FARM-SCALE BIOGAS PLANTS

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SUMMARY

In Germany there are only about fifteen years of experiences in the planning and construction of farm-scale biogas plants. In the meantime, approximately 1,600 biogas plants are in operation under stable conditions on farms. This is primarily due to investment funding and payment for each kWh delivered to the public energy grid. In general, three different kinds of digester types are in use for anaerobically treating manure and other organic input substrates: small horizontal digesters, medium-sized upright concrete ones, and large upright steel digesters. Depending on several factors, which have to be known before engineering of the biogas plant is begun, an experienced engineer chooses the most suitable process technology. This allows for a great variety of technical solutions, and their successful implementation frequently depends on the experience of the engineering and construction companies.

1. INTRODUCTION

Biogas plant is becoming more and more attractive for the treatment of high strength organic wastes such as pig slurry since it produces renewable energy (methane) and valuable digested residue that can be used as liquid fertilizer and soil conditioner (Angelidaki and Ahring, 1994; Bonmati *et al*., 2001; Hansen *et al*., 1998, Hansen *et al*., 1999). The strong demand for renewable energy generation and a range of new and forthcoming environmental legislation, such as the Climate Change Levy and the Landfill Directive may increase an interest in the biogas plant using anaerobic digestion technology (Van Lier *et al*., 2001).
In the mid-eighties, the first biogas plants for the digestion of animal manure were constructed in Germany. Denmark and East Germany focused on large centralised biogas plants; whereas in West Germany mainly farm-scale biogas plants were constructed at first. But the circumstances were very difficult, as there was no funding and no payment for the energy produced. Although there had been two previous major efforts – just after World War II and during the oil-crisis – there had been no success in establishing more than approximately a few dozen plants until the mid-eighties. After getting off to a slow start, the biogas business gradually began to become successful. In the nineties the implementation of two very important regulations favoured the economic and technical success of renewable energy in general and biogas plants in particular in Germany. Meanwhile, after approximately 15 years of biogas engineering work, German biogas engineers have a great deal of experience in the planning and construction of biogas. Around 1,600 biogas plants had been in operation in Germany by the end of 2001. Most of them are still operated with manure and additional organic wastes (cofermentation) but the digestion of energy crops like corn, beets or grass is becoming increasingly important. There is no clear definition for the farm-scale biogas plant, but in this context it means the biogas plant, which is strictly related to one single farm. In contrast to this, there are also biogas plants that are owned by two or three farmers and belong to several farms or even large community biogas plants that can digest all the manure of the farms located in a single municipality or county. There is a great variety of farm sizes in Germany. In Southern Germany, for example in Bavaria and Baden-Wurttemberg, small farms with 100 cattle and/or 500 pigs or even

fewer are still common. In Northern Germany, for example in Schleswig-Holstein and Lower Saxony the farms are larger. There are often several hundred cattle and some thousand pigs on the farms there. In Eastern Germany and in Western Lower Saxony really large farms are in operation, which sometimes have several thousand cattle and sometimes tens of thousands of pigs. The amount of manure produced corresponds to these numbers of animals. Farm-scale biogas plants can have a manure input of between 1,000 m^3/yr and 70,000 m^3/yr. These significant differences in the amount of input require a variety of different digester technologies but, in principle, all farm-scale biogas plants are the same.

2. BASIC LAYOUT OF A BIOGAS PLANT

Basically, each biogas plant consists of the same principle components: a digester, a gas holder, a gas engine, tubes, mixers, etc. The rough layout is shown in Figure 1. Unfortunately, the pig farms in Korea do not have enough arable land to utilize all produced digested manure. Thus, in this case, post advance treatments have to be severely considered to meet the stringent discharge standards.

