Statement of Verification

Technology: Periodic anaerobic bioreactor [OBB] in ANABIOREC™ technology with the energy system for generating power and heat from biogas.

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The verification process, whose results are summarised in this Statement, complies with the EU ETV General Verification Protocol 1.3 and with the ISO 14034:2016 Environmental Management - Environmental Technology Verification (ETV).

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1. Technology description

The ANABIOREC™ technology was developed to enhance the energy recovery from municipal waste after mechanical treatment. The key elements of the production line include large-scale periodic anaerobic bioreactor, leachate preparation system and the biogas-to-energy processing unit.

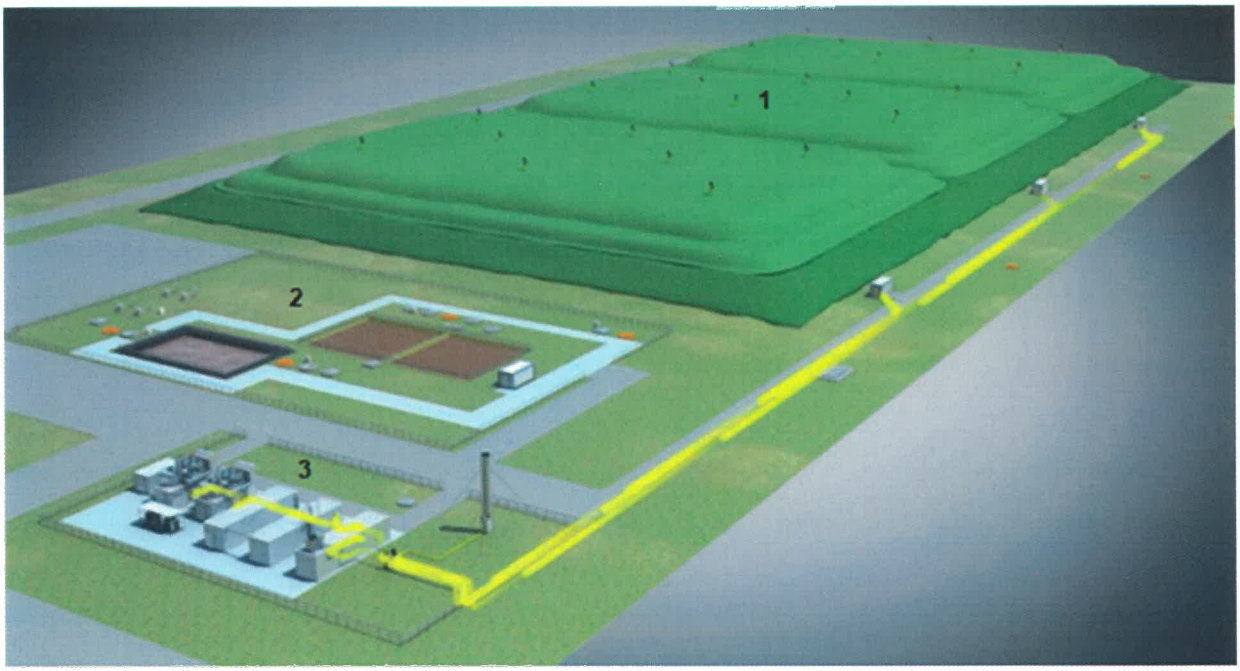
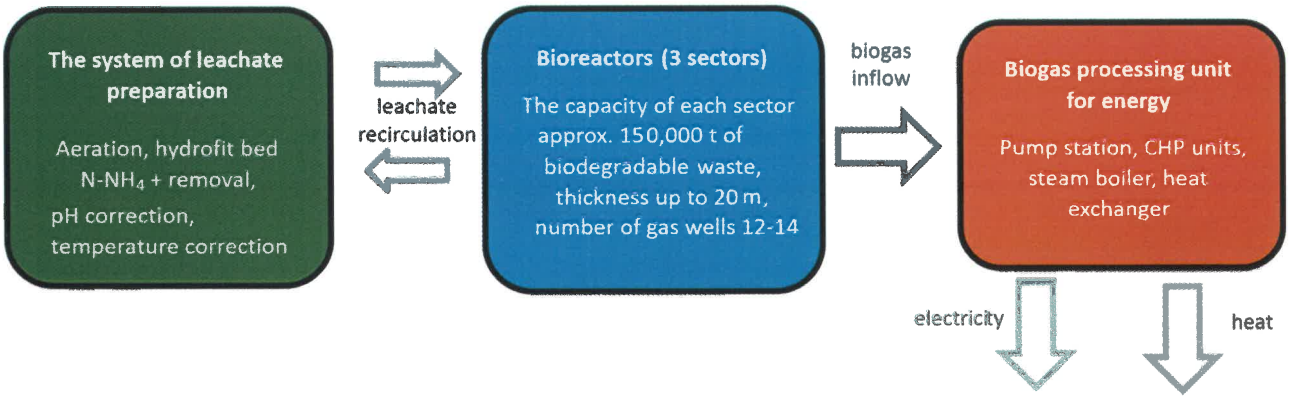


