Biogas production in agriculture: safety guidelines, cofermentation and emissions from combined heat and power couplings

Production de biogaz en agriculture : recommandations de sécurité, cofermentation et émissions issues du couplage chaleur et puissance.

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Abstract

Biogas production is an effective means for improving the efficiency of slurry utilisation. It has several positive effects : energy gaining from a renewable source, reducing of methane emissions during slurry storage, improving the nitrogen availability after spreading of the slurry.

The number of agricultural biogas plants increases continuously. There is a shortage of documets for constructing biogas plants and of saftey guidelines. At the moment there are no standardized guidelines available for planning and building of biogas plants. Those guidelines would be necessary to guarantee a saftey operation and cost effective building of biogas plants as well as for authorizing procedures. The ILUET is developing technical standards for the different components of biogas plants. Those standards are currently realized on several farms.

The cofermentation of agricultural wastes together with non agricultural wastes is of growing interest, because the conditions for biogas production and cofermentation have recently improved. There is little knowledge on the influence of composition of the organic wastes, of the relation from organic wastes to agricultural wastes on the biogas yield, biogas quality and on the stability of the digester operation.

Investigations deal with the course of biogas yield and composition depending on different cofermentation substrates. Results show that the biogas yield doubles, when 10% of fat are added to slurry from milking cows. From 30% of cofermentation substrates onwards the biogas yield does not increase anymore but the stability of the digester decreases. Therefore the percentage of organic wastes should not exceed 30%. All positive effects of cofermentation can be used. The cycle of the organic wastes is of manageable size which helps to control the quality. Many agricultural farms can use the positive effects of cofermentation.

Biogas is converted to electricity and heat by combined heat and power coupling. Exhaust fumes from combustion engines, that are run with biogas, contain air *polluting substances : HC, SO_2, NO, NO_2 and CO e.g. The emissions depend on the composition of the biogas, which is not constant. There is only knowledge on the emissions from combustion engines used in agricultural biogas plants.*

Influences on the amount of emissions of air polluting substances from biogas combustion engines and on the efficiency factor of the engine are to be found : quality of biogas, exhaust fume cooling, biogas to air relation, lean concept. Combustion engines of different power levels and design are investigated. From the results proposals for means to reduce the emissions are derived. Biogas combustion with a little oxygen surplus ($\lambda > 1,3$) is at the moment the most cost-effective means to reduce NO_x and CO emissions. Construction and operation technique means should be aimed to enable the engine to work in the lean range ($\lambda > 1,3$).

Keywords : biogas production, cofermentation, exhaust fume emissions.

Résumé

La production de biogaz est une mesure efficace pour améliorer l'utilisation des lisiers. Cette technique présente de nombreux avantages tels que l'économie d'énergie à partir d'une ressource renouvelable, la réduction des émissions de méthane au cours du stockage et l'amélioration de la disponibilité en azote lors de l'épandage des lisiers.

Le nombre d'unités de méthanisation en milieu agricole augmente régulièrement sans qu'il existe de document décrivant les recommandations liées à la construction et à la sécurité de ces installations.

La cofermentation de déchets agricoles avec des déchets non agricoles est une option qui se développe bien qu'il reste à améliorer les connaissances sur la composition de ces déchets organiques et leur lien avec le rendement en biogaz et la qualité du biogaz produit ainsi que sur le fonctionnement des unités.

Nos résultats ont par exemple démontré que le rendement en biogaz était doublé lorsque l'on ajoute 10% de graisses à du lisier vaches laitières.

Le biogaz est converti en électricité et chaleur. Les fumées qui s'échappent des appareils de combustion contiennent des polluants atmosphériques tels que SO_2, NO, NO_2 et CO. Ces émissions dépendent de la composition du biogaz brûlé qui n'est pas constante.

La combustion du biogaz avec un léger excès d'oxygène ($\lambda > 1,3$) est à présent la méthode la plus efficace et la moins coûteuse pour réduire les émissions de NO_x et CO.

Mots-clés : production de biogaz, cofermentation,

1. Introduction

In Austria 18 Mio t/a of agricultural manures and 8 Mio t/a of organic wastes can be used for an energy production of about 2700 GWh/a. The number of agricultural biogas plants continuously increases. If all of the agricultural manures and organic wastes that are suitable for biogas production should be used for anaerobic digestion, 13000 to 46000 biogas plants would be necessary depending on the size of the biogas plants. Cofermentation of agricultural manures and organic wastes can reduce CO_2 emissions by 3 Mio t CO_2/a. For the building and the operation of the biogas plants about 13000 working situations are required (AMON 1998).

