEM 2016, VOL III: p.345-350.
16. Lewicki, A., Dach, J., Janczak, D. and Czekała, W., (2013) The Experimental Macro Photoreactor for Microalgae Production. 6th International Conference On Information And Communication Technologies In Agriculture, Food And Environment (HAICTA 2013). Book Series: Procedia Technology, Vol. 8, p.622-627.
17. Neugebauer, M. and Sołowiej, P. (2017) The use of green waste to overcome the difficulty in small-scale composting of organic household waste. Journal of Cleaner Production, 156, p.865-75.
18. Obidzinski, S. (2012) Analysis of usability of potato pulp as solid fuel. Fuel Processing Technology, 94, p.67-74.
19. Sigurnjak, I., Vaneeckhaute, C., Michels, E., Ryckaert, B., Ghekiere, G., Tack, F.M.G. and Meers, E. (2017) Fertilizer performance of liquid fraction of digestate as synthetic nitrogen substitute in silage maize cultivation for three consecutive years. Science of The Total Environment, 599–600, p.1885-94.
20. Szmigielski, M., Zarajczyk, J., Kowalczyk-Jusko, A., Kowalczuk, J., Rydzak, L., Slaska-Grzywna, B., Krysiak, Z., Cycan, D. and Szczepanik, M. (2014) Quality of biomass briquettes as stock for thermochemical conversion and syngas production. Przemysl Chemiczny, 93, p.1986-90.
21. Tampio, E., Marttinen, S. and Rintala, J. (2016) Liquid fertilizer products from anaerobic digestion of food waste: mass, nutrient and energy balance of four digestate liquid treatment systems. Journal of Cleaner Production, 125, p.22-32.
22. Waszkielis, K.M., Wronowski, R., Chlebus, W., Białobrzewski, I., Dach, J., Pilarski, K. and Janczak, D. (2013) The effect of temperature, composition and phase of the composting process on the thermal conductivity of the substrate. Ecological Engineering, 61, p.354-57.
23. Wolna-Maruwka, A. and Dach, J. (2009) Effect of Type and Proportion of Different Structure-Creating Additions on the Inactivation Rate of Pathogenic Bacteria in Sewage Sludge Composting in a Cybernetic Bioreactor. Archives of Environmental Protection, 35, p.87-100.
24. Wu, D., Lü, F., Shao, L. and He, P. (2017) Effect of cycle digestion time and solid-liquid separation on digestate recirculated one-stage dry anaerobic digestion: Use of intact polar lipid analysis for microbes monitoring to enhance process evaluation. Renewable Energy, 103, p.38-48.