Chapter 10

Small-Scale Energy Use of Agricultural Biogas Plant Wastes by Gasification

Dariusz Wiśniewski, Mariusz Siudak and
Janusz Piechocki

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71700

Abstract

In Poland, there are 78 biogas plants producing a total electrical power of 85.94 MW. The byproduct of biogas plants is called a digestate. A single biogas plant with a power of 500 kW produces more than 10,000 ton of digestate per year. The goal of this chapter is to present a low-cost method of raw digestate processing with water content of about 94.55%, and also the results of thermal gasification of dried and pelletized digestate. Initial dehydration method is based on mechanical separation of the solid fraction in screw separator with a slot filter. Pre-dewatered digestate had been dried in biodrying process in semi-technical scale bioreactor. Afterward, the digestate was dried in tubular dryer and pelletized. The chapter covers the energy consumption for each stage of preparation of digestate for thermal gasification process. The gasification tests were conducted in fixed bed downdraft reactor. The chapter also features the physicochemical properties of digestate used in gasification process. The result of research on the gasification of drier digestate was gaseous fuel that does not differ from the quality of fuels obtained from the thermal treatment of other types of biomass.

Keywords: gasification, digestate, wastes, solid fuels, syngas

1. Introduction

The biogas production from agriculture waste in anaerobic digestion is a profitable direction for their energetic use [1, 2]. The byproduct of anaerobic digestion is called a digestate, which consists of both liquid and solid fractions. They can be separated using screw separators, presses, or decanter centrifuges. Liquid fraction can be used to fertilize farmlands because it contains substantial amount of the elements necessary for plant growth. Liquid fraction can also be further treated and recirculated to the fermenter [3]. Solid fraction can also be used for agriculture or as a solid fuel, e.g., in the combustion process [4].

1.1. Digestate treatment in Europe

Nowadays, the digestate in the regulations is considered as waste in Europe. It does not have the status of a biofuel or an alternative fuel and is most commonly used as a soil improver. Such use often requires additional tanks to store the digestate mass to allow it to be used during fertilization periods. This can generate significant capital expenditure on the construction of liquid fraction storage tanks [5]. Another problem that causes the necessity of processing digestate is too small cultivable area where it can be used directly. Agricultural use of digestate is limited by the maximum allowable nitrogen dose of 170 kg N ha^{-1} y^{-1} [6]. For this reason, European countries have begun to use the separation of digestate to solid and liquid fraction. These fractions differ in physicochemical properties. As a result, a much smaller area for storage of digestate is required, while liquid fraction is again used to dilute the substrates to the fermentation process to the required 12% of dry matter. Liquid fraction can also be used as fertilizer by acquiring mineral compounds. It is characterized by lower phosphorus content and a higher content of nitrogen and potassium. Solid fraction is used in areas with low phosphorus content, liquid fraction on the other hand—in phosphorus saturated areas [7].

For fertilizer purposes, the liquid fraction is used either directly or in the production of mineral fertilizers through further purification. Further purification can be achieved through ultrafiltration in order to remove solid particles, followed by the reduction of high concentrations of nitrogen through stripping or crystallization of struvite [8]. These methods are used extensively in Germany and the Netherlands, and are mainly derived from a pig farm where ammonia load is very high.

For separation, screw separators with slot filter are most commonly used, which have previously been used successfully to separate liquid manure. Those devices feature low energy consumption because of low pressure of pumped digestate and low rotational speed of the screw shaft. Dry matter content obtained is about 30% of the solid fraction, while the liquid fraction remains about 4% of the dry matter. More advanced equipment, such as decanter centrifuges or belt presses, allow more efficient operation, but are rarely used in small biogas plants because of high investment costs.

Often solid fraction of digestate is processed in composting process, which reduces its volume, moisture, and improves fertilizer and storage properties [9]. Separation devices are often directly integrated with composting reactor, e.g., container with moving floor and aeration system or drum reactor.

Another method often used is drying in belt or drum dryers using the heat from CHP units. Dried digestate is used to produce pellets for energy purposes or for use as bedding for animal farm [10].

http://dx.doi.org/10.5772/intechopen.71700

2. The treatment of raw digestate

A digestate from a pilot biogas plant located at the Experimental Station in Bałdy, Poland (N54° 36′ 1.8073″, E20° 36′8.5295″) was used in this research. The following technological parameters of the fermenter were used [11]:

- Feedstock moisture—90%
- The total batch fed to a digester—1.2 m^3
- The total load of organic compounds—2.3 kg VS/m^3
- The set temperature during the fermentation process—35 to 40°C
- Residence time in the pre-fermentation tank—3 days
- Residence time in the fermentation chamber—20 days
- Residence time in the post-fermentation tank—20 days

Tables 1 and **2** show the properties of the raw digestate.

2.1. Mechanical dewatering of digestate

Raw digestate from biogas plant has been pre-dewatered in screw separator with slot filter with a filter gap of 0.5 mm. Raw digestate contained 94.55% of water. Energy consumption of the mechanical dehydration process was measured using the Schneider ION7650 electrical network meter. In separation process test 0.035 m^3 of raw digestate was used. **Figure 1** shows the photograph of the screw separator.

As a result of the separation process, 30 kg of liquid fraction and 5 kg of solid fraction was obtained. Energy consumption during the experiment was 0.02 kWh. The tests were carried out without the pump forcing the digestate pressure in the separator. Digestate was fed to the separator only under its hydraulic pressure. Absence of pressure force does not interfere with separation operation and performance results may be lower than expected. The usage of a forced pump can increase productivity but can also increase the energy consumption of the process.

Parameter									
pH	Water content	Loss of ignition	N	N-NH_4	P_2O_5	K_2O	MgO	CaO	Na_2O
pH	%	% D.M.	% D.M.	mg/kg D.M.	% D.M.	% D.M.	% D.M.	% D.M.	% D.M.
8.24	94.55	68.97	7.16	1830.0	2.38	6.61	1.28	3.48	1.28

Table 1. Properties of raw digestate.

Parameter						
Cu	Zn	Mn	Fe	Salinity	S	Cl
mg/kg D.M.	mg/kg D.M.	mg/kg D.M.	mg/kg D.M.	g/dm^3	% D.M.	mg/dm^3
8.24	94.55	68.97	7.16	1830.0	2.38	6.61

Table 2. Contamination content in raw digestate.

Figure 1. The photograph of a screw separator with slot filter.

Based on the power and energy measurements and mass of the separated fractions, the energy consumptions of the mechanical separation process in the screw separator with slot filter was determined. Energy consumed for separating 1 kg of solid fraction from raw digestate was 0.004 kWh (14.4 kJ), while the separation of 1 kg of liquid fraction consumed 0.00066 kWh (2.37 kJ). Solid fraction after mechanical separation process contained an average of 76.1% of water.