2. Technical Standards for Biogas Plants

Standardised guidelines would be necessary to guarantee a safety operation and cost effective building of biogas plants as well as for authorising procedures. The ILUET is developing technical standards for the different components of biogas plants. Those standards are currently realised on several farms.

Figure 1 gives an overview over the components of a typical agricultural biogas plant. Agricultural manures and organic wastes are collected, mixed and if necessary chopped in the preparation pit. Isolated concrete tanks with underfloor heating and vertically and horizontally adjustable mixers are common digesters for agricultural biogas plants. Horizontal steel tanks with heated mixer and mud outlet are also used. They are most suited for fermentation of substrates with a high dry matter content. Because biogas production can still be observed in the *effluent storage*, it should also be integrated in the gas bearing system. The *sulphur removal* from the biogas can be done by blowing small amounts of air (max. 4% of the biogas quantity) on the surface of the substrate in the digester or in the secondary fermentation tank. Biogas is then desulphurized by micro-organisms.

The *gas reservoir* has to be gas tight, durable, pressure and temperature resistant. Flexible gas storages must be shielded from weather, UV light and mechanical damages by a housing. Agricultural biogas plants are always operated with low pressure in the *gas bearing* system (< 100 mbar, usually 2-5 mbar). The operating pressure is guaranteed by a pressure safeguarding, which also serves as a *condensate separator*. The gas bearing system has to be corrosion and mechanical resistant. The gas line must have a slope of at least 1% to let the condensation water drop out.

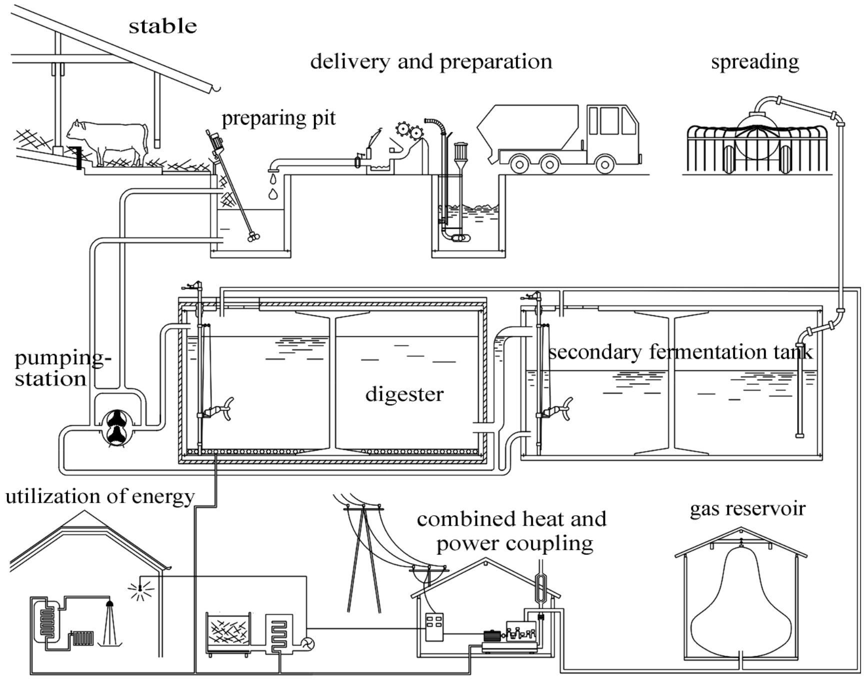

Figure 1.
Model of a typical agricultural biogas plant (AMON ET AL. 1997)

The *engine room* contains the combined heat and power coupling. Its door must be fire resistant and must open to the outside. At the entrance a gas shut off has to be installed, that switches off the combined heat and power engine. The combined *heat and power coupling* should meet the following demands: supervision of oil pressure and water temperature, sound proofing and vibration damper, collection of oil losses and fume line to the outside. The combined heat and power coupling should easily be accessible for operation and maintaining.

3. Cofermentation

Cofermentation of organic wastes and agricultural manures increases the biogas yield and offers an environmentally friendly alternative to landfilling of organic wastes. However amount and quality of the added organic wastes have to be carefully watched to guarantee a safety operation of the biogas plant and a good biogas quality. Therefore it is necessary to have figures on the amount and composition of organic wastes that are added to agricultural manures as well as on the hydraulic residence time that is needed to guarantee a sufficient degradation of the organic matter.

