

Operational Results of an Agricultural Biogas Plant Equipped with Modern Instrumentation and Automation

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INTRODUCTION

In this paper the authors will show and discuss details and operational results of a modern agricultural biogas plant (design value 500 kW_{el}) typical for many plants now being planned or under construction.

DESCRIPTION OF BIOGAS PLANT 'SBW LELBACH'

Key components

BP Lelbach consists of following key components: a silo for biosolids such as silage (12,000 m³), a storage tank for liquid manure (250 m³), one digester and one post-digester (1,700 m³ each), a digested slurry storage tank (5,000 m³) and a machine hall, in which one can find a control room, a switch cabinet, a dosage system for biosolids, a machine for washing/cutting of larger biosolids and a central heat and power generation unit (CHP).

Procedural principles

The biogas plant was designed according to following principles:

- Two-stage process with digester and post-digester to increase plant safety
- Simultaneous wet fermentation: 7.3-7.8 pH, 5-9% total suspended solids (TSS)
- Mesophilic conditions: approximately 40°C (i.e. 313K or 104°F)
- Hydraulic retention time (HRT): 60 days for efficient use of ensiled maize
- Automatic dosage system for biosolids: container (68 m³) with weighing machine, push-rod discharger and several vertical and horizontal screw-conveyors
- Central pumping station with automatically controlled slides
- Digester tanks are covered with membranes for collection and storage of biogas
- High level instrumentation and automation (see below)
- Aerobic hydrogen sulphide removal: in order to reduce H₂S (<250 ppm) in biogas, a little air (<0.5% O₂) is injected into the gas storage of digester and post-digester
- Enough reserve spaces, i.e. extension to 1,000-1,200 kW_{el} is easily possible

CHP unit

The utilization of biogas occurs in a CHP unit with a 16 cylinder gas engine and a synchronous electric generator. The gas engine (year of construction: 2004) can produce a maximum of 530 kW_{el} (efficiency: 35.6%) and 625 kW_{th} thermal heat (efficiency 45%). The electricity is fed into the local electricity network. The heat is used to heat digesters and machine hall (≈70k W_{th}). In order to increase energy efficiency as well as revenues several heat use concepts (HUC) were implemented: drying of wood chips (four mobile containers with 35 m³ each) and pieces of wood (one stationary container with ≈10 m³), and a prototype of a mobile latent heat storage unit. Depending on weather conditions and outside temperatures, it is possible to use between 350 and 430 kW_{th} by these HUCs.

Investment costs

The total investments costs amount to approximately 1.8 million € (without VAT), including the costs for the building site, site development and shovel loader for the transport of biosolids from the silo to the dosage system. The specific investments costs are 3,396 €/kW_{el} (inclusive HUC) or 3,100 €/kW_{el} (exclusive HUC). Operation of the plant requires «30hours per week.

Input substrates

In this plant biogas is produced using only agricultural products (manure, ensiled maize/green rye/sudan grass, grain, poultry excrements and sugar/fodder beets). [maize is the main source of organic dry mass, as indicated in Table 2]

Instrumentation, control and automation (ICA)

In contrast to most biogas plants, this plant is equipped with numerous online measurement devices (*Table 1, in full paper*), powerful programmable logic controllers (PLC) and a modern PC-based supervisory control and data acquisition (SCADA) system. Furthermore, it is possible to operate the plant via remote control. The system is also equipped with a digital process fieldbus. The data can be used for numerous different ICA applications, e.g. a virtually complete automatic balance of solid, fluid and gaseous material flows (volume, weight) is possible. The type of substrate can also be recorded. Energy balances (electricity, heat) can be calculated. A comparison of calculated and measured biogas/methane yields is possible. All this information is very important for controlling and benchmarking as well as for plant operation. The temperature, which is measured continuously in digester/post-digester, can be controlled by automatic control of the heating system. ORP, and pH and TSS are checked several times a day in the digester/post-digester, i.e. an overload situation can be recognised in time. The changing of the biogas composition and the biogas flow rate can also be used to avoid/identify critical operating conditions. The hydraulic retention time (HRT) can also be calculated automatically. In May 2007, a near infrared spectroscopy (NIRS) system (800-1,800 nm) was installed for research purposes. Such instruments are already in operation in the agribusiness (e.g. quality control) or in the chemical industry. In case of agricultural applications it is already possible to measure on-line and off-line concentrations of (organic) dry matter (DM/oDM), proteins, crude fibres as well as fat content by using NIRS. Due to the fact that these parameters are also very important for (agricultural) biogas plants, there is a good chance that full-scale biogas application (e.g. monitoring of input substrates) are also feasible in the near future.