Fig. 1. System for energy recovery from waste in ANABIOREC™ technology: (1) bioreactor, divided into three sectors, (2) system for leachate treatment (aeration tank and hydrophyte bed), (3) biogas-to-energy processing unit

The bioreactor is an earthen structure, recessed down to about 8 m below the ground level, sealed by means of a geomembrane and divided into sectors in which biodegradable waste is deposited at specified intervals. After filling the bioreactor sector with waste up to a height of 12 m above the ground level, its top-down sealing takes place, and then a bed degassing system is installed. The assembling collector is equipped with shut-off and regulating valves as well as measuring devices for monitoring basic parameters of the biogas system, including flow, under pressure and methane content in biogas. Biogas wells are also equipped with shut-off and control fittings and a drainage system consisting of a piston pump supplied with compressed air. The system uses its own plastic pipelines for discharging leachate from gas wells to the leachate assembling collectors, and further to the main pipeline connected to the recirculation system.



Intensification of biogas production in the bioreactor is possible due to recirculation of treated leachates to the waste deposit, which allows for maintaining high moisture content across the entire thickness of the deposit. This helps to ensure a uniform distribution of microorganisms and extends the retention time of organic compounds in the deposit what accelerates waste decomposition. The scope of operation of the leachate recirculation system, consisting of groups of tanks and pumping stations, embraces stabilisation of pH, temperature and partial removal of ammonium nitrogen, whose excess is toxic to fermentation microorganisms. The operation of the bioreactor is controlled by a system consisting of an electronic control unit, working according to a prescribed algorithm of automatic operation and connected to a set of measuring devices. This system works using data on biogas temperature, flow rate, methane content, pH value and leachate temperature. After the completion of the biogas recovery phase (usually within 8 years), the waste is steam sterilised, stabilised in aerobic process, followed by the extraction of waste for further processing. The technology assumes the re-filling of the bioreactor.

2. Application

2.1. Matrix

Mechanically separated biodegradable fraction of municipal waste; under-sieve fraction (0 – 80 mm). It is also acceptable to introduce into the bioreactor other biodegradable waste, the moisture of which is above 50% of the weight, and the ratio of carbon to nitrogen remains in the range from 20:1 to 35:1.

2.2. Purpose

The purpose is to intensify the process of energy generation from municipal waste through accelerated biomethanization in a large-scale bioreactor, with recirculation of the pre-treated and adequately dosed leachate, resulting in a significant increase in the rate of energy generation from a waste mass unit.

2.3. Conditions of operation and use

The bioreactor which was the verification object is located in the village of Różanki (the Susz municipality, Warminsko-Mazurskie Voivodeship, Poland). Due to the long-term nature of the full work cycle of the bioreactor operating in ANABIOREC^{TM} technology, only the initial phase of an operation of one of the bioreactor sector (called OBB 2) was included into verification, starting from the commencement of the bioreactor degassing over the next eight months.

The efficiency of biogas production in the bioreactor working in ANABIOREC^{TM} technology depends on various factors, thus specification of the conditions in which the verified object have operated is necessary. The filling OBB 2 with 144,463 Mg of waste (composition is given in par. 3.3) was completed in July 2017. The biogas recovery and re-circulation of leachate on this sector have been commenced in August 2018. The leachate recirculated into the OBB 2 it is a mixture of the effluents from all sectors. It is treated in aeration unit (sealed open tank 25 m x 25 m and a blower delivering 1,000 m^3/h) and hydrophyte units (shallow bed with dimensions of 23 m x 40 m and 27 m x 40 m, with an expanded clay bottom layer and planted with common reed, at designed hydraulic load of the hydrophyte deposit of 22 $l/(m^2 \cdot d)$).