Two biogas plants have so far been investigated. Both biogas plants had heated digesters with vertically and horizontally adjustable mixers. The digester of biogas plant A had a size of 450 m^3, a temperature of 55°C, a mean hydraulic residence time of 75 days and a heated but not isolated secondary fermentation tank (1000 m^3). On biogas plant B biogas was collected from a digester of 150 m^3 with a temperature of 30-33°C and a mean hydraulic residence time of 125 days. Biogas plant A fermented 6 m^3/d of cattle slurry, farmyard manure, pure fat, flotation fat and water. On biogas plant B 2 m^3/d of cattle slurry were fermented with 7 l/d of pure fat and 110 l/d of food wastes.

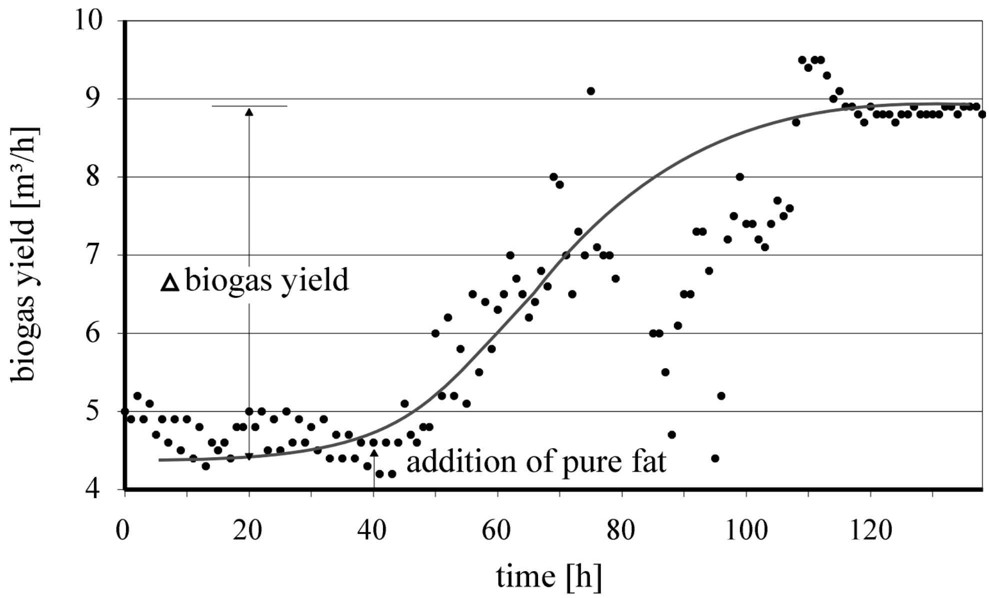

Figure 2.
Course of biogas yield after addition of pure fat to a mixture of cattle slurry

Composition of input materials, biogas yield and biogas quality were measured. On biogas plant B 860 kg oDM of pure fat were added to 608 t oDM of fermentation substrate (80% oDM cattle slurry and 20 % oDM food wastes). The biogas yield increased immediately after the addition of fat. 60 hours later it had doubled (fig. 2). This high yield lasted for about one day, after that the biogas yield decreased again and reached its former level. After 5 days the added fat was completely degraded.