INPUT SUBSTRATES AND ENERGY PRODUCTION

Between August 2006 and January 2007 following substrates had been used to produce biogas: 3,242 t cattle liquid manure (17.8 t/d, 4%DM), 335 t wheat/rye (1.8 t/d, 85% DM, 120 €/t), 5,108 t silage (28.1 t/d, 23-32% DM, 24 €/t). The silage used consisted of Sudanese grass (1%), green rye (27%) and maize (72%). The average dry matter concentration of the input mixture was 21.2%. Since end of January 2007 4 to 6 t/d sugar beets (23%DM, 25-30 €/t) are used in order to substitute wheat/rye. Based on these input substrates and the biogas/methane yields, which were published by KTBL (2006), the theoretical potential for electricity production is 1,945,015 kWh_{el} (Table 2). However, in reality 2,181,325 kWh_{el} (Average: 495 kWh_{el}/h) were produced. The fact that the energy production is 12% higher than the theoretical potential may result from KTBL values being based on lab experiments with shorter retention time (HRT: lab 28 days, plant >50-60 days).

Table 2. Energy balance (1 August 2006 to 31 January 2007); biogas yields (in standardised m³), published methane yields; conversions: gross energy = 10kWh/m³CH₄ and gas engine efficiency 35.5%; oDM = organic dry matter (or volatile solids) as % of total DM.

| Input | Weight (tonnes) | Biogas Yield (m ³ /t oDM) | Methane Yld (%) | DM (%) | oDM (%DM) | oDM (t) | Gross Electrical energy (kWh) | Transport Net Energy (Litres Diesel equiv.) |
|----------|-----------------|--------------------------------------|-----------------|--------|-----------|---------|-------------------------------|---|
| Manure | 3242 | 280 | 55 | 4 | 80 | 104 | 56,717 | 10,864 |
| Silage | 5108 | 600 | 52 | 28 | 96 | 1373 | 1,520,768 | 291,302 |
| Grain | 335 | 700 | 53 | 85 | 98 | 279 | 367,529 | 70,400 |
| Sum/Ave. | 8685 | | 53.2 | 21.2 | | 1756 | 1,945,015 | 372,566 |

[This table has had an extra column added, for nett transport energy]

This was calculated using the energy content conversion factor of 1 litre diesel fuel = 1 m³ CH₄. The nett calculation also assumes:

- (a): 15 % of methane energy is needed for power production for digester plant operation;
- (b): 20 % of methane fuel is used for purification and compression of biogas to vehicle fuel standard; and
- (c) the waste heat produced in (a) and (b) will cover all digester heating and electricity requirements.

FEEDING STRATEGY

High-level automation and the large container of the dosage system enables a quasi-continuous feeding of both digesters: 24times per day (for liquids as well as biosolids). The manure is pumped only into the digester, but in order to use both reactors efficiently the biosolids can be dosed into digester and post-digester. According to Table 2, the average organic dry mass (oDM) load is 9.5t/d. Under normal operating conditions, 70% of silage/grain is dosed into the digester, 30% into the post-digester. Sugar/fodder beets can be converted into biogas fast (<1week). So, to avoid an overload of digester (Figure 2), since March 2007, 70% of the beets are now dosed into the post-digester. The effective volume of both anaerobic reactors is 1,383 m³ each, i.e. average organic load ratio is 3.5 kg oDM/ (m³or.d). The organic load ratio in the digester is 5 kg oDM/(m³or.d). Approximately 6 m³ slurry are recirculated daily from the post-digester and/or slurry storage tank to reduce the total suspended solids (TSS) concentration. Despite the fact that the organic load rate in the digester is very high for agricultural biogas plants (Figure 2), concentrations of organic acids are unusually low (<1,000 mg/l), which is mainly caused by quasi-continuous feeding. Higher concentrations of organic acids could only be observed in autumn and beginning of winter 2006: The fresh silage in the silo was not covered watertight, i.e. the stormwater from the silos was highly polluted (grab sample of Dec. 21st 2006: pH 3.7, organic acids 17,430 mg/l, soluble COD 68,960 mg/l). This highly polluted rainwater was pumped into the liquid manure tank. Between Dec. 6th and Dec. 19th several hundred cubic metres of stormwater were pumped manually from the manure tank into the digester. Despite this serious malfunction, the average electricity production in Dec. 2006 was still 461 kW_{el}

because the load of the undisturbed post-digester was increased. Now, in the case of heavy stormwater events, the rainwater is pumped into the final storage tank and the silo was covered with plastic films. A small plant laboratory was retrofitted to measure important operating parameters (TSS, sum of organic acids, NH₄-N and acid capacity) regularly. This case is a good example that permanent monitoring is very important for stable and efficient plant operation.

