*Agronomy Research* **13**(2), 455–463, 2015

# A proposition of management of the waste from biogas plant cooperating with wastewater treatment

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**Abstract.** The energy policy relevant to ecological aspects in all EU members since couple of years is determined by renewable energy sources (RES) development. Specific activities related to the increase of the share of RES in national energy like certificates of origin, penalties and fees all together make up a kind of enforcement that would encourage society to searching new possibilities to generate energy in accordance to respect to the natural environment. Seeking alternatives to fossil energy sources is the best option to force the approaching energy crisis.
The paper aimed at analysis of possibility in using the digestate coming from biogas plant which cooperating with wastewater treatment. In details, some aspects of underestimated energy potential of digestate was developed as well as energy flow in analysed technological solution to demonstrate that it is possible to close this balance circle. As a result of the undertaken considerations there are some suggestions how to adopt the treatment system to improve effectiveness of waste management in accordance with energy production.

**Key words:** biogas, pellet, waste water treatment.

## INTRODUCTION

The energy policy relevant with ecological aspects in all EU members since couple of years is determined by RES (renewable energy sources) development. Specific activities related to the increase of the share of RES electricity in national energy like certificates of origin, penalties and fees all together make up a kind of enforcement that would encourage society to searching new possibilities of energy generation in accordance with respect to the natural environment. Seeking alternatives to fossil energy sources is the best option to force the approaching energy crisis. The paper presents an innovation solution as power generation from wastes called digestate. The digestate is a left-over from biogas production process. Economic viability of energy and pellet manufacturing process of undergoing anaerobic digestion of municipal sewage sludge, as a product of integrated technology of sewage sludge disposal were investigated but this paper shows only energy part of elaborations.

In Poland operates more than 4,000 municipal and industrial wastewater treatment plants. This kind of systems produce large amount of sediments. For biogas production usually goes so called biological fraction of the sludge that can be an excellent material for methane fermentation for two main reasons (Kirchmann & Bernal, 1997):

1) do not contain toxic substrates,
2) contains 4–5% dry matter, in which more over 90% is organic.

Despite this potential, they are usually disposed-off in landfills. In the light of the Council Directive 99/31/EC and Polish law (Act of 14 December 2012 on waste – Dz.U. 2013 No. 21) transparent to this document that's become an increasing problem. Since the letter of the law limits the storage of sediment, it is necessary to disseminate appropriate methods of disposal of sewage sludge and its rational management. Recycling of organic materials has essential role due to protection of the environment.

The oxygen fermentation (aka anaerobic digestion - AD) is one of the most universal methods of decreasing the quantity of organic wastes. Utilization of the organic wastes means efficient conversion to the energy and heat. In addition biogas production technic as known as destroying pathogens (Paavola & Rintala, 2008) gives ideal product for advanced research that calls digestate. Digestate quality is determined by selected technology of fermentation and character of products used in the process. However, some common stages can be found in the course of the digestion process which allows evaluating the quality of the digestate.

The most important integrands helpful with energy use of digestate are (Stinner et al., 2008):

- amount of ODM (organic dry matter) and
- the carbon content which quantity determines final energetic value of product.

## MATERIALS AND METHODS

### Case study

The subject described in the following paper is a sewage treatment plant designed for an average amount of treated wastewater in quantities of 38,000 $m^3$ per day. Sewage treatment plant is equipped with mechanical, biological and chemical purification technologies. Final waste in a shape of sludge consists organic crudes from the mechanical treatment (from primary settling tanks), and the biological sludge produced in the secondary clarifiers. Average sludge production is about 6,000 tons per day with an average hydration level of 80%.

The deposit (biological active sludge) is transferred to closed fermentation chamber (CFC) by gravity thickeners. Before entering CFC the sludge passes through the spiral heat exchanger which heats it to the correct temperature (mesophilic which amounts about 310 K). Heated sludge is pumped into open fermentation chamber, which acts as storage where deposit is subjected to the stabilization with the help of oxygen, dewatering in gravitational tank, degasification and homogenization.