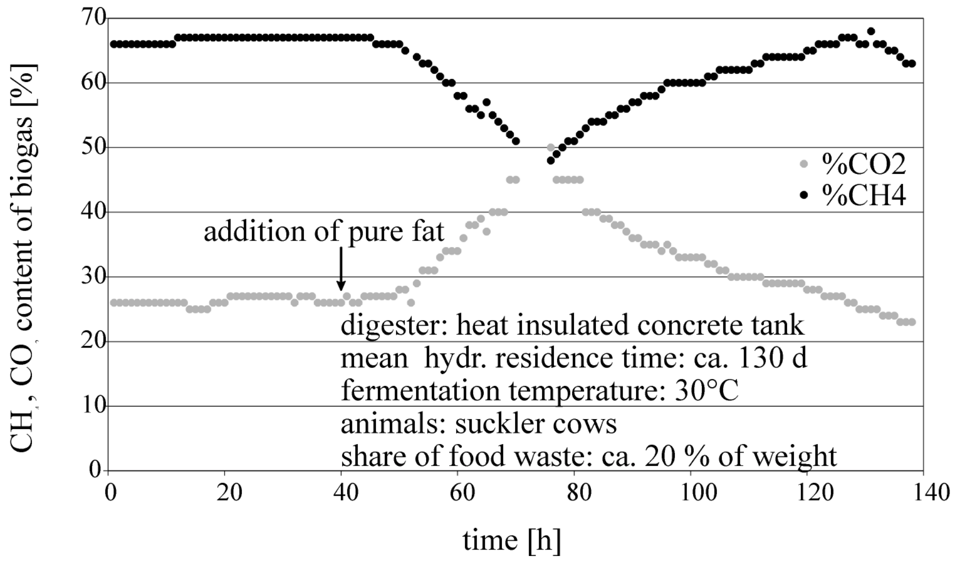

Figure 3.
Course of biogas composition after addition of pure fat to a mixture of cattle slurry.

Addition of fat also influenced the biogas composition (fig. 3). Immediately after the addition of fat the methane concentration in the biogas decreased and the CO_2 concentration increased. After 40 hours the methane concentration had reached its minimum and began to increase to meet its former level 90 hours after the fat addition. At the beginning of the degradation of organic matter mainly CO_2 is formed. CH_4 formation begins later in the degradation process. On the whole the fat addition resulted in an increase of the methane yield from 31.3 to 54.0 m^3/h.

Table 1 shows the composition of the input material and of the substrates in the digester and in the secondary fermentation tank of biogas plant A. The hydraulic residence time was 75 days.

In the digester the oDM was degraded from 173.47 g/kg to 45.80 g/kg. This corresponds to a degradation rate of 74%. In the secondary fermentation tank the oDM was further degraded to 30.95 g/kg (= 32% degradation rate). A substantial degradation rate in the secondary fermentation tank was frequently observed (DANZINGER 1998, SCHEIBLER 1998). Therefore the hydraulic residence time in the digester and in the secondary fermentation tank should not fall below 80 days. This provides a high degradation rate, a high biogas yield and helps to avoid environmental problems that occur, if methane is formed in the storage tank and emits into the atmosphere.

ingredient	input[a] [g/kg]	digester [g/kg]	secondary ferm. tank[b] [g/kg]

	n = 22	n = 8	n = 12
DM	197.40	67.58	49.25
oDM	173.47	45.80	30.95
NH_4-N	0.69	1.23	1.16
N_{org}	4.25	3.48	2.94
pH	5.56	8.15	8.06

[a]calculated from the ingredients of the different substrates and their share in the fermentation substrate
[b]addition of 20% of flotation fat (19 g oDM/kg FM) after the digester

Table 1.
Composition of substrates of biogas plant A

During the anaerobic digestion a part of the organic nitrogen was degraded to ammonium. The pH increased from 5.56 in the input material to 8.06 in the fermentation substrate. Those results correspond well with values given in the literature (BESSON ET AL. 1981, MESSNER 1988). Anaerobic digestion increases the fertiliser value of agricultural manures. Dry matter content in the slurry decreases. Therefore the slurry can easily be band spread with high accuracy.

4. Emissions from combined heat and power couplings

Gas-engines in combined heat and power couplings enable the upgrading of biogas to electricity and heat. Gas-Otto-engines are most common. Sporadically diesel-gas-engines are used. In agriculture engines with a relatively simple technique are employed. Engines with a large volume and a small performance density are most common. Mostly the air-to-biogas ratio is manually controlled.

There is a variety of possibilities to influence the operating behaviour of the engine, the emission level and the efficiency by technical construction or by the way of operation (fig. 4). The operating life of the engine is strongly dependent on the sulphur content of the biogas and on the maintenance of the engine. Technical details such as piston displacement, inlet and outlet port design or charge air cooling define the operation and emission behaviour and the efficiency of the engine (PISCHINGER & SCHMILLEN 1994, SCHÄFER & VAN BASSHUYSEN 1993). The air-to-biogas ratio can easily be influenced by the farmer. This measure does not cause any technical effort, but can substantially reduce the emission of air polluting substances. The efficiency of this measure is expected to be very high.

