Simone Besgen and Peter Schulze Lammers, Bonn, as well as Karl Kempkens, Köln

Energy and Substance Conversion in Biogas Plants

Results of Technical Measurement Examinations from Agricultural Biogas Plants

Biogas plants increasingly generate energy from various waste substrates. Slurry, supplemented with various co-substrates, is the basic substrate used in four newly constructed biogas plants on farms, which had livestock prior to the measuring period. The biogas digesters were equipped with instrumentation to record data on power generation, capacity utilization, internal energy consumption and substrate consumption. Two plants were provided with gas flow gauges, to record gas production from the secondary fermenters.

Dr. Simone Besgen was employee of the Chamber of Agriculture, Northrhine-Westphalia and doctoral candidate at the Institute of Agricultural Engineering of Bonn University; e-mail: *Simone.Besgen@web.de*.
Dr. Karl Kempkens is Head of the unit Organic Agriculture und Horticulture of the Chamber of Agriculture, Northrhine-Westphalia; Centre for Organic Farming, Gartenstr. 11, 50765 Köln-Auweiler
Prof. Dr. Peter Schulze-Lammers heads the Section System Engineering in Plant Production at the Institute of Agricultural Engineering of Bonn University; Nussallee 5, 53115 Bonn

Keywords

Renewable energy, biogas, secondary fermenter, co-substrate

Literature

Literature references can be called up under LT 07101 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

The motivation for this examination was the fact that only few data or mainly data from laboratory experiments existed in the field of biogas technology. Within a period of three years, procedural data from four agricultural biogas plants were gathered. Extensive measurement technology was installed in the plants that utilise farmyard manure as well as renewable resources and organic residues. On the one hand, the examinations comprised measurements of gas yield, energy efficiency and energy usage; on the other hand, a process analysis was made. The aim of the process analysis was the examination of parameters concerning the stability of the fermentation process and the substrate's compounds. The results make up planning criteria for the design and construction of biogas plants.

Description of the plants and instrumentation for the collection of data

Table 1 introduces the plants and the respective farms. The facilities are composed of standing containers operated as a continuous flow system within a mesophilic temperature range. The secondary fermenters are furnished with gas-tight foil gasholders.

Methodology

Figure 1 shows the measurement concept of the plants. The single measuring devices are connected to data loggers, which recorded, read and analysed the data. The manure feed and – in the case of plant 1 – the feed of liquid co-substrates can be monitored with the help of inductive flow meters. The amount of solid co-substrate can be measured with weigh bars installed at the dosage unit for solids. This procedure is necessary to determine the gas yield of the various co-substrates and the daily substrate feed.

The methane concentration of the biogas was gauged three times per day with infrared gas analysers. Moreover, the methane content was quantified at intervals of 20 minutes within the period from the end of 2003 till the middle of 2004. The following components were examined in the gas analyses:

- Methane in % (± 2 % accuracy of measurement; infrared sensors)
- Hydrogen sulphide in ppm (± 5 % accuracy of measurement; electrochemical)
- Oxygen in % (± 0.5 % accuracy of measurement; electrochemical)

Prerequisite for the measurement of the gas yield in the secondary fermenter is a se-

Table 1: Description of the biogas plants and the farms

Biogas plant	plant 1	plant 2	plant 3	plant 4
Husbandry				
Kind of animals	dairy cows	pigs/dairy cows	dairy cows	pigs
LUs	214	349	300	159
Technology of substrate feeding				
liquide co-substrates	50 m³ tank	pre-pit	manure storage	pre-pit
solid co--substrates	pump	plunger	mixer	plunger
Container volume				
fermenter netto [m³]	610	905 (concr. cover)	905 (concr. cover)	571
sec. ferm. netto [m³]	1182 (heated)	1100	2500	905 (heated)
Energy production/use				
BHKW [kW_{el}]	2•100	2•100	2•80	2•100
Heat use	heating house	heating house	heating houses (6)	stable heating, houses (2)

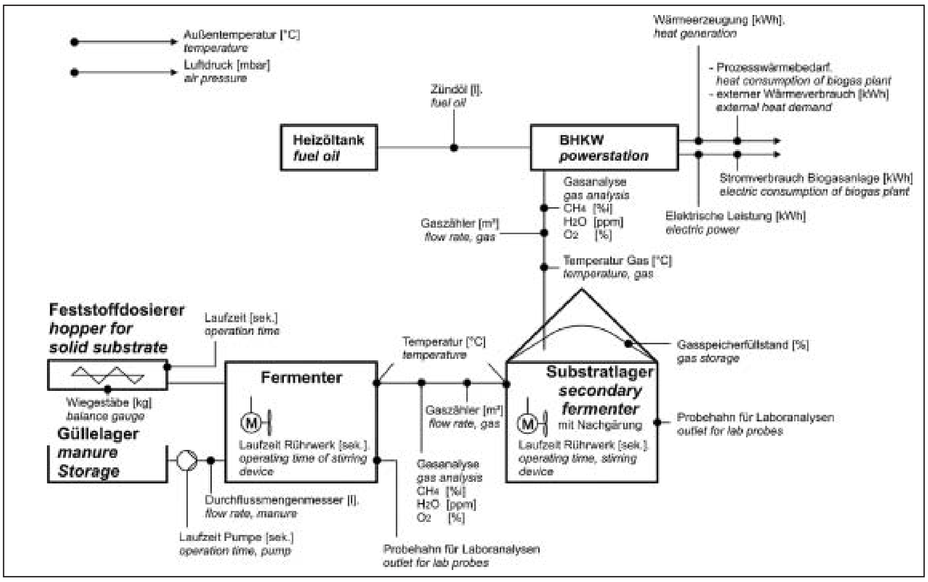

Fig. 1: Scheme of instrumentation of the plants 2 and 3 (fermenter with concrete cover)