Produced biogas composed mainly of methane (approx. 65%) and carbon dioxide with annual production is determined on average level of 990,000 $m^3$ per year ant its calorific value is 26 MJ $m^{-3}$.

### Proposed solution

The solution of digestate management described in this paper assumes remaking the redundant substrate into valuable product – the fuel by transformation of digestate into pellets. Pellet is an increasingly popular fuel. Heating technology based on it is in the mainstream. Competitively low price and high boilers efficiency makes this energy carrier a very cost-effective alternative to conventional fuels.

Designed technology bases on three main elements:

1. Decantation centifruge;
2. Greenhouse (solar drying);
3. Pelletizer.

Digestate is provided by conveyor belt, which transports it from the post-fermentation tank directly into decanter centrifuge and next driven by the inverter spreading on the floor of the greenhouse. Dry and shredded material goes to the store which fulfils the role of a stabilizing tank where permanent humidity standardizing the process. Chain arterial selector transfers the material to bucket elevator. The next step is material gravity pouring into the pelletizer buffer tank.

Prepared material goes into the pelletizer buffer tank where waits for granulation. Pelletizing process by-product is water vapour, which is removed from the granulation chamber by gravity through exhaust pipe system. Hot pellet is transported by feeder system to the cooler counter.

Furthermore the conception is projected to use a co-generator unit which would products:

- Electricity: used to ensure the continuity of decanter and pelletizer work and generate incomes from *green* certificates of origin.
- Heat: used as a central heating and technological process heat source.

Basis on these criteria was selected cogeneration unit VITOBLOC 200 EM 363/498 produced by VIESSMAN with the following technical data:

fuel: biogas; engine: Otto's 6-cylindder turbocharged with internal combustion; efficiency: 90.4%; electric power: 363 $kW_e$; heat power: 498 $kW_{th}$.

**Theory and calculations**

The main aim of the investigation is to optimize a treatment work with an usage of produced wastes. Assumed methodology based on diversified analysis. In case of it complexity this paper shows only main assumption data. More details will be approached in further articles.

At the beginning it is important to mention the calorific value of digestate pellets as an amount of 11 GJ $t^{-1}$ which results from calculation shown in (Michalik, 2011) but scrutiny is going to be experiment soon.

First step in calculation gives amount of annual biogas production which was computing in accordance with (Curkowski et al., 2009).

By assuming that the methane average content for analysed study is equal to 65% of total biogas volume (1)

Methane capacity

$$\mathrm{p_{CH_4}} = \mathrm{V_{bio}} * \sigma \qquad (1)$$

where: $\mathrm{V_{bio}}$ – biogas volume ($m^3$); σ – average methane content (%); the model equation for an energy balance was possible.

The value is a base for estimation energy CHP production which in final gives net heat and electricity production in monthly configuration.

Subsequently annual digestate production was estimated by process simple transformation as it is shown below.

Annual dry matter production:

$$d.m. = annual\ volume\ of\ treated\ sludge * dry\ matter\ contain \quad (2)$$

Annual digestate production:

$$d = (annual\ dry\ matter\ production * 100\%)/20\% \quad (3)$$

Wastewater treatment plant is a consumer of electricity from the local supplier in the terms of ordered capacity – declared by the customer – amounts 500 kW, by medium voltage network, with variable demand. Rely on data given from the wastewater treatment operator author elaborated consumer profile of electricity consumption which was set together with monthly electricity production from CHP unit.

All technical elements mentioned in Table 1 as electricity consumption factors are permanent elements of technological line. Biogas plant and technological line components work 8,000 hour per year. Treatment plant works incessantly. Monthly electricity production was calculated by multiply biogas plant installed capacity (according to prior computations and working time (Pieczykolan & Romańczuk, 2012).