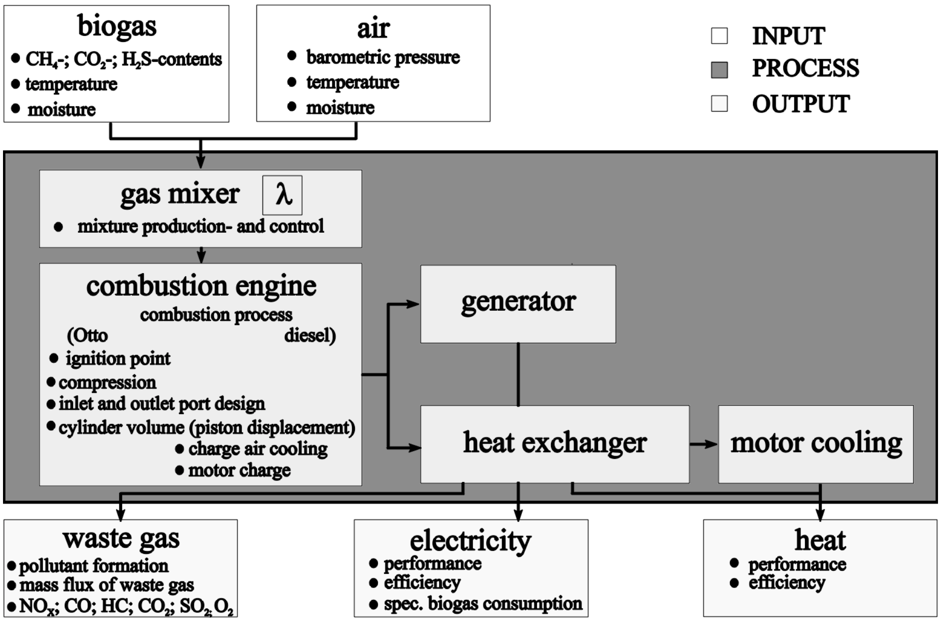

Figure 4.
Model of electricity and heat production in combined heat and power couplings.

There is little knowledge on the effect of the air-to-biogas ratio on the reduction of emissions of CO and NO_x and on the biogas consumption from gas-Otto-engines that are worked with biogas. This effect is of great interest for agricultural biogas plants.

So far the experiments have been carried out with gas-Otto-engines of two biogas plants under field conditions. Table 2 shows the characteristics of the investigated gas-Otto-engines.

The air-to-biogas ratio was manually regulated. The technical outfit of the engines was simple. The biogas consumption was continuously measured near the biogas inlet into the engine. The exhaust gas was sampled immediately after the exhaust heat exchanger in the exhaust pipe of the combined heat and power coupling. After the exhaust heat exchanger the exhaust gas sample was taken from the pipe by a heated probe and was brought to the analyser by a heated gas line. NO_x (NO and NO_2) were measured with electro-chemical cells.

The formation of air polluting substances and the biogas consumption were determined by the air-to-biogas ratio (l). The NO_x-concentration showed a clear maximum (3000 mg NO_x/m^3) with l = 1.1-1.2 (engine A, fig. 5). This air-to-biogas ratio offered enough oxygen for the NO_x formation. The high combustion temperature also favoured the NO_x formation. When l increased, the NO_x content of the exhaust gas decreased. At l > 1.5 it fell below 350 mg/m^3. 350 mg/m^3 is the limiting value given by the Austrian order concerning the prevention of air pollution.

However from l = 1.4 onwards ignition failures were observed. During ignition failures it is probable that the biogas is not combusted and leaves the engines uncombusted. This causes methane emissions that have to be avoided.

	Engine A	Engine B
motor parameters		
motor scheme	gas-Otto-engine (Ford)	gas-Otto-engine (Perkin-Elmer)
performance ($P_{el.}$ [kW])	18-25	16-23
cylinder	6	4
piston displacement [l]	4.9	3.9
engine speed	1500	1500
biogas quality		
CH_4 [Vol.%]	55-60	58-60
CO_2 [Vol.%]	39-44	39-41
H_2S [ppm]	35-50	40-80
biogas temperature [°C]	30-32	not measured
air temperature [°C]	30-31	27-29
atmospheric pressure [mbar]	943-950	974- 977

Table 2.
Characteristics of the investigated gas-Otto-engines and the surrounding parameters