OPERATIONAL DATA

TSS/DM concentration

The average values for total suspended solids (TSS) concentration in the digester was 7.68%, in the post-digester 6.19% TSS [*this results from a dilution of the DM in the feedstocks*]. The average DM concentration in the input mixture is 21.2%. The degree of degradation based on oDM is 76.9%. In this regard, one should bear in mind that between 20 and 35% of the dry matter of ensiled maize/green rye/Sudanese grass is lignin, which is indigestible by microbial enzymes.

Energy balance

The total net energy efficiency (heat and electricity) is 60.6%. Thus this plant is a good example that decentralized energy concepts can reach higher energy efficiencies than centralized large-scale powerplants (e.g. coal-fired power stations: 43%). In this context one has to take into consideration that the newest generation of small gas engines (<1,000kW) can reach electrical efficiencies up to 42% (instead of 30-36%). Hence the total energy efficiency of similar plants, which will be built in 2007/2008 will be higher (>65%)

Biogas liquid manure

The second end product, the biogas manure (TSS≈6%) has very good fertilizer quality (pH: 7.7, TN: 3.4kg/t, NH₄-N: 2.1kg/t, P₂₀₅: 1.6kg/t, K₂O: 4.4kg/t). The odour of biogas manure is much less intense than that of fresh liquid manure because VFA are converted into biogas. Hence, the regional demand for biogas liquid manure is high.

Table 3. Operational key data of BP Lelbach (182 days, Aug. 2006 to January 2007); (abbreviations: a = average, m = median, r = range)

| Operational key data | Unit | Value | Benchmark |
|---|---|-------|-------------------|
| Electricity production into input ratio | kWh/t _{input} | 251 | 53-570 r, 150 m |
| Electricity demand (biogas plant) | % | 7.7 | 3-14 r, 8 a |
| Electricity production to biogas ratio | kWh/m ³ _{Biogas} | 2.08 | 1.4-2.4 r |
| Methane production to effective reactor volume | m ³ _{CH₄} /(m ³ _{Rd}) | 1.21 | 0.3-1.1 r, 0.74 a |
| Effective reactor volume to power (installed) ratio | M ³ _R /kW _{el} | 5.22 | 3.5–22 r |
| Degree of engine utilization | % | 93.4 | 62.0 a |
| Investment costs per kW (excl. heat use conc.) | €/kW _{el} | 3,100 | 3,160 a |
| Degree of degradation | % | 76.9 | 61.5 a |

Operational key data

Table 3 shows some operational key data of BP Lelbach and comparable values from two different benchmark studies:

- Hesse (2006): A study of the Hesse ministry for environment about 16 biogas plants, which were built in Hesse between 1996 and 2002.
- FNR (2005): A study (59 plants) published in 2005 by the agency for renewable resources (FNR), a subsidiary of the German ministry for education and research.

Table 3 shows that the operational results of BP Lelbach are very good, especially because of the fact that the biogas yield of maize and manure is (much) lower than that of organic residues (e.g. grease, glycerine), which are used in many biogas plants. For example, the gas engine utilization is very high (93.4%). Due to the small fraction of manure (37% of input mass), the effective reactor volume is lower than usual.

CONCLUSION AND OUTLOOK

The example “BP Lelbach” shows that agricultural biogas plants equipped with modern ICA equipment and reliable/adapted machineries and engines, can reach very good operational results. With engine efficiencies of >60% modern biogas plants can produce base load electricity/heat and can be an alternative to large centralized power plants. E.g. by using modern automation and telecommunication equipment it is possible to connect numerous biogas plants into one virtual large-scale power plant. Due to the fact that biogas can be stored biogas plants can also produce peak load energy. Thus, biogas plants are an ideal complement to other renewable energies, which cannot produce peak and base load (e.g. solar cells, wind turbines). Furthermore, the production of biogas leads also to an increase of the agricultural value-added chain and– as a regional energy resource– to an increase of supply security. Thus, agricultural biogas plants are very interesting investments for rural areas as well as countries with deficiencies in their energy infrastructure.

Reference

Lens P, Hamelers B, Hoitink H & Bidlingmaier W (Editors) 2004. *Resource Recovery and Reuse in Organic Solid Waste Management, Integrated Environmental Technology Series*. ISBN 1-84339-054-X, IWA Publishing, UK.

[other German references in full paper]