2.2. Biodrying of digestate

The pre-dewatered digestate was used as a feedstock in biodrying process. Biodrying technology is typically used in the mechanical and biological treatment of wastes [12]. This technology involves the usage of heat generated by aerobic microorganisms in organic matter decomposition processes [13]. The general stoichiometric equation for the decomposition of the organic matter has the following form [14]:

$$C_a H_b O_c N_d + 0.5(ny + 2s + r - c)\, O_2 \xrightarrow{heat} n\, C_w H_x O_y N_z + sC\, O_2 + r\, H_2 O + (d - nz) N H_3 \quad (1)$$

The amount of heat released during biological transformation has been investigated by many authors. The range of this value is from 17.8 to 24.7 (kJ/g decomposed dry matter of organic), calculated as removed organic matter, it can reach up to 28.0 kJ/g organic dry matter [15].

To increase porosity and permeability of the feedstock, the digestate was combined with wood chips in 1:1 mass proportion. The addition of woods chips also intended to reduce the water content of pre-dehydrated digestate to create the mixture with the optimal water content for biodrying process—from 50 to 70% [16]. During biodrying process in the reactor the temperature was measured in four points on different heights. Volume flow rate of the air supplied to the reactor was measured by thermoanemometer. The reactor was set on strain gauges to measure the change of feedstock's mass during the process. During biodrying process, energy consumption was measured using the electricity meter. Stream of air was supplied by side channel blower through floor of the reactor. **Figure 2** presents schematic diagram of the biodrying reactor.

The biodrying process was carried out using 730 kg of mechanically dehydrated digestate and 730 kg of wood chips to ensure adequate porosity of the mixture. Aeration ratio was of average 0.025 $m^3 kg^{-1} h^{-1}$. The process took about 4 weeks. **Figures 3** and **4** show the results of the process.

As a result of the biodrying process was the weight loss of 500 kg—68% of the initial weight of digestate and 34% of initial weight of combination of wood chips and digestate. Total electricity consumption for the biodrying process was 17.792 kWh, equivalent to 0.0295 kWh/kg of reduced weight. **Table 3** shows the energy properties of digestate after the biodrying process.

2.3. Thermal drying of digestate

Digestate after biodrying process was isolated from wood chips by drum sieve and thermally dried in a flow-through tubular dryer. The drying process was controlled by changing the

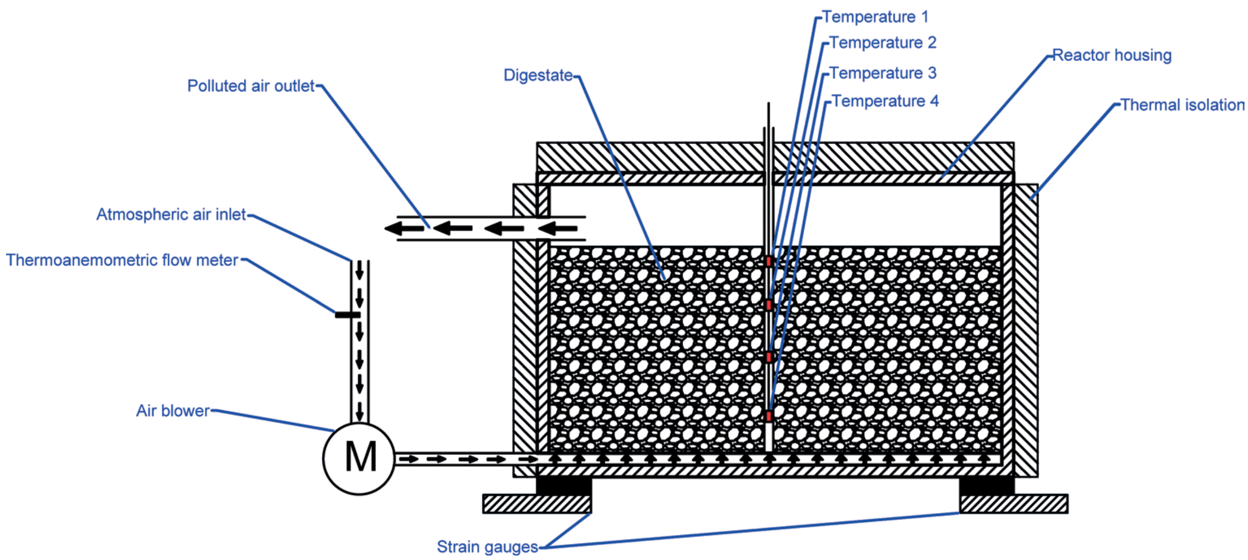

Figure 2. Schematic diagram of the biodrying reactor.

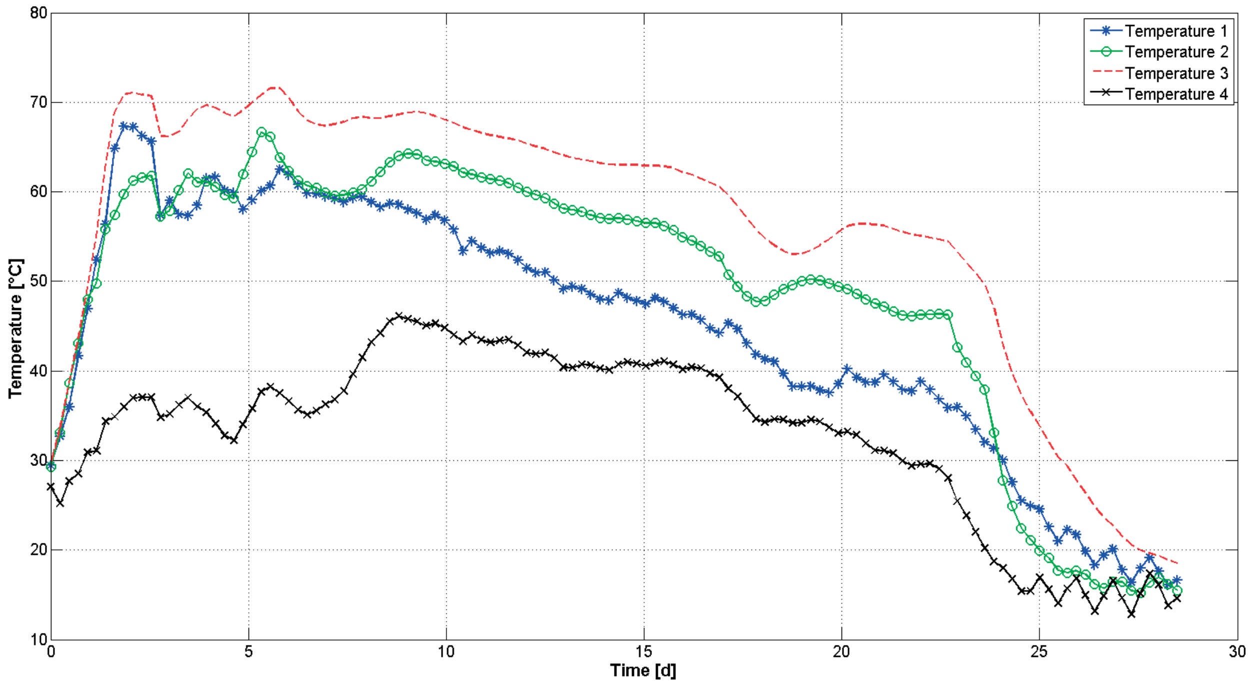

Figure 3. Temperature change graph during biodrying process.

