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Biogas from manure – a new technology to close the nutrient and energy circuit on-farm

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Abstract

The Biodynamic Research Institute in Järna developed a two-phase on-farm biogas plant. The plant digests manure of dairy cattle and organic residues originating from the farm and the surrounding food processing units containing 17.7-19.6 % total solids. A new technology for continuously filling and discharging the hydrolysis reactor was developed and implemented. The output of the hydrolysis reactor is separated into a solid and liquid fraction. The solid fraction is composted. The liquid fraction is further digested in a methane reactor and the effluent used as liquid fertiliser. Initial results show that anaerobic digestion followed by aerobic composting of the solid fraction improves the nutrient balance of the farm compared to mere aerobic composting. Composted solid fraction and effluent together contain about 70.8 % of total input nitrogen and 93.3 % of input NH4. The manure that was merely aerobic digested contained about 51.3 % of total input nitrogen and 3.9 % of input NH4. Additionally anaerobic digestion improves the energy balance of the farm producing up to 269 l biogas kg^{-1} volatile solids or 1.7 kWh heat kg^{-1} volatile solids.

Keywords: biogas, compost, nutrients, carbon, anaerobic digestion

Introduction

During the last decade some so called ‘dry fermentation’ prototype plants were developed for anaerobic digestion of organic material containing 15-50 % total solids (Hoffman, 2001). These plants show added advantages compared to slurry digestion plants: Less reactor volume, less process energy, less transport capacity, less odour emissions. However on-farm dry fermentation plants are not common and rarely commercially available. We assume that lack of tested technical solutions, difficult and time-consuming feeding and discharging, and scarceness of on-site research results are the main reason for low acceptance of dry fermentation technology. Recent on-farm research (Kusch & Oechsner, 2004) and prototype research (Linke, 2004) show promising technical solutions for dry fermentation batch reactors on-farm. This paper reports about an innovative two phase prototype biogas plant. The plant digests continuously manure of dairy cattle and organic residues of the farm and the surrounding food processing units. The two phase reactor technology was chosen for two reasons: First it offers the separation of a solid and a liquid fraction for composting after hydrolysis and secondly the methanisation of the liquid fraction using fixed film technology results in a very short hydraulic retention time, reduction in reactor volume, and higher methane content of the biogas (Lo et al., 1984).

Material and methods

Process A: Manure of a dairy stanchion barn with 65 adult bovine units is shifted by a hydraulic powered scraper into the feeder channel of the hydrolysis reactor. The urine is separated in the barn via a perforated scraper floor. The manure is a mixture of faeces, straw and oat husks. Figure 1 shows the material flow of the biogas plant at the Ytterenby farm.

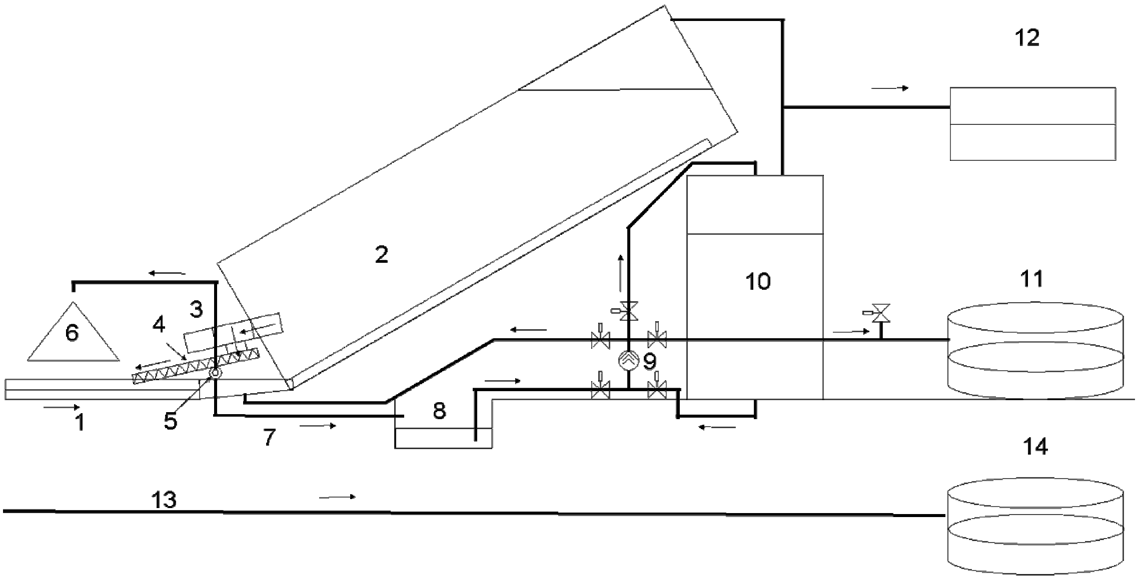

Figure 1. Material flow of the biogas plant at the Yttereneby farm in Järna. 1 feeder channel; 2 hydrolysis reactor; 3 drawer; 4 transport screw; 5 extruder screw; 6 solid fraction; 7 liquid fraction; 8 buffer; 9 screw pump and valves; 10 methane reactor; 11 effluent store; 12 gas sack; 13 urine pipe; 14 urine store