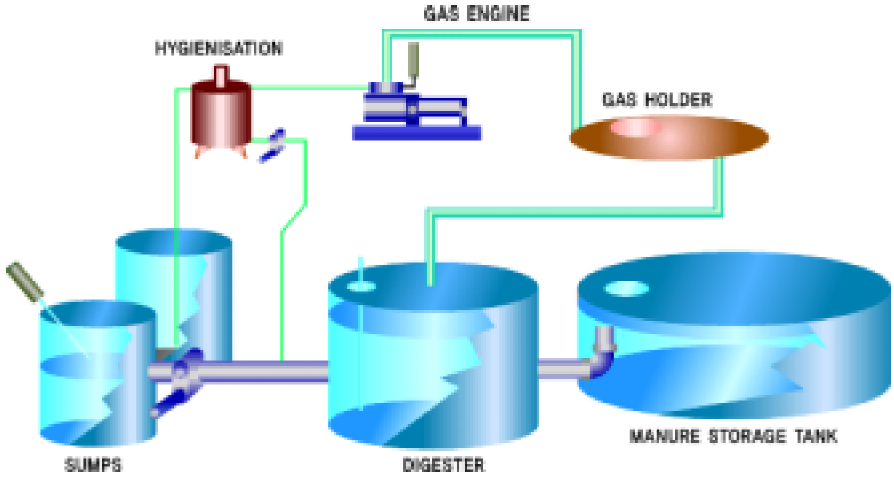

Figure 1. Basic layout of a biogas plant; hygienisation is optional for the co-fermentation.

3. PLANNING OF BIOGAS PLANTS

The planning of biogas plants is generally not easy, as considerable data is required before engineering can begin. Above all, information has to be provided about the followings:

- Type of input substrate (biodegradability, VS and TS contents)
- Quantity of input substrate
- Local circumstances
- Heat use
- Pasteurisation
- Automation

Based on this data for each individual farm or each separate occasion, first the basic engineering that establishes the rough technical design of the plant has to be performed. The results of this design are as follows:

- Gas prognosis
- CHP-size (Combined Heat and Power Station – gas engine size)
- Digester size
- Flow-sheet
- Layout design
- Cost assessment

This includes the engineer's decision about most appropriate process technology in each case. Depending on the input substrate, a process technology, which enables the operator to run the biogas plant with the highest possible process stability, has to be determined. Therefore, the decision has to be made between the followings:

- Mesophilic and thermophilic process temperature
- One- and two-stage processes
- Type of mixing
- Type of heat input
- Type of feed mode

The results of the planning determine which of the three major digesters types that are constructed in Germany will be implemented.

4. CONSTRUCTION OF DIGESTERS FOR FARM-SCALE BIOGAS PLANTS

4.1 Horizontal Digesters

The smallest biogas plants are often constructed with horizontal digesters (Figure 2). The material used is steel. Originally, old used tanks were taken to avoid unnecessarily high costs. These tanks were cleaned, reconstructed with central shafts, equipped with mixer arms, insulation, gas dome, etc., and re-used as a digester. Today, the digester tanks are normally new and fabricated for use as a digester. Generally, the standard volume is between 50 and 150 m³. The breadth is 3.20 to a maximum of 3.50 m in order to be able to transport the tanks on German streets without additional costs. The final rigging is performed on site.

The hydraulic retention time is usually between 30 and 50 days, depending on the input substrate. The input is first heated by the heating arms as shown in Figure 2. When mesophilic temperatures are reached, the necessary mixing is done by standard mixing arms. This type of tank is well-suited for treatment of dung and poultry manure as there are very good mixing conditions even for solids. Grid removal is unproblematic. This digester type is comparatively cheap but cannot be transported in large sizes.