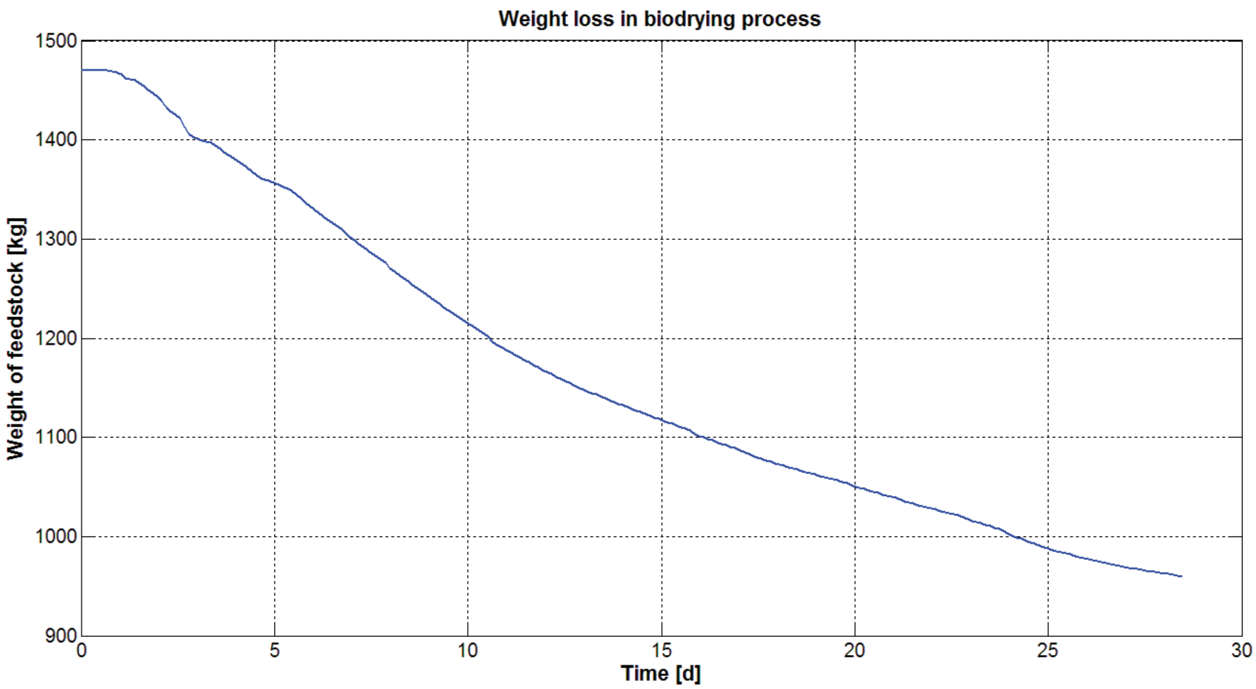

Figure 4. Mass change graph during the process.

feed rate of the dried material and the power of the electric heater. Energy consumption of the digestate thermal drying process was measured using the Schneider ION7650 electrical network meter. **Figure 5** shows a schematic of a tubular dryer.

Type of digestate	Parameter			
	Water content	**Ash content**	**Heat of combustion**	**Calorific value**
After biodrying	%	% D.M.	MJ/kg D.M.	MJ/kg
	43.67	18.07	17.82	8.97

Table 3. Energy properties of digestate after biodrying process.

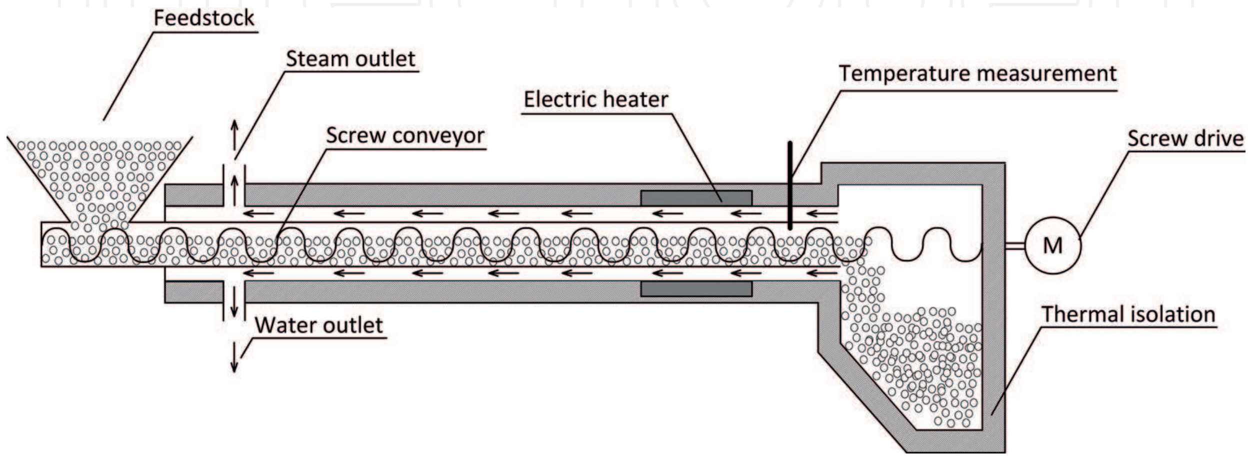

Figure 5. Schematic diagram of tubular dryer.

The tubular dryer was designed to allow steam and condensate drain-off in the initial part of the dryer. This design enables to transfer part of the heat energy of steam and condensed water to the dryer part before the electric heater, increasing the energy efficiency of the drying process.

Energy consumption test was carried out using 36.65 kg of digestate after biodrying process. The material feed rate was 2 m/min, temperature of drying process was about 150°C, and the ambient temperature was 12°C. The result of the drying process was mass reduction of 22.72 kg. The weight loss was 13.92 kg, and the water content of dried product was 9.15%. The drying process consumed 10.28 kWh, and the unitary electricity consumption for evaporation of 1 kg of water was 0.73 kWh/kg. The energy required to produce 1 kg of digestate with water content of 9.15% was about 0.136 kWh. **Table 4** shows the energy properties of digestate after thermal drying.