Other information significant from the viewpoint of the proper functioning of the bioreactor is given in par. 5 (Additional parameters).

2.4. Verification parameters definition summary

The range of the verified parameters and their definitions are presented in table 2.1.

Table 2.1. Parameters declared by the Proposer

Parameter		Definition	Claimed value	Requirements (legal provisions, BAT, etc.)
PERFORMANCE PARAMETERS				
Methane content (C_{CH4})		Volume percentage of methane in the biogas	≥ 45 % vol.	Technical requirements
Specific energy production rate (ν_b)		Theoretical amount of energy recovered from the biogas, produced from a unit of waste mass deposited in the bioreactor per time unit	≥ 16 MJ/(Mg_{waste}· month)	No requirements
OPERATIONAL PARAMETERS				
Specific leachate loading rate (q_r)		Average monthly volume of the pre-treated leachate introduced into the bioreactor, per mass unit of waste deposited in the bioreactor	1–1.9 dm^3/(Mg· month)	No requirements Recommendations
Matrix properties	Moisture content (MC)	Ratio of the weight of water contained in the waste sample to its total mass, expressed in the percentages by weight	40-70% of weight	No requirements Recommendations
	Loss of ignition (LOI)	Ratio of weight loss of air-dry waste mass during its ignition at 550°C to the weight of the initial sample, expressed in the percentages by weight	> 35% dry weight	Journal of Laws 2017 item 2490
	Total organic carbon content (TOC)	Share of carbon mass in organic compounds contained in the unit of mass of dry waste, expressed in the percentages by weight	>20% dry weight	Journal of Laws 2017 item 2490
Quality of recirculated leachate	$N\text{-}NH_4^+$ concentration (C_{NH4+})	Mass of nitrogen in the form of ammonium ions contained in the unit of volume of leachate fed to the bioreactor after initial purification	≤ 1,500 mg/dm^3	No requirements Recommendations
	Reaction (pH_r)	Value of negative logarithm of the concentration of hydrogen ions contained in the leachate introduced into the bioreactor, subjected to initial pre-treatment	pH 6.8 - 8.6	No requirements Recommendations
	Temperature (T_r)	Value of average daily temperature of the leachate subject to initial purification, introduced into the bioreactor	30 - 40°C	
ENVIRONMENTAL PARAMETERS				
Groundwater quality	Reaction (pH_w)	Value of negative logarithm of the concentration of H^+ in water	6.5-9.5	Journal of Laws 2016 item 85
	Electrical conductivity (EC)	Inverse value of the specific resistance of water sample, measured under specified conditions (measure of the concentration of dissolved substances)	≤ 2500 µS/cm	
	Concentration of total organic carbon (TOC_o)	Mass of carbon contained in organic compounds present in the unit of water volume	≤ 10 mg C/dm^3	
	Heavy metal content: copper (C_{Cu})	Mass of individual elements contained in the unit of water volume	≤0.2 mg/dm^3	
	Heavy metal content: zinc (C_{Zn})		≤ 1 mg/dm^3	
	Heavy metal content: lead (C_{Pb})		≤0.1 mg/dm^3	
	Heavy metal content: cadmium (C_{Cd})		≤0.005 mg/dm^3	
	Heavy metal content: chromium (C_{CrVI})		≤0.02 mg/dm^3	
	Heavy metal content: mercury (C_{Hg})		≤ 0.001 mg/dm^3	
	Content of polycyclic aromatic hydrocarbons (WWA)	Sum of hydrocarbon mass contained in the unit of water volume	≤ 0.0003 mg/dm^3	

3. Test and analysis design

3.1. Existing and new test data

The scope of all the data accepted for verification is presented in Table 3.1.

