PROCESS CONTROL AND FLUXES OF MEDIUM SIZE AGRICULTURAL BIOGAS PLANTS MANAGEMENT AT AMBIENT TEMPERATURE: A CASE STUDY IN BEIJING

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1 INTRODUCTION

In China, more than 4000 middle and large scale biogas plants are operated. It is widely used to reduce the environmental pollution from animal wastes and to produce energy (Zhang et al., 2009).

Many Chinese agricultural biogas plants are operated at the lower range of the mesophilic temperature range and a minimum temperature around 20°C is kept during winter. In this case, the plant is heated with external energy sources e.g. coal. In summer, the temperature in the plant depends on ambient temperature. This operation mode is different as compared to biogas plants in Europe where the temperature is kept around 37-39°C all over the year.

The objective of this work was to evaluate the performance of a Chinese biogas plant on a pig farm operated with pig excrements at low temperatures, regarding mass balance (oDM input, oDMoutput and biogas out).

2 MATERIALS AND METHODS

2.1 Manure system on the farm

The pig farm which has 8000 pigs is located in the Shunyi district of Beijing. For manure management, the "Ganqingfen" is in operation: The solid pig manure in the barn is collected separately by manpower. Then water is used to flush the floor of the barn.

2.2 Biogas plant

The continuous biogas plant is a complete stirred reactor with a volume of 1000m^3 is located on the farm. It has been running for 3 years since 2006. The plant consists of four digesters (D1-D4) with a horizontal agitator in each digester. Each of them has a volume of 250 m³. Temperature is monitored with a thermometer submerged in the liquid phase. The solid pig manure and slurry produced by barn flushing are mixed and fed into the four digesters via a mixing and feeding pump. Around 400-600kg per day pig manure is fed to the fermenters D1 and D2 additionally and directly. The produced biogas is fed into a micro gas grid and used in households for cooking and heating. The feeding operation of the plant is heat demand driven. In summer, the input into the biogas plant is reduced as the biogas demand is lower as compared to the winter season. In this case, the non treated and surplus pig manure is composted.

2.3 Methodology

An analyzing campaign was conducted in summer, in June and July of 2009, for 49 days. The fluxes of organic dry matter into and out of the biogas plant (oDM in, oDM out, biogas out) were analyzed. The mass flow and conversion of oDM into biogas were calculated using equation (1) and (2). Additionally the produced biogas volume in standard temperature and pressure was calculated using equation 4 and 5.

$$oDM_{input} = oDM_{output} = oDM_{CH_4+CO_2} + oDM_{effluent} + oDM_{sedimentation} \quad (1)$$

$$\mathrm{E}fficiency = \frac{oDM_{CH_4+CO_2}}{oDM_{input}} \quad (2)$$

The hydraulic retention time (HRT) was estimated by equation (3):

$$HRT = \frac{1000 \times 49}{\sum_{i=1}^{49} V_i} \qquad (3)$$

where 1000 is the volume of biogas plant (m^3), 49 is the duration of measurement in days, V_i is the daily feeding volume (m^3), i is the time (days).

$$V_0 = V + \frac{T_0}{T} \cdot \frac{p - p_w}{p} \qquad (4)$$

where V is measured gas volume (L), V_0 is gas volume in stardard tempareture and pressure, p is gas pressure (mbar), p_W is vapor pressure (mbar) related to gas temperature in the fermenter, T is gas temperature (K), T_0 is normal temperature (273.15 K).

The vapor pressure can be calculated using the equation 5:

$$p_w = 6.11213 \cdot e^{\frac{(17.5043 T_c)}{(241.2 + T_c)}} \qquad (5)$$

where p_w is vapor pressure (mbar), T_c is gas temperature in °C

2.4 Sampling procedure and Parameters

The influent (slurry and manure) and effluent of the biogas plant were sampled daily, respectively. The total inorganic carbon (TIC) and volatile fatty acid (VFA) were analyzed by titration (Rieger, 2006) daily in the first week (intensive sampling week) and once a week in the following 6 weeks. A volumetric method was used to determine the alkalinity in the effluent at the same time.

pH, Electrical Conductivity (EC), Dry matter (DM), organic dry matter (ODM) of the samples were measured every day. Biogas quality was measured by mobile analyzer for biogas (Eheim Visit 03, Messtechnik EHEIM GmbH) was measured daily in the first week and once a week in the following weeks. Gas quantities are given at norm conditions (T=273 K and 1013 mbar). Biogas quantity was recorded by the installed gas meter daily. The feeding volume of the influent was estimated by measuring the pumping interval and the pump rate. The pump with a rate of 0.7m^3 min^{-1} was determined in a separate experiment. The amount of solid manure fed into the plant was estimated by the volume and the density of the material.

2.5 Biogas potential

The biogas potential of three types of manure from the farm, sow, fattening and weaner, was analysed in 5L plastic batch reactors at 37°C and 20°C, respectively. 300g fresh solid manure were mixed with 3L effluent from the biogas plant as inoculum and stirred. A control with 3L effluent only was used to determine the gas production from the inoculum. Each treatment was triplicated. Accumulated biogas and methane production were measured (Eheim Visit 03, gas meter LMF-1). The slurry was a mixture of the different manures and flushing water. For our calculations, we assumed the slurry consists of same aliquots of the three manures (sow, fattening and weaner).

3 RESULTS AND DISCUSSION

The average temperature in the fermenter of the biogas plant increased with the ambient temperature from 23.4 to 26.5°C during seven weeks. In average, the input had a pH of 6.8, and the effluent had a pH of 7.3 indicating a degradation of VFA.