Type of digestate	Parameter		
	Water content	**Ash content**	**Heat of combustion**
After thermal drying	%	% D.M.	MJ/kg D.M.
	9.15	18.11	17.516

Table 4. Energy properties of digestate after thermal drying process.

Digestate after thermal drying process has been pelletized to increase of bulk density. Energy consumption for pelletization process was 0.085 kWh.

3. The gasification of digestate

3.1. Configuration of gasification system

Main features of the research gasification reactor:

- Reactor was designed and constructed as a downdraft
- Reactor without "throat" in oxidation zone
- Fixed bed reactor
- Thermal power about 200 kW
- Gasification agent—atmospheric air

Figure 6 shows schematic diagram of research gasification reactor. The reactor construction was mounted on strain gauges to real-time measurement of the reactor mass. This allows to determine the conversion speed of the batch material. The temperature measurement is carried out in four gasification zones and additionally in the outlet of syngas by thermocouples. Gasification agent is fed into the reactor by a side channel compressor, volumetric flow rate is measured by a rotameter. Syngas composition and calorific value are measured using the industrial GAS 3100R Syngas Analyzer.

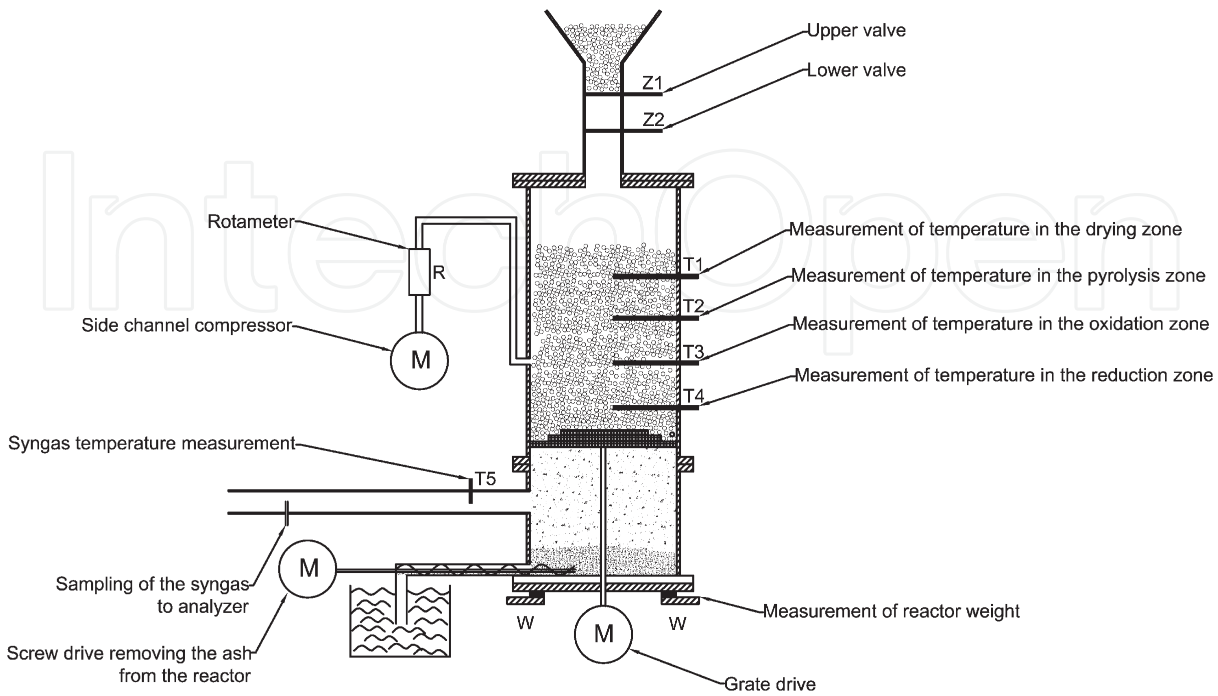

Figure 6. Schematic diagram of gasification reactor.

Reactor construction can be divided into:

- Biomass feeding unit
- Gasification agent supply system
- Ash removal unit
- Reactor chamber

Figure 7 shows 3D model of the gasification reactor with support frame. Biomass for the reactor is provided by screw feeder to the hopper and then through two knife gate valve to the interior of the reactor chamber. Such construction of the biomass feed system ensures the tightness of the installation.