Analyzed treatment plant is equipped with gas boiler working as an only source of heat for whole facility (biogas plant, sewage treatment plant and social buildings). To balance heat demand with its production (purchase) it was necessary to inspect the energy audit for buildings which are part of treatment plant infrastructure.

**Table 1.** Monthly electricity consumption

| Month | Electricity consumption: | | | |
|---|---|---|---|---|
| | proposed equipment | biogas plant | treatment plant | total |
| | MWh | | | |
| January | 21.1 | 22.9 | 200.3 | 244.2 |
| February | 19.0 | 20.7 | 180.9 | 220.6 |
| March | 21.1 | 22.9 | 200.3 | 244.2 |
| April | 20.4 | 22.2 | 193.8 | 236.4 |
| May | 21.1 | 22.9 | 200.3 | 244.2 |
| June | 20.4 | 22.2 | 193.8 | 236.4 |
| July | 21.1 | 22.9 | 200.3 | 244.2 |
| August | 21.1 | 22.9 | 200.3 | 244.2 |
| September | 20.4 | 22.2 | 193.8 | 236.4 |
| October | 21.1 | 22.9 | 200.3 | 244.2 |
| November | 20.4 | 22.2 | 193.8 | 236.4 |
| December | 21.1 | 22.9 | 200.3 | 244.2 |

Source: Michalik, 2013

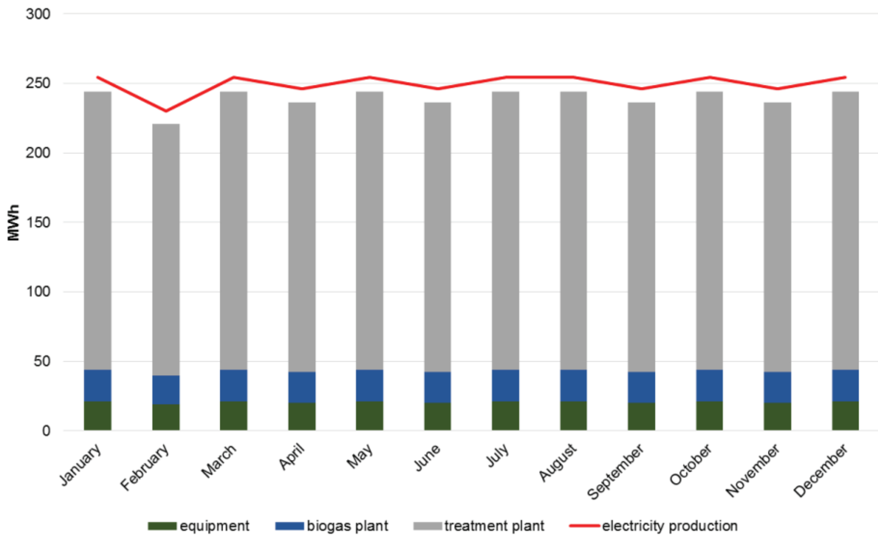


**Figure 1.** Monthly electricity balance (Source: own elaboration).

Whole audit procedure base on particular acts:

- Act of 19 September 2007 Building Law.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 17, poz. 104) of 21 January 2008 the conduct of training and examination for persons seeking permission to draw up the certificate of the energy performance of a dwelling and the building which is the independent whole technical-utilitarian.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 201, poz. 1240) of 6 November 2008 a methodology for calculating the energy performance of the building and an apartment building or part of a whole which is the independent technical-utilitarian and the preparation and presentation of certificates of energy performance.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 201, poz. 1239) of 6 November 2008 amending the Regulation on the scope and form of the building project.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 228, poz. 1513) of 17 December 2008 amending Regulation of the amended Regulation on the scope and form of the building project.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 201, poz. 1238) of 6 November 2008 amending the Regulation on technical conditions to be met by buildings and their location.
- Ministry of Transport, Construction and Maritime Economy Regulation (Dz. U. z 2008 r. Nr 228, poz. 1514) of 17 December 2008 amending Regulation of the amended the Regulation on technical conditions to be met by buildings and their location.
- Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