4.2 Upright Standard Agricultural Digester

The standard digester in German biogas business is the upright, manufactured concrete digester, Figure 3. The standard size is between 500 and 1,500 m³. The height is often between 5 and 6 m; the diameter varies between 10 and 20 m. The tanks are equipped with a heating system which delivers hot water into tubes fixed along the walls. The mixer is either completely immersed or equipped with a motor located outside the tank as shown in Figure 3. Large tanks are equipped with two or more mixers. Top of the tank is a double-membrane, gas-holder roof. The inner membrane is the gas-holding buffer; the outer membrane is the weather cover. The inner membrane is flexible in height; whereas the outer one is always ball shaped, as there is a blower which maintains a constant slightly elevated air pressure in the space between the two membranes in a manner similar to that used to support an air hall. The hydraulic retention time is generally between 40 and 80 days depending on the input substrate. This type of tank is well-suited for every kind of input substrate as long as the flow rate is low enough. Grid removal is not a problem if there is a special device for mechanically removing this grid. For this reason some tanks are equipped with a concrete roof. This type of digester is used for the treatment of up to 10,000 m³ input per year.

4.3 Upright Large Digester

For large quantities of input substrate, for example more than 30,000 m³ per year, large upright steel digesters are in use. The steel is generally coated in order to avoid corrosion. In most cases glass-coated prefabricated steel plates are used. The standard size is between 1,500 and 5,000 m³. The height is often between 15 and 20 m; the diameter varies between 10 and 18 m. The mixing is done by a centrally located mixer on the roof, which is in operation continuously. The input substrate is pre-heated before entering the digester. The hydraulic retention time is generally 20 days. This short retention time can be chosen because of the advantages of continuous mixing and pre-heating. This type of digester is used for the treatment of up to 90,000 m³ input per year per single unit. Large centralised digestion plants often have two or more tanks.

5. GAS ENGINE

In a standard farm-scale biogas plant in Germany there will be an engine to produce electricity and hot water from the biogas. Of course, there are other possibilities for using the biogas, for example pure hot water production or direct delivery of the biogas into a public natural gas network. There are research and development projects for fuel cells or biogas turbines. But in general – even on a long-term basis – the standard solution will be an engine. There are basically two solutions for the question of what kind of engine will be chosen.

5.1 Gas Engine

For larger farm-scale biogas plants the pure gas engine will be the standard solution. This engine is based on an Otto engine and is the same standard engine that is used for landfill and sewage gas treatment. Depending on the circumstances on site, for example its heat use requirements, the use of such an engine is economically feasible for biogas plants with an electrical power of more than 150 to 200 kW. The electrical efficiency will be higher than 34%, and the investment will be a bit larger than for a dual fuel engine but the write-off period is longer.

5.2 Dual Fuel Engine

This kind of engine is based on a diesel engine and has to use up to 5 to 15% diesel fuel of the overall energy input. If this fuel is compressed by the piston and burns inside the cylinder the biogas (90%) burns, too. 5 to 15% of supplemented diesel fuel lubricates the system and protects it from erosion. Even for small engines the electrical efficiency is between 33 and 37%. This is extremely important for the economy of smaller farm-scale biogas plants in Germany as the farmer earns money mainly with the production of electricity. Another advantage of this type of engine is the fact that they can be operated with diesel fuel alone. To start-up a biogas plant hot water is required to heat the digester contents. A dual fuel engine can be operated with diesel fuel, produces hot water until the biogas production starts and then can be operated with biogas. Even low-quality biogas with any given methane content can be utilised by a dual fuel engine. In contrast, for a gas engine – besides the biogas consumption – a second gas operation option must be found, for example natural gas or propane gas. Or an extra burner has to be installed. The largest dual fuel engines available on the market have an electrical power output of 250 kW. At upper end of this range the disadvantages gradually become important, for example the high consumption of diesel fuel and the fact that the electrical efficiencies of gas engines are similar to those of dual fuel engines have to be given careful consideration.

6. GAS HOLDER

There are several different kinds of gas holders available. But basically three of those are used most often:

- Balloon-shaped external gas holders. They are constructed from a flexible membrane and are often located under a simple roof, for example a carport.
- Gas holder roofs. They are installed on top of a (concrete) digester. The cheap version is just a single membrane but the better version is a double membrane roof.