parate recording of the amount of biogas in the fermenter and in the secondary fermenter, respectively. This is only possible with closed fermenters (with a concrete ceiling). In this case, the biogas can be conducted to the secondary fermenter's gasholder via a gas pipe.

The mean ($\bar{x}$) and the coefficient of variation (V) are displayed as values for the descriptive statistical calculations of the recorded data.

Presentation and Discussion of Results

Biogas production and quality

Plant 3 showed the smallest rate of gas production (1,642 m^3/d), because it is supplied with an electrical power of only 160 kW_{el}, while plants 1, 2 and 4 are furnished with 200 kW_{el} each, hence the bigger total amount of gas yield of 1,813 up to 1,941 m^3/d. It has to be taken into consideration that the gas consumption is also effected by the quantity of used fuel oil for the ignition system of the engine.

Gas quality

The average methane content in all four plants was 57% (52.3 % to 59.7 %). The mean hydrogen sulphide content amounts to 259 ppm (143 to 358 ppm).

Biogas formation in the secondary fermenter

In plants 2 and 3 it was possible to separately determine the biogas production in the fermenter and in the secondary fermenter. Within the period between 20th of May and 19th of August 2003, 195,514 m^3 were produced altogether. A share of 132,236 m^3 of this amount was gauged directly behind the fermenter (residence time: 38.4 days). The difference of 63,278 m^3 was accordingly ascribed to the secondary fermenter (residence time: 46.7 days). Hence, the gas production in the secondary fermenter constitutes 32.4 % of the overall gas synthesis. The gas yield from the secondary fermenter amounted to 32.2 %. This value was found to be very high in comparison to the cited literature, where yields of only 10 % to 20 % are reported about.

Generation and consumption of electricity and operating time of the block-type combined heat and power units (CPU)

Table 2 depicts the plants' electricity generation per day and the resulting calculated capacity utilization. Concerning the utilization of the eight CPU's, an average of 95 % was determined, with a coefficient of variation of 4.8 %. Thus, all plants achieved a very good utilisation of the installed power. The result of power station 2 is due to an excess capacity. The four plants consumed an average of 157.9 kWh_{el}/d, which equals 3.7 % of the generated electrical energy.

Analyses of substrates

The pH-value of the plants averages out at 7.7, the dry matter contents at 6.2 % and the organic dry matter contents at 44.5 kg/m^3.

Residence time

Table 3 displays the average residence times of the substrates in the respective fermenters. The residence times depend on the quantity of substrate feed as well as on the volume of the fermenters.

Nutrients in the secondary fermenter

Nutrient contents in the secondary fermenter are influenced by the substrate input. The value for total nitrogen amounts to an average of 4.3 kg/m^3, with a coefficient of variation as small as 3.5 %. The proportion of ammonium (NH_4) made up 2.3 kg/m^3, while the coefficient of variation of 4.6 % showed to be similarly small as that of total nitrogen. Data from FNR result in a mean value of 3.69 kg ammonium per m^3. As regards phosphorus, the average content is 1.5 kg/m^3 and the coefficient of variation is 10.3 %. Results for potassium summed up to 3.4 kg/m^3 in plants 1 and 4, to 4.2 kg/m^3 in plant 3 and to 4.5 kg/m^3 in plant 2.

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TTable 2: Average electricity generation and consumption, operating hours and utilization of all CHP's CHP power station; $\bar{x}$: mean value; V: coefficient of variance

	plant 1 (2•100 kW_{el})		**plant 2** (2•100 kW_{el})		**plant 3** (2•80 kW_{el})		**plant 4** (2•100 kW_{el})		$\bar{x}_{1,2,3...8}$	$V_{1,2,3...8}$
CHP	1	2	1	2	1	2	1	2		
energy production [kWh_{el}/d]	2261	2475	2286	2155	1708	1847	2367	2276	2172	12,1
energy consumption [kWh_{el}/d]	250,4		111,1		185,1		86,0		157,9	36,5
operating hours [h/a]	8252	9032	8348	7867	7796	8427	8637	8305	8333	4,2
utilization [%]	94,2	103,1	95,3	89,8	89	96,2	98,6	94,8	95,1	4,8

Plant	**1[d]**	**2 [d]**	**3 [d]**	**4 [d]** (2BHKW)	**4 [d]** (3 BHKW)
Fermenter	30,6	33,7	41,7	18,6	14,4
Sec. fermenter	59,4	41,0	115,2	29,5	22,8
Final storage	64,1				
Total	154,1	74,7	156,9	48,1	37,2

Table 3: Retention times of substrates in the facilities