**Table 2.** Monthly heat consumption

| Month | Heat consumption: | | | |
|---|---|---|---|---|
| | social buildings | biogas plant | treatment plant | Total |
| | MWh | | | |
| January | 20.2 | 81.9 | 170.4 | 272.4 |
| February | 15.9 | 73.9 | 153.9 | 243.7 |
| March | 4.4 | 81.9 | 170.4 | 256.6 |
| April | -5.7 | 79.2 | 164.9 | 238.4 |
| May | 0.1 | 81.9 | 170.4 | 252.4 |
| June | 0.0 | 79.2 | 164.9 | 244.1 |
| July | 0.0 | 81.9 | 170.4 | 252.2 |
| August | 0.0 | 81.9 | 170.4 | 252.2 |
| September | 9.3 | 79.2 | 164.9 | 253.4 |
| October | 14.7 | 81.9 | 170.4 | 267.0 |
| November | 22.2 | 79.2 | 164.9 | 266.3 |
| December | 23.7 | 81.9 | 170.4 | 275.9 |

Source: Michalik, 2013

Apparently in November and December total heat demand exceed gross heat production (Table 2) as follows. Taking into account that heat producers should secure continuity of heat production by other fuel this little exceeds does not pose. Instead of additional fuel was proposed an installation of a buffer tank.

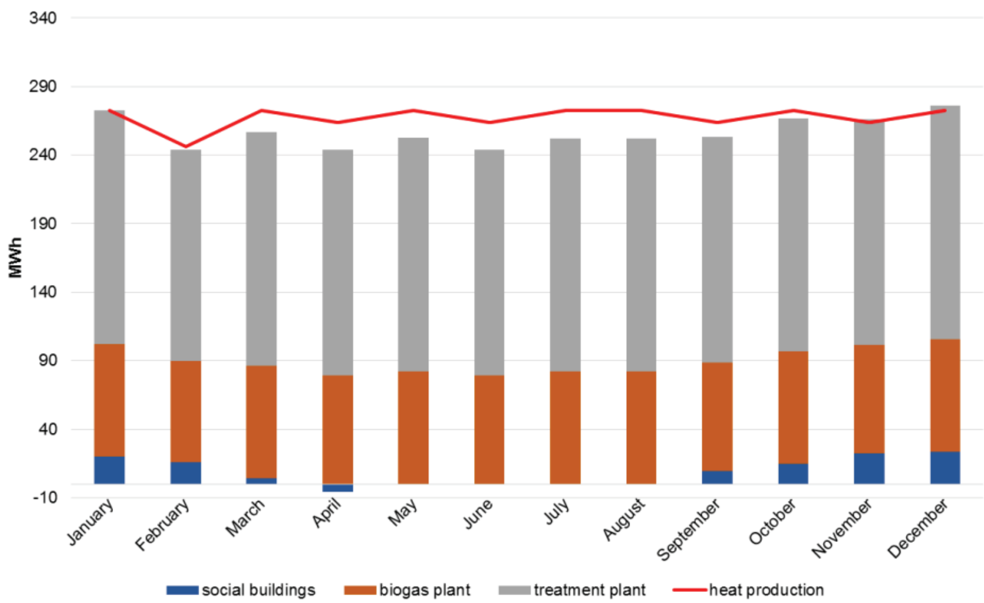


**Figure 2.** Monthly heat balance (Source: own elaboration).

Total heat consumption for analyzed year was calculated in assessment of biogas annual consumption which was given by treatment operator and defined as total heat consumption in 2011 – 11,081 GJ. From case study calculation comes out biogas plant heat demand – 3,481 GJ and social building heat demand – 377 GJ. More detailed and exhaustive material are presented in (Michalik 2013) and (Michalik 2011) as well would be elaborated in further studies.