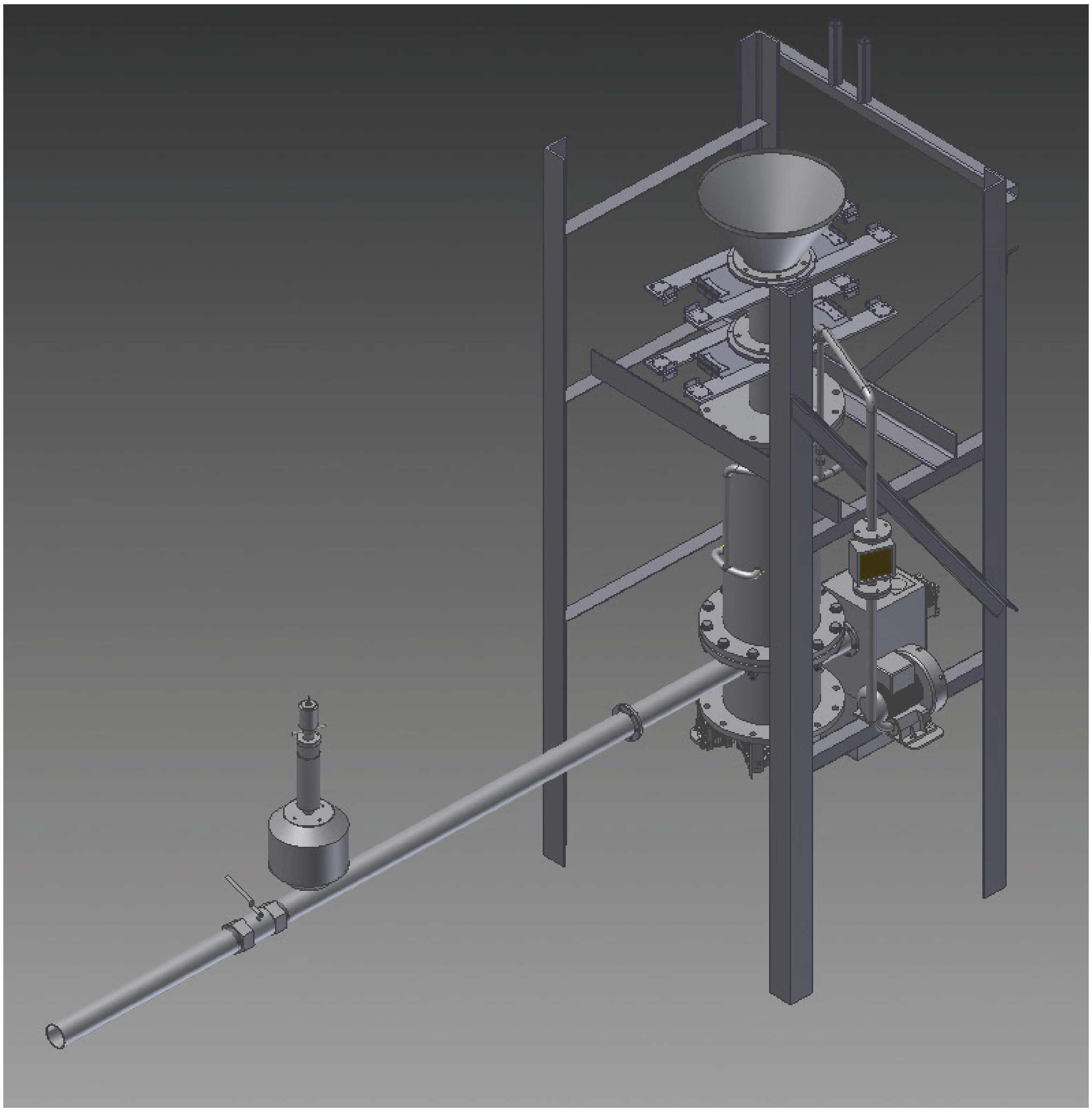

Figure 7. 3D model of gasification reactor.

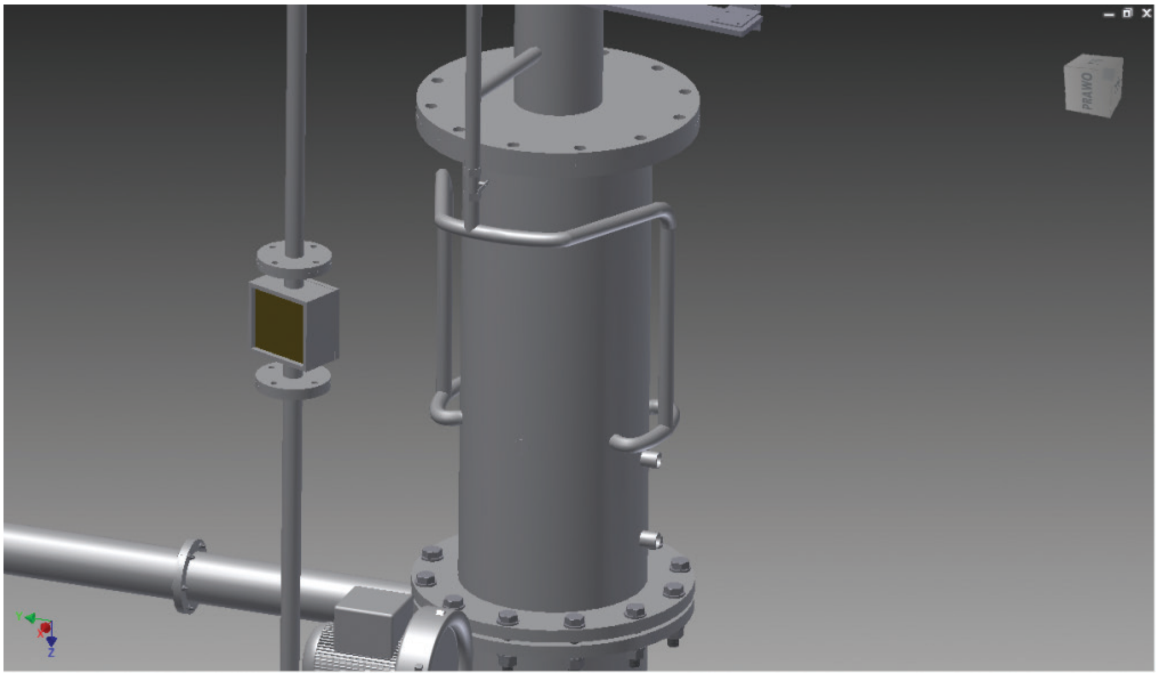

Figure 8. Air supply system to gasification reactor.

The gasification agent supply system consists of four nozzles arranged at the periphery of the oxidation zone (**Figure 8**). Atmospheric air as a gasification agent is forced into the oxidation zone of the reactor through a piping system using a side channel compressor. In order to achieve greater uniformity of the aeration, the nozzles were made at an angle of 15° to produce a vortex of air inside the reactor chamber.

The ash removal unit from reactor consists of a rotary grate integrated with an ash scraper and a screw conveyor (**Figure 9**). The ash removal rate mainly depends on rotational speed of the grate. The holes of grate were made in the form of cones increasing their diameter toward the bottom. Such a construction of the holes results in a lower risk of collimation and enables free removal of ash from the reactor space.

In order to achieve a high level of tar conversion, reactor structure was extended in relation to the diameter to increase the gas flow time through the hot zone. In the research reactor the internal diameter D = 300 mm, while the length of the gasification chamber L = 1200 mm.

3.2. Energy consumption for substrate preparation to gasification process

The substrate of the gasification process was pelletized digestate, after mechanical separation process, biodrying process, and thermal drying process. **Figure 10** shows energy consumption for each stage of preparation process to prepare 1 kg solid fuel from digestate. **Figure 11** shows picture of pelletized digestate. The total energy consumption for production 1 kg of fuel was 0.2545 kWh/kg. The largest part (about 53.43%) of energy was spent on thermal drying process in tubular dryer. Dehydration of digestate in mechanical separation process and in biodrying process was characterized by high energy efficiency of the processes.