Table 3.1. Data accepted for verification

No.	Parameter	Test description	Test or measurement methods
		Accepted primary data	
1	Amount of waste deposited in sector 2 OBB *)	Weight measurement of each waste load in conformity with the internal instruction of weighbridge operator,	Gravimetric, Documented scale readings
2	Moisture (MC) of the waste	Samples taken from 12 wells of examined sector 2, from three depths (tested in three replications)	PN-EN 14346:2011
3	Total organic carbon content (TOC) in the waste	Samples taken from 8 wells of examined sector 2, from three depths (tested in three replications)	PN-EN 13137:2004
		Supplementary data	
4	Loss on ignition (LOI) of the waste	Samples taken from 5 wells of examined sector 2, from three depths (tested in three replications).	PN-EN 15169:2011 +Ap1:2012
5	Methane content (C_{CH4}) in biogas	Biogas inflow to the manifold unit for sector 2. Weekly and monthly means (and the uncertainty of the monthly mean)	Documented readings of gas analyser
6	Biogas production (B_{biogas})	Biogas inflow to the manifold unit for sector 2. Weekly and monthly means (and the uncertainty of the monthly mean)	Documented readings of gas flow meter
7	Leachate flow rate (q_r)	Leachate inflow into sector 2 bioreactor. Weekly and monthly means (and the uncertainty of the monthly mean)	Documented readings of leachate flow meter
8	Leachate N-NH_4^+ concentration (C_{NH4+})	Raw data for three in parallel taken samples from leachate inflow pipe. Monthly measurement.	PN-EN ISO 11732:2007
9	Leachate reaction (pH_r)	Raw data for three in parallel taken samples from leachate inflow pipe. Monthly measurement.	EN ISO 10523:2012
10	Leachate temperature (T_r)	Leachate inflow into sector 2 bioreactor. Thermometer readings. Monthly mean (and the uncertainty of the mean).	Documented meter readings
11	Groundwater reaction (pH_w)	Piezometers, 8 locations, two levels, analysis for three in parallel taken samples of groundwater.	EN ISO 10523:2012
12	Groundwater specific electrical conductivity (EC)	Piezometers, 8 locations (4 from subsurface and 4 from usable water-bearing horizon), Three quarterly analysis.	PN-EN 27888:1999
13	Concentration of total organic carbon (TOC_o) in groundwater	Piezometers, 8 locations (4 from subsurface and 4 from usable water-bearing horizon), Three quarterly analysis.	PN-EN 1484:1999
14	Content of heavy metals: copper (C_{Cu}), zinc (C_{Zn}), lead (C_{Pb}), cadmium (C_{Cd}), chromium (C_{CrVI}), and mercury (C_{Hg}) in groundwater	Piezometers, 8 locations (4 from subsurface and 4 from usable water-bearing horizon), Three quarterly analysis.	PN-EN ISO 11885: 2009 (Cu, Zn, Pb, Cd) PN-EN ISO 23913:2009 (CrVI) Accredited method KJ-I-5.4-274 (A),(NR) with pre-concentration (Hg)
15	Polycyclic aromatic hydrocarbons (PAHs) content in groundwater	Piezometers, 8 locations(4 from subsurface and 4 from usable water-bearing horizon, Three quarterly analysis. Tests according to accredited method KJ-I-5.4-97 (iv) (A) HPLC-FLD	Accredited method with use of liquid chromatography (HPLC-FLD)

*) these data (conditionally accepted for verification) were adopted on the basis of the audits performed on 18.09.2018 and 16.05.2019.

The data was obtained from several accredited testing bodies: SGS Polska Sp. z o.o. certificate No. AB1232, J.S. Hamilton Poland S.A. certificate nr AB079, Ośrodek Badań I Kontroli Środowiska Sp. z o.o certificate No. AB213 and non-accredited NOVAGO Sp.z o.o.

3.2. Laboratory or field conditions

Due to the specific character of verified technology, the testing period had been planned for 8 months to cover various meteorological conditions. Sampling, transport and storage of each type of the samples were conducted in accordance with the procedures of the accredited Testing Bodies and the relevant Test Plans.
The continuous measurement of methane content in the biogas, the biogas production, the leachate flow rate and the leachate temperature were done by NOVAGO, using measurement devices that are integral elements of ANABIOREC™ technology.