To estimate mass flow in the process it has be done a reverse operation. Annual real biogas production is 998,978 $m^3$ and it is known that 1 $m^3$ of sewage sludge delivered into the digester tank should give 20 $m^3$ of biogas (Gans et al., 2010).

$$\dot{m} = \frac{p_{rb}}{p_{tb}} * \rho_s \tag{4}$$

where: $p_{rb}$ – real biogas production (t year$^{-1}$); $p_{tb}$ – theoretical biogas production ($m^3$ of biogas $m^{-3}$ of sewage sludge); $\rho_s$ – sewage sludge density (t $m^{-3}$).

According to the research carried out by Michalik (2011) the hydration of digestate after 30 days of storage is 74%. When the digestate retention time ends the mass is delivery to the decantation centrifuge by conveyor belt. The device guarantees 50% decrease of hydration of the substrate. Afterwards greenhouse (solar drying) provides obligated hydration of pelletized substrate about 20%.

## RESULTS AND DISCUSSION

Classic combustion of sewage sludge is well understood and mastered but in case of nitrogen oxides emission and heavy metals content could cause negative effects on environment and be a source of social objections (Werle & Wilk, 2011).

Agricultural use of sewage sludge is bothersome due to legislative connotation (Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture).

Oxygen fermentation (aka anaerobic digestion – AD) is one of the most universal methods of organic wastes utilization that provides efficient transformation into electricity and heat and also helps with pathogens destroying (ENconsult Council, 2011). Product of the AD process calls digestate.

In accordance of theoretical research (Michalik, 2011) during the pelletization process substrate loses even 50% of water contains. According to formulas from (Morris, 2011) and author's data total mass of produced pellets amounts almost 17,000 tons per year which can be sell as an alternative fuel allow generating incomes.

Digestate quality (as a product of AD) is determined by fermentation technology and substrates used in the process (Paavola & Rintala, 2008). However, some common assuming can be done by the available literature.

**Table 3.** Typical fuel properties of digestate pellets

| Net calorific value | Ash content | Water content | Softening temperature of ash | Nitrogen | Sulphur | Chlorine |
|---|---|---|---|---|---|---|
| GJ $t^{-1}$ | % | % | K | % | % | % |
| 15–18 | 16–20 | 9–10 | 1,373 | 1.5–3 | 0.3–1 | 0.3–0.9 |

Source: Christa & Wopienka, 2009

On account of lack of possibility of laboratory research of calorific value of produced pellets only experimented quantity was carried out base on simple calculation:

$$Q_i=Q_s-24.42*(W^a+8,94H^a) \quad (5)$$

where: $Q_i$ – heat of combustion (MJ $kg^{-1}$); 24.42 – heat of water vaporization in temperature of 298.15 K corresponding to 1% water content in the fuel (MJ $kg^{-1}$); $W^a$ – water content in the fuel sample (%); $H^a$ – hydrogen content in the fuel sample (%).

The result amounts 11 MJ $kg^{-1}$. More exact experiment will be subject of further research.

## CONCLUSIONS

This paper has investigated the reasonableness of alternative way in digester management. To do this it has to by choose suitable methodology. Obtained results gives reasonable arguments about whole conception.

Energetic results are very positive. The electricity demand for biogas plant, treatment plant and proposed pelletization line is minor than theoretical production. Also heat theoretical production is high than its demand, but only in annual depiction. Monthly analysis show that in November and December could take place the deficiency of produced heat. The proposed solution is use of a buffer tank.

The main research conclusions:

1. The production process where pellets are created from digestate resultant from anaerobic digestion is possible to carry out.
2. Thanks to small number of technologies changes in treatment plant the facility could obtains energy independence.
3. Suitable management of analysed digestate gains free fuel in a form of pellets.

Further research could be conducted to determine the effectiveness of pellet production from different types of digestate.

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