http://dx.doi.org/10.5772/intechopen.71700

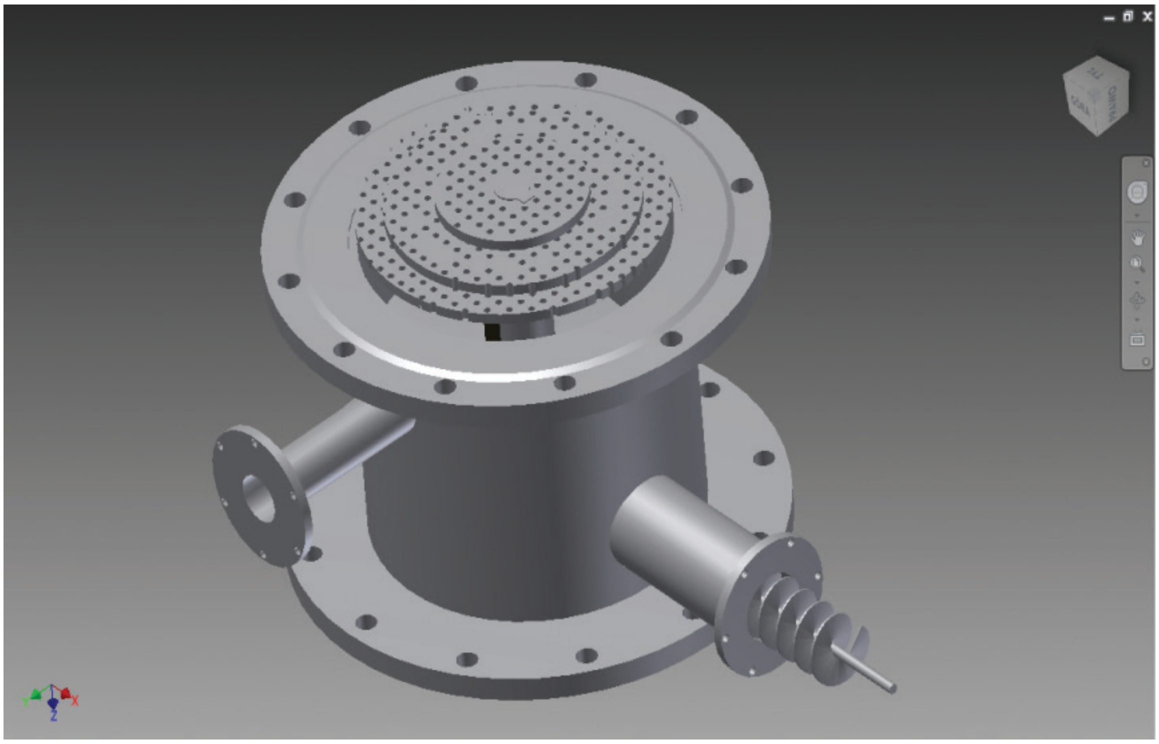

Figure 9. Ash removal unit from gasification reactor.

3.3. The gasification process

The main purpose of the experiments was to evaluate the gasification potential of the fuel produced from digestate and to analyze the obtained syngas. Gasification process was started using a wood pellet. After stabilizing the reactor work, supplying fuel from the digestate was started. Process was carried out with air volumetric flow rate of 30 m^3/h. The dispenser feeder has been setup to maintain fuel mass of about 30–31 kg. Syngas from gasification process was burned in atmospheric conditions immediately after leaving the reactor.

The results of the gasification process of the fuel produced from digestate include composition of syngas, calorific value (**Figure 12**), and the temperature in the oxidation zone of the process (**Figure 13**). In addition, the mass of the reactor measured by strain gauges during process is presented. From the chart, it is possible to read the conversion rate of biomass to syngas. For comparison purposes, the **Table 5** also shows composition of syngas from wood pellets.

During digestate gasification process a high fluctuation of temperature was observed in the oxidation zone of the reactor. Fluctuations reached ±50°C (**Figure 13**). The average temperature in the oxidation zone was 940°C. **Figure 14** shows fuel mass change in reactor chamber during gasification process. The thermal conversion speed of the digestate to syngas was average 26.63 kg/h.

Due to the low melting temperature of ash from digestate, during gasification process, ash slagging caused some problems. Because of this, temperature fluctuations in the oxidation zone probably occurred. During longer work of reactor, conglomerate prevented the

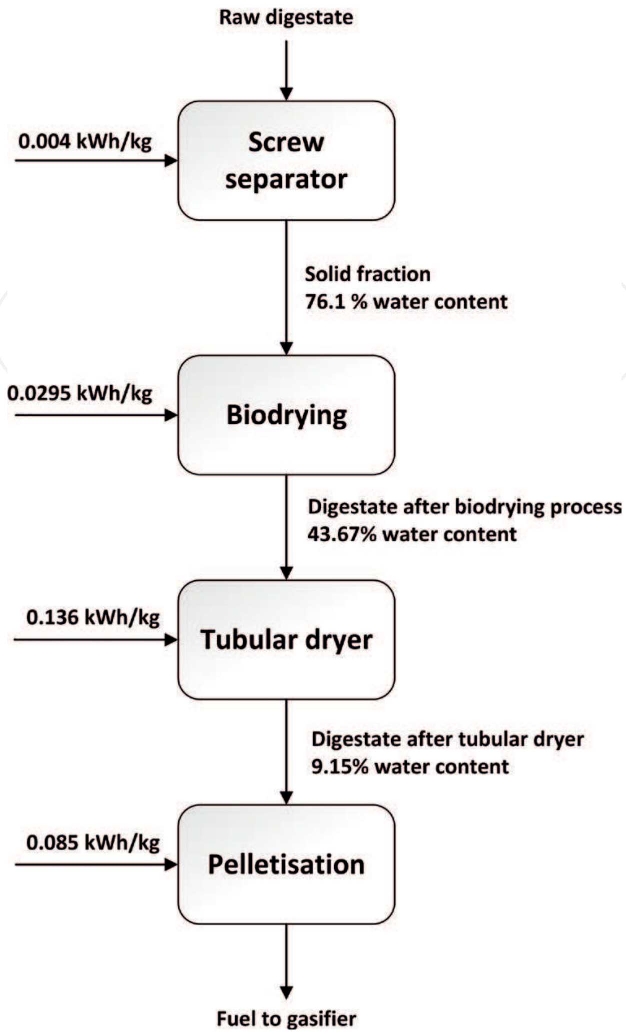

Figure 10. Scheme of digestate processing and energy consumption of each processing stages.

Figure 11. Photo of pelletized digestate—fuel for gasification reactor.