3.3. Matrix compositions

The mixture of four types of waste containing a biodegradable fraction: 19 12 12 – 127,082.74 Mg; 16 03 80 – 6.92 Mg; 20 01 08 – 17,322.24 Mg; 20 02 01 – 50.96 Mg deposited in the examined sector (OBB 2) of the bioreactor constituted the matrix. It underwent the examinations on moisture content, loss of ignition, and total organic carbon content, that were considered as operational parameters. The waste was deposited in the bioreactor gradually within one year (details given in para 2.3). The samples of the matrix for the analysis were collected in January 2018 and April 2018 (age of the waste was between 8 and 24 months). Biogas recovery was commenced in August 2018 (when the waste age was between 14 months to 2,5 years).

3.4. Test and analysis parameters

3.4.1 Performance parameters

Evaluation of the efficiency of the verified technology was based on the analysis of:

- ***methane content in biogas –*** measured parameter,
- ***the specific energy production rate of biogas –*** calculated parameter - calculation on the base of the measured data (biogas production and methane content in biogas) and the mass of the waste deposited in OBB 2 and calorific value of the methane. Values of both parameters were related to normal conditions (pressure 1013.25 hPa, temperature 273.15 K).

3.4.2. Operational parameters

The verification of the bioreactor's working conditions was referred to two groups of the parameters:

1) parameters of the matrix undergoing the anaerobic digestion inside the bioreactor, i.e
- ***moisture of the waste*** - measured parameter,
- ***organic matter content in the waste*** - measured parameter,
- ***total organic carbon content in the waste*** - measured parameter.

All these parameters were determined only once, before the start of degassing and leachate recirculation into the bioreactor.

2) operational parameters of the leachate recirculation system, i.e.
- ***the specific leachate loading rate*** of bioreactor – calculated parameter - calculation on the base of the measured data recirculated leachate flow rate and the mass of the waste deposited in OBB 2,
- ***concentration of ammonium ions*** in the leachate entering the bioreactor - measured parameter
- ***pH of leachate*** entering the bioreactor - measured parameter,
- ***temperature of leachate*** entering the bioreactor - measured parameter.

3.4.2. Environmental parameters

The verification of technology in terms of environmental impacts was referred to the groundwater parameters taken from piezometers located around the bioreactor, ie. pH, electrical conductivity, concentration of total organic carbon, concentration of heavy metals (copper, zinc, lead, cadmium, chromium, and mercury) and concentration of polycyclic aromatic hydrocarbons.

3.5. Tests and analysis methods summary

All methods of the test performance and the data analysis met the recommendations given in the Specific Verification Protocol. No. 1/WTSUnit /2018. Analytical methods used to determine the particular parameters of groundwater were compliant with the reference methods given in regulation on surface and ground water quality (Journal of Laws of 2016, item 1778). The summary of the methods and standards used for the verification is presented in Table 3.1.

3.6. Parameters measured

The parameters accepted for verification were measured by the accredited Test Bodies and NOVAGO Sp. z.o.o. that was approved as the Test Body by the Verification Body.

The parameters accepted for verification derived from:

1. TEST REPORT of NOVAGO of 21 June 2019 with data on:
   - methane content - performance parameter
   - specific energy production rate - performance parameter
   - specific leachate loading rate of bioreactor – operational parameter
   - leachate temperature - operational parameter
2. TEST REPORT of SGS Pszczyna of 20 February 2018 with data on:
   - moisture content of the waste - operational parameter
3. TEST REPORT of OBIKS of 19 April 2018 with data on:
   - loss of ignition (LOI) of the waste - operational parameter
4. TEST REPORT of J.S. HAMILTON of 20 February 2018 with data on:
   - total organic carbon content in the waste – operational parameter
5. TEST REPORT of SGS Pszczyna of 24 May 2019 with data on:
   - recirculated leachate quality parameters– operational parameters
   - groundwater quality parameters – environmental parameters

4. Verification results (performance, operational and environmental parameters)

Both, the performance and operational parameters claimed the values declared by the Proposer. In case of specific leachate loading (q_r) only the average value was in the declared range, and some measurements exceeded the upper limit. The high value of this parameter could be related to the "wet" season in which the measurements were done (autumn, winter and spring), what increased the amount of the leachate recirculated into the bioreactor.