The concentration of TIC and VFA ranged from 3740 to 5780 mg $CaCO_3$ L^{-1} and 300 to 755 mg L^{-1}, respectively. During the seven weeks, the VFA/TIC ratio fluctuated between 0.04-0.16 which is much less than 0.3, a threshold that indicates for a regular performance of the anaerobic process (WRC, 1992).

3.1 Mass flow and efficiency estimation

The overall input was 17 570 kg oDM during seven weeks. The output was 19 430 kg oDM, of those the amount of biogas was 12 890 kg oDM (TABLE 1). The overall efficiency was calculated according to equation (1) and (2) and was either 68% or 73%. The HRT was 35 days.

Because only the overall biogas production of the biogas plant could be measured, the efficiency of each single digester could not be calculated.

TABLE 1 **Mass flow of the biogas plant in seven weeks**

Input	Mass kg oDM	**Output**	Mass kg oDM
Slurry	8 750	Biogas	12 890
Solid manure fed to D1 and D2	7 395	effluent	6 180
Solid manure fed to D3 and D4	1 425	Sedimentation[a]	0
	Sum: 17 570		Sum:19070
	biogas efficiency: 73%		biogas efficiency: 68%
Estimated organic loading rate (OLR) kg oDM m^{-3} d^{-1}	F1 and F2 0.5		F3 and F4 0.2

a: sedimentation was assumed as 0, because no sedimentation has been discharged since 2006.

The biogas plant performed rather well at low organic loading rates at ambient temperature. These findings go along with the results from Wellinger & Kaufmann (1982). They operated two full-scale, unheated, batch-fed digesters (accumulation systems) in Switzerland. The systems proved to be an economically viable alternative to mesophilic continuous-flow digesters. Daily gas production approached net energy values known for fermenters operating at 35°C.

The demand driven operation hasn't affected the performance of the biogas plant at low temperature. Experimental results from Massé et al. (1996) also indicated that intermittent feeding did not affect performance during anaerobic digestion of swine manure slurry at 20°C.

Sutter and Wellinger (1988) reported that the gross biogas production by a digester operating at 20°C and at retention time of 40–50 days is comparable to a digester operating at mesophilic temperature but at half the retention time. This result cohered with the estimated longer HRT of 35 days. Similar result was reported by Sigh et al. (1995).

3.2 Evaluation of estimation results

Interestingly, the estimated methane production (6540m^3) on the plant was higher as compared to the methane production analyzed in the batch experiments. At 37°C the methane production (5502m^3) was 17%, and at 20°C (4810m^3) 28% lower, respectively (TABLE 2). Reasons may be (i) an error in the determination of mass fluxes on the farm: the input into the fermenter was estimated using the time the pump fed substrate into the fermenter and its pumping capacity. The output of the fermenter was estimated by the volume of output material measured by buckets. (ii) sediment in the biogas plant that contributed to the biogas production on the farm. In this study, the sedimentation was assumed zero because the operators did not have any sedimentation problem during the three year operation (iii) the stimulation of biogas production by a mixed substrate compared to the batch experiments where the single substrates were tested and not mixtures.

TABLE 2 **Calculated methane production on the base of methane yields from batch tests at 37°C and 20°C**

	Input kg ODM	CH_4 potential m^3 CH_4/kg ODM	CH_4 production m^3	CH_4 potential m^3 CH_4/kg ODM	CH_4 production m^3
		20 °C		37 °C	
		oDM in solid fraction			
sow	1630	0.22	359	0.29	473
fattening	910	0.23	209	0.26	237
piglet	6280	0.27	1696	0.29	1821
Sum	8820		2264		2531
		oDM in slurry			
Calculated using output data	10250	0.24	2460	0.28	2870

Overall calculated methane production	4724	5401
Measured methane production of the biogas plant	6540	

4 CONCLUSIONS

Biogas plants with low loading rates are very stable and don´t need intensive process control. And intermittent feeding will not affect the efficiency of them.

The microbial community in the biogas plant seems to be adapted well to temperatures below the optimum temperature in the mesophilic range. Perhaps the microorganisms are adapted in the three years of operation to changing and rather low temperatures.

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REFERENCES

Massé DI, Patni NK, Droste RL, Kennedy KJ 1996. Operation strategies for psychrophilic anaerobic digestion of swine manure slurry in sequencing batch reactors. Canadian Journal of Civil Engineering 23, 1285-1294.

Rieger C, Weiland P 2006. Prozessstörungen frühzeitig erkennen. Biogas Journal 4, 18-20.

Singh L, Maurya MS, Ramana KV, Alam SI 1995. Production of biogas from night soil at psychrophilic temperature. Bioresource Technology. 53, 147-149.

Sutter K, Wellinger A 1988. The ACF system: a new low temperature biogas digester. In: Welte, E., Szabolcs, I. (Eds.), Agricultural Waste Management and Environment Protection, Proceedings 4th International Symposium of CIEC, pp. 61-70.

Weilinger A, Kaufmann R 1982. Psychrophilic methane production from pig manure. Process Biochemistry. 17, 26-30.

WRC 1992. Anaerobic digestion of waste-water sludge: operating guide. Water Research Commission Project No, 390, Pretoria, South Africa.

Zhang PD, Yang YL, Tian YS, Yang XT, Zhang YK, Zheng YH, Wang LS 2009. Bioenergy industries development in China: Dilemma and solution. Renewable and Sustainable Energy Reviews 13 (9), 2571-2579.