From the feeder channel the manure is pressed via a 400 mm wide feeder pipe to the top of the 30° inclined hydrolysis reactor of 53 m^3 capacity. The manure mixes itself with the substrate sinking down by gravity force. After a hydraulic retention time of about 26 days at 38 °C, the substrate is discharged by a bottomless drawer from the lower part of the reactor. Every drawer cycle removes about 100 l substrate from the hydrolysis reactor to be discharged into the transport screw underneath. From the transport screw the substrate partly drops into a down crossing extruder screw where it is separated into solid and liquid fractions. The remaining material is conveyed back to the feeder channel and inoculated into the fresh manure. The solid fraction from the extruder screw is stored at the dung yard for composting. The liquid fraction is collected into a buffer and from there pumped into the methane reactor with 17 m^3 capacity. Liquid from the buffer and from the methane reactor partly returns into the feeder pipe to improve the flow ability. After a hydraulic retention time of 16 days at 38 °C the effluent is pumped into a slurry store covered by a floating canvas. The gas generated by both reactors is stored in a sack and fed by a compressor to the process heater and the furnace of the estate for heating purposes. We took samples on 3.3.2004 and 6.5.2004 from the input manure, solid fraction, effluent, straw, and oat husks. Total solids and nutrient content was analysed by HS Miljölab Ltd. in Kalmar, Sweden and Novalab Ltd. in Karkkila, Finland. Volatile solids were analysed at the laboratory of MTT/Vakola by heating samples for 3 h at 550 °C. The gas yield of each reactor was measured by a gas meter (Actaris G6 RF1) and the reading was daily recorded. CO2-content of the biogas was measured once by falling out soda in soda lye.

Process B: For the compost trials (10.5.2004-13.8.2004) samples of 50 l manure and 50 l solid fraction from the hydrolysis reactor were aerobically digested at 15 °C in the climate chamber of MTT/Vakola. During the trial period the samples were turned three times and 1.3 l water was added.

Results

Between 15.11.2003 and 8.5.2004 the plant generated 44 m3 biogas d-1 or 283 kWh heat d^{-1} that corresponds to 84 l methane kg^{-1} volatile solids. Mass and nutrient balance is shown in table 1.

Table 1. Mass and nutrient balance of the biogas plant at Yttereneby in Järna. FM Fresh mass; VS volatile solids; Norg organic nitrogen; Nsol soluble nitrogen; Ntot total nitrogen

	FM	VS	N_{org}	N_{sol}	N_{tot}	NH_4	NO_3, NO_2	K	P
	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}	kg d^{-1}
Faeces	1717	99			8.29			6.06	2.01
Straw	27	23			0.14			0.61	0.04
Oat husks	257	218	0.55	0.02	0.56		0.018	1.13	0.20
Sum input	2000	340	7.36	1.64	9.00	1.34	0.242	7.80	2.25
Process A: anaerobic digestion of 2000 kg d^{-1} manure									
Solid fraction	919	243	3.26	0.69	3.95	0.63	0.056	2.85	0.76
Liquid fraction	1025	41	2.15	1.44	3.79	1.23	0.205	3.49	0.81
CO_2	34								
CH_4	20.8								
Vapour	1.15								
Sum output	2000	284	5.41	2.13	7.74	1.86	0.261	6.33	1.57
Compost of solid fraction	398	96	2.51	0.04	2.55	0.02	0.020	2.89	0.64
Compost and effluent	1424	137	4.66	1.48	6.34	1.25	0.225	6.37	1.45
Losses	576	203	2.70	0.16	2.66	0.09	0.017	1.43	0.80
Process B: aerobic compost of 2000 kg d^{-1} manure									
Compost	872	160	4.51	0.11	4.62	0.05	0.061	5.93	1.74
Losses	1128	180	2.85	1.53	4.38	1.29	0.181	1.87	0.51

More than 70 % of the volatile solids originate from oat husks and straw. About 70 % of the total solids of the manure remained in the solid fraction and after composting the solid fraction we measured about 38 % overall dry matter losses in process A. In contrast, during process B, up to 47 % of total solids in the manure escaped into the atmosphere. Carbon losses of processes A were about 47 % of which 14 % were bound in the biogas but more than 57 % in process B. Total nitrogen losses exceeded 48 % in process B and more than 29 % in process A. Similar values we found for NH4 and NOx: 6 % losses in process A versus 96 % in process B and 7 % versus 74 % respectively. Potassium and phosphorus losses in both processes ranged between 18 % and 36 %.

Discussion

The biogas yield measured is in accordance with common slurry biogas plants on-farm although the biogas production potential measured in laboratory is up to three times higher (Lo, 1998, Linke, 2004, Møller et al., 2004). Nitrogen losses are reduced compared to mere aerobic digestion, a fact that is known also from slurry biogas plants (Möller, 2003). Further the prototype biogas plant in Järna provides good compost. Additionally anaerobic digestion improves the energy balance of the farm. The results cannot yet be statistically confirmed because there are up to now mean values of only two measuring days on-farm available.

Conclusions

Anaerobic digestion of manure and organic residues followed by composting the dry fraction of the hydrolysis reactor improves the energy and nutrient balance on-farm. Appropriate new technology as used at the prototype biogas plant in Järna is a key factor. To confirm the present results more measurements are necessary. The optimisation of the plant in respect of hydraulic retention time and load rate may lead to higher gas generation but requires an improved measuring technique. Thereafter an economic evaluation is necessary to assess the competitiveness of the new technology.

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