Additionally, ***no negative effects of the technology on the groundwater quality*** were found during the testing period, taking into account the requirements given in Regulation of the Minister of the Environment of 21 December 2015.

Exceedance of total organic carbon (TOC) in groundwater does not indicate a negative impact of the verified technology on the environment, but it is associated with the high background level of TOC in the groundwater in the vicinity of the tested facility. According to data given in the Geological Documentation of September 2013, the concentration of TOC in the groundwater (measured on compliance with reference method) in the pre-operational phase of the bioreactor was 32.54 mg C/dm^3, which results from the presence of organic deposits with natural origin in the ground. Thus, the value of TOC_o is not significantly different than the background level of this parameter.

The results of verified performance and operational parameters are presented in Table 4.1.

Table 4.1. The verified performance and operational parameters

Parameters			Value	Unit	Verified value
PERFORMANCE	Methane content (C_{CH4})		≥ 45	% vol.	**55.29 ± 0.03**
	Specific energy production rate (ν_b)		≥ 16	MJ/(Mg_{waste}· month)	**17.93± 0.70**
OPERATIONAL	Specific leachate loading rate (q_r)		1–1.9	dm^3/(Mg· month)	**1.80 ± 0.32**
	Recirculated leachate quality	N-NH_4^+ concentration (C_{NH4+})	≤ 1500	mg/dm^3	**1204 ± 63**
		pH_r	6.8 - 8.6	-	**8.13 ± 0.02**
		Temperature (T_r)	30 - 40	°C	**32.05 ± 0.03**
	Matrix parameters	Moisture content (MC)	40-70	% of mass	**48.02±0.94**
		Loss of ignition (LOI)	> 35	% dry mass	**44.37±1.16**
		Total organic carbon (TOC_w)	>20	% dry mass	**23.15± 0.83**

The values of the verified parameters were given as means and expanded uncertainty U. The uncertainty was expanded at 95% confidence level (coverage factor k = 2), with a maximum error of estimation precision - 5%.

5. Additional information, including additional parameters

Additional parameters include mainly the information important from the viewpoint of the proper functioning of the bioreactor and cost of its performance. The data were collected and given by the Proposer. The determination of additional parameters based on the analysis of data from the meters that are the inherent part of the ANBIOREC™. According to the statement of the Proposer during the testing period 01/09/2018 - 30/04/2019, there was no excess of the effluent from the OBB which require discharge the sewage treatment plant as well as there was no necessity to supply the recirculation and leachate treatment system by additional water (tap or groundwater) and adjust pH of the leachate with reagent NaOH.

The electricity and heat which is given in the table (that correspond to the amount of the biogas chemical energy) refer only to the sector OBB 2. Contrarily, the data related to the pollutant emissions to the atmosphere concern emissions generated from all power generation units (CHP1, CHP2, steam boiler) in Różanki facility.

These data come from the report prepared for the Marshal of the Warmian-Masurian Voivodeship that contains the fee calculation for using the environment in 2018.

The proposer recommends the minimum mass of waste deposited in one sector above 50,000Mg.

Table 5.1. Additional parameters

Parameters	Unit	Value
Hydrogen sulfide (C_{H2S}) and oxygen (C_{O2}) concentration in biogas	ppm	C_{H2S} - 328±128
	% vol.	C_{O2} - 0.020±0.009
Climatic data: precipitation and temperature	mm	The monthly mean for the testing period: 48 mm Extremes: 2 mm and 94 mm
	°C	The monthly mean for the testing period: 5.0°C Extremes: -8°C and 19°C
Estimated energy balance only for sector 2 OBB, ΔE	MWh_{el}	1 197.580
	GJ	10 608.051
Pollutant emissions to the atmosphere from CHP	kg	Carbon oxide – 2515.34 kg Nitrous oxide (as NO_2) – 1103.86 kg Sulphur dioxide – 458.43 kg Dust from biogas combustion – 249.28 kg

6. Quality assurance and deviations

Conducted tests and verification met the quality requirements of General Verification Protocol Ver. 1.3. NOVAGO implemented a quality system to comply with the requirements of ISO 17025 in the area of testing activities. The compliance was checked by VB during two on-site audits and by submission of weekly reports. All other Testing Bodies were accredited in the scope of used testing methods. There were no important deviations during the verification.