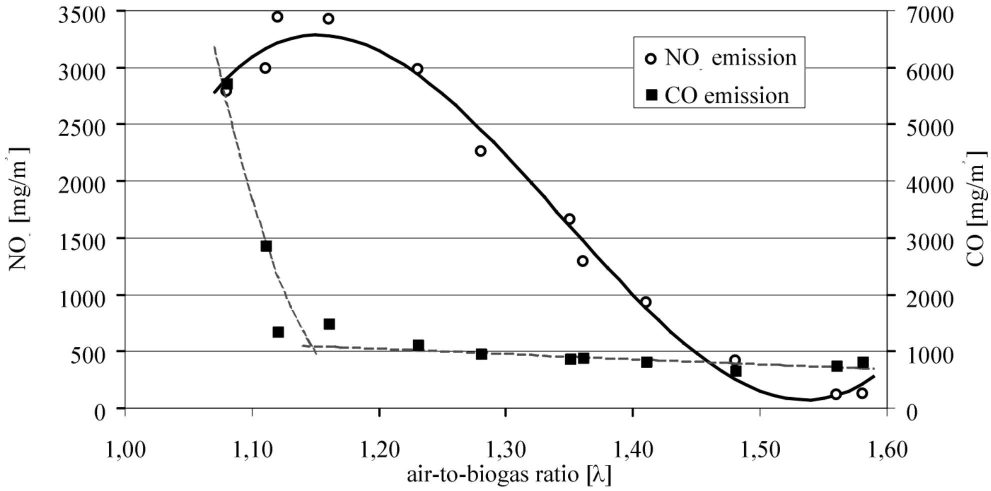

Figure 5.
NO_x and CO concentration in the exhaust gas in dependency on the air-to-biogas ratio (engine A).

Engine B showed the maximum of NO_x emissions (1000-1500 mg/m^3) with l = 1.5-1.2. From l = 1.3 onwards the NO_x content of the exhaust gas fell below 200 mg/m^3. A further oxygen surplus caused ignition failures.

CO is formed, when there is a lack of oxygen during the combustion. Figure 5 shows the CO content of the exhaust gas in dependency on the air-to-biogas ratio (engine A). As l decreased, the CO formation heavily increased and reached its maximum of 6000 mg/m^3 at l = 1.1. From l = 1.2 onwards the CO concentration in the exhaust gas did not substantially decrease anymore.

With engine B the CO content of the exhaust gas decreased from 7000 mg/m^3 at l = 1.05 to 500 mg/m^3 at l = 1.1. A further oxygen surplus did not decrease the CO content. The limiting value for CO given by the Austrian order concerning the prevention of air pollution is 500 mg/m^3. The results of the experiments correspond well with other emission measurements from gas-Otto-engines that were operated not with biogas but with fuel and natural gas (Kuhlmann 1994, Pischinger & Smillen 1994, Schäfer & van Basshuysen 1993). Operating gas-Otto-engines with biogas therefore leads to similar emissions.

The air-to-biogas ratio also influenced the biogas consumption. With increasing l the biogas consumption grew degressively. Engine A consumed 0.84 m^3 of biogas for the production of one kWh electricity at l = 1.1. With l = 1.5, 0.93 m^3 per kWh were needed. The biogas consumption of engine B was very similar: from l = 1.1 - 1.3 the biogas consumption increased from 0.7 to 1.1 m^3 biogas per kWh electricity. With increasing oxygen surplus the biogas consumption grows and the efficiency decreases. This means that with the engine technology that is currently employed in agricultural biogas plants the operation of the engines must find a compromise between low emission and low biogas consumption.

5. Conclusions and recommendations

1. *Safety guidelines*
At the ILUET technical standards for building and operation of biogas plants have been developed. They are currently realised on several farms.

2. *Cofermentation of agricultural manures with organic wastes*
Cofermentation increases the methane yield. The share of fat and other easily degradable organic substrates should be limited to a maximum of 5% of oDM to avoid instability of the biogas process. The hydraulic residence time of the fermentation substrate in the biogas plant should not fall below 80 days to guarantee the degradation of the organic substance to a high extent.

Every tank containing fermentation substrate should be integrated in the gas bearing systems to collect the methane that is built from the substrate not only in the digester but also in the other parts of the biogas plant. The emission of methane into the atmosphere has to be avoided.

To avoid ammonia losses during and after spreading of the anaerobically digested slurry, band spreading application techniques have to be used and the fertilisation has to be done during the growth period of the plants, when there is a need of ammonium-N (Boxberger & Amon 1997).

3. *Combined heat and power coupling*
With gas-Otto-engines employed on agricultural biogas plants the air-to-biogas ratio (l) substantially influences the emission of NO_x and CO. However l may not exceed 1.35 to 1.4, because ignition failures occur and the methane emissions of the exhaust gas are expected to increase. If fluctuations of the biogas quality are expected, an automatic regulation of the air-to-biogas ratio can efficiently reduce NO_x and CO emissions.

The biogas consumption increases with growing l. The operation of gas-Otto-engines should therefore not only consider low emissions but also low biogas consumption. With a compromise of both demands the best environmental control can be reached.

6. References

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