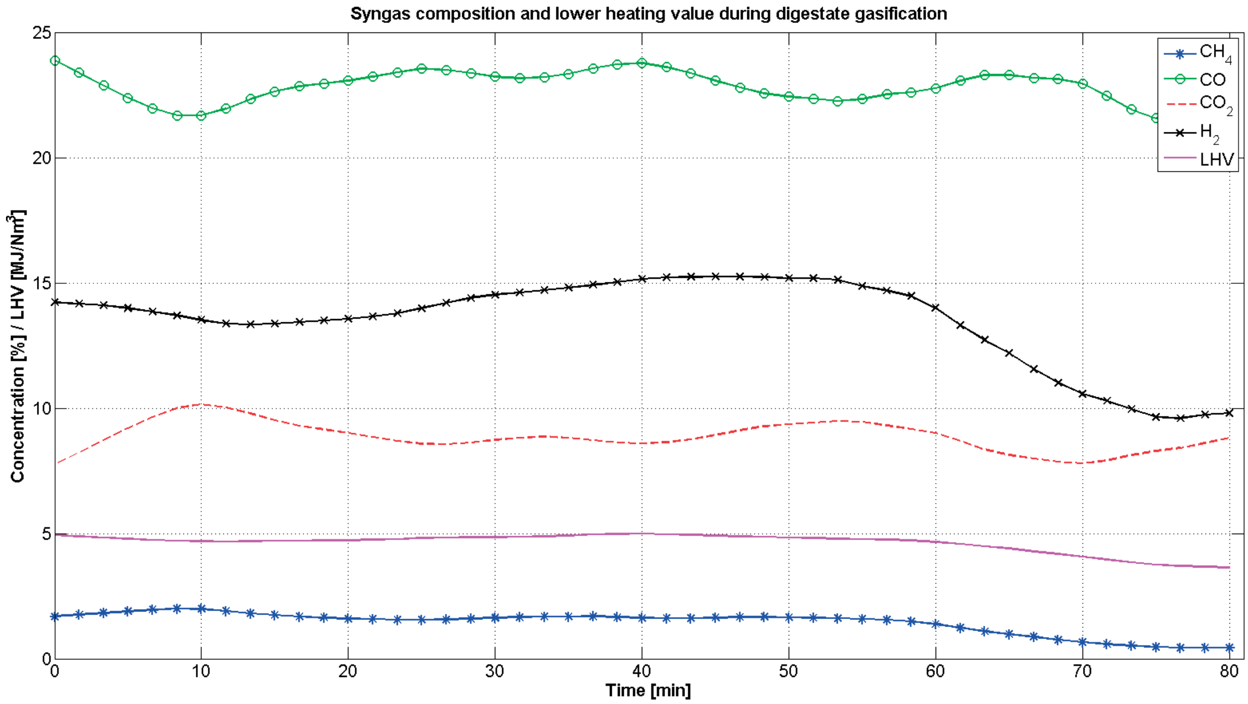

Figure 12. Syngas composition and its calorific value from the digestation gasification process.

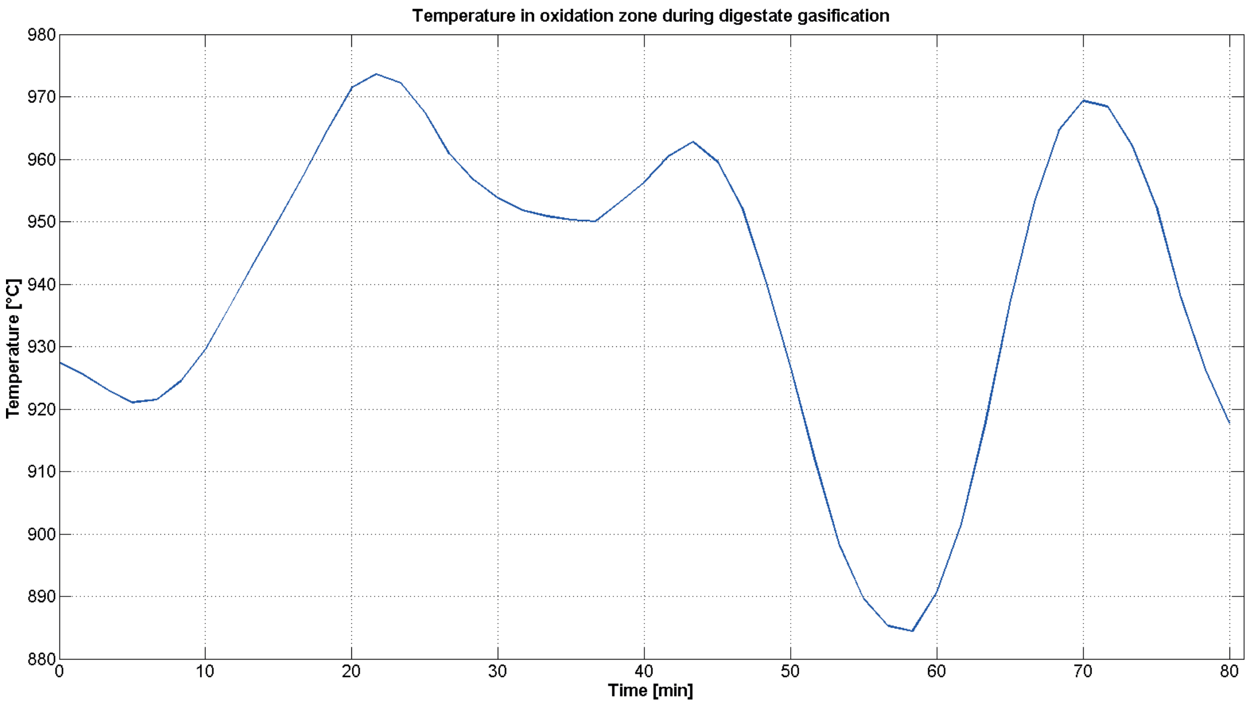

Figure 13. Temperature in oxidation zone during gasification process.

gasification reactor from working properly. A long-term operation of digestate gasification process would be possible by modifying the ash removal system for example by eliminating the solid grate. Some technological solutions of gasification reactors include a system of injecting pure oxygen below the oxidation zone. Molten ash is removed from reactor by

Parameter	Digestate	Wood pellet
CH_4	1.44%	2.3%
CO	22.75%	23.2%
CO_2	8.85%	9.5%
H_2	13.51%	11.0%
LHV	4.62 MJ/Nm^3	4.9 MJ/Nm^3

Table 5. Syngas composition and its calorific value—for comparison, table shows also syngas composition from wood pellets.

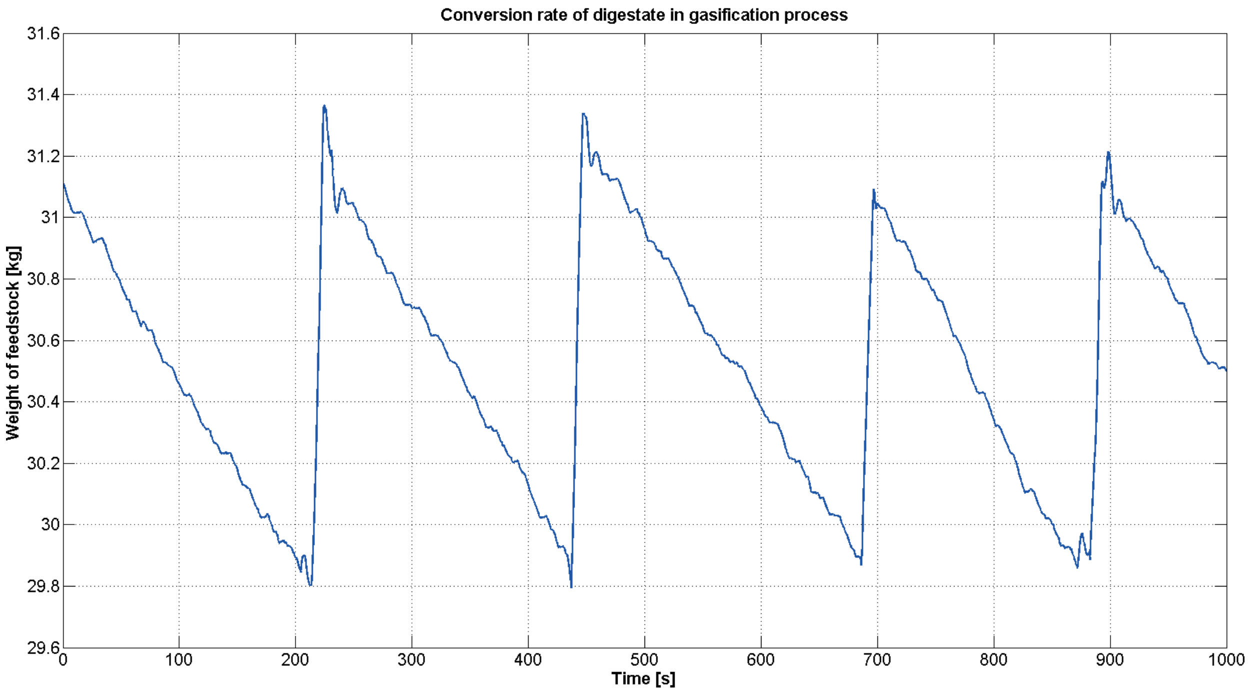

Figure 14. Slice of recorded mass change during gasification process.

a separate channel. This solution results in an increase of energy consumption for gasification process. To solve this problem, authors are currently working on the use of a double screw conveyor on the entire lower surface of the gasification reactor.

4. Summary

It is possible to produce second-generation fuels from dried digestate. The residues from thermal treatment of digestate can be used in the production of mineral fertilizers. Difficulties may occur during the gasification in downdraft reactors with fixed bed. High ash content, which in the case of biomass of agricultural origin features a low melting temperature, can cause problems with slagging.

http://dx.doi.org/10.5772/intechopen.71700

The result of the research of the gasification of dried digestate was gaseous fuel that does not differ from the quality of fuels obtained from the thermal treatment of other types of biomass. The calorific value of obtained syngas was approximately 5 MJ/Nm^3. This type of fuels can be used for combustion in the engine or turbine systems; however, they require adequate conditioning in advance.

Author details

Dariusz Wiśniewski[1], Mariusz Siudak[2]* and Janusz Piechocki[1]

*Address all correspondence to: siudak.mariusz@gmail.com

1 Faculty of Technical Sciences, Department of Electric and Power Engineering, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

2 Faculty of Technical Sciences, Department of Systems Engineering, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

References

[1] Börjesson P, Berglund M. Environmental systems analysis of biogas systems—Part I: Fuel-cycle emissions. Biomass & Bioenergy. 2006;**30**(5):469-485. DOI: 10.1016/j.biombioe.2005.11.014

[2] Börjesson P, Berglund M. Environmental systems analysis of biogas systems—Part II: The environmental impact of replacing various reference systems. Biomass & Bioenergy. 2007;**31**:326-344

[3] Al Seadi T, Drosg B, Fuchs W, Rutz D, Janssen R. Biogas digestate quality and utilization. In: Wellinger A, Murphy J, Baxter D, editors. The Biogas Handbook. 1st ed. Woodhead Publishing; 2013. pp. 267-301. DOI: https://doi.org/10.1533/9780857097415.2.267

[4] Kratzeisen M, Starcevic N, Martinov M, Maurer C, Muller J. Applicability of biogas digestate as solid fuel. Fuel. 2010;**89**(9):2544-2548. DOI: https://doi.org/10.1016/j.fuel.2010.02.008

[5] Al Seadi T, Lukehurst C. Quality Management of Digestate from Biogas Plants Used as Fertiliser [Internet]. 2012. Available from: https://www.iea-biogas.net/files/daten-redaktion/download/publi-task37/digestate_quality_web_new.pdf [Accessed: September 07, 2017]

[6] EU. Directive 91/676/EC of the European parlament and the council of 12 December 1991. Concerning the protection of waters against pollution caused by nitrates from agricultural sources. In: E. Comission (Ed.) Official Journal L. 1991;**375**:pp. 0001-0008

[7] Alburquerque JA, de la Fuente C, Campoy M, Carrasco L, Najera I, Baixauli C. Agricultural use of digestate for horticultural crop production and improvement of soil properties. European Journal of Agronomy. 2012;**43**:119-128. DOI: https://doi.org/10.1016/j.eja.2012.06.001

[8] Vaneeckhaute C, Janda J, Vanrolleghem P, Meers E. Phosphorus use efficiency of bio-based fertilizers: Bioavailability and fractionation. Pedosphere. 2016;**26**(3):310-325. DOI: 10.1016/S1002-0160(15)60045-5

[9] BioEnergy Farm. Digestate Treatment [Internet]. 2014. Available from: www.bioenergy-farm.eu/en/digestate-treatment/ [Accessed: 2017-09-07]

[10] Lebuf V, Snauwaert E, Michels E, Meers E, Sigurnjak I, De Clercq L, et al. Nutrient Recovery from Digestate: Case Study Report. Belgium: INTERREG IV.B NWE ARBOR; 2015. p. 33

[11] Wisniewski D, Gołaszewski J, Białowiec A. The pyrolysis and gasification of digestate from agricultural biogas plant. Archives of Environmental Protection. 2015;**41**(3):70-75

[12] Ritzkowski M, Heerenklage J, Stegmann R. An overview on techniques and regulations of mechanical-biological pre-treatment of municipal solid waste. Environmental Biotechnology. 2006;**2**(2):57-68

[13] Velis C, Longhurst P, Drew G, Smith R, Pollard S. Biodrying for mechanical-biological treatment of wastes: A review of process science and engineering. Bioresource Technology. 2009;**100**(11):2747-2761. DOI: https://doi.org/10.1016/j.biotech.2008.12.026

[14] Białobrzewski I, Miks-Krajni M, Dach J, Markowski M, Czekała W, Głuchowska K. Model of the sewage sludge-straw composting process integrating different heat generation capacities of mesophilic and thermophilic microorganisms. Waste Management. 2015;**43**:72-83. DOI: https://doi.org/10.1016/j.wasman.2015.05.036

[15] Mason I. Mathematical modelling of the composting process: A review. Waste Management. 2006;**26**(1):3-21. DOI: https://doi.org/10.1016/j.wasman.2005.01.021

[16] Yang B, Zhang L, Jahng D. Importance of initial moisture content and bulking agent for biodrying sewage sludge. Drying Technology 2014;**32**(2):135-144. DOI: http://dx.doi.org/10.1080/07373937.2013.795586