External gas holders. In a separate tank there are gas holders with a volume of up to 5,000 m³. They are constructed such that either a complete balloon is enclosed in this tank or a half-balloon is integrated in the tank structure.

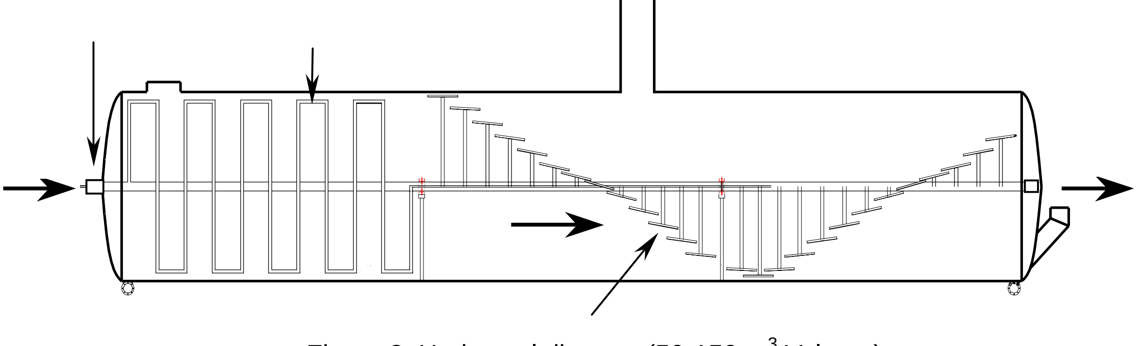

Figure 2. Horizontal digester (50-150 m^3 Volume)

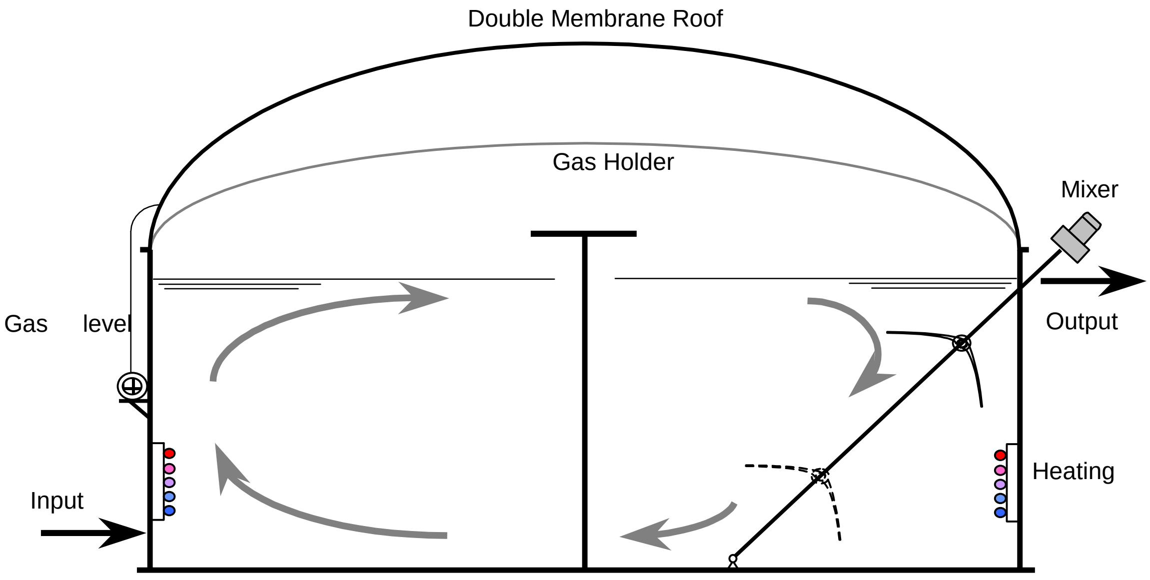

Figure 3. Upright standard digester in agriculture (up to 1,000 m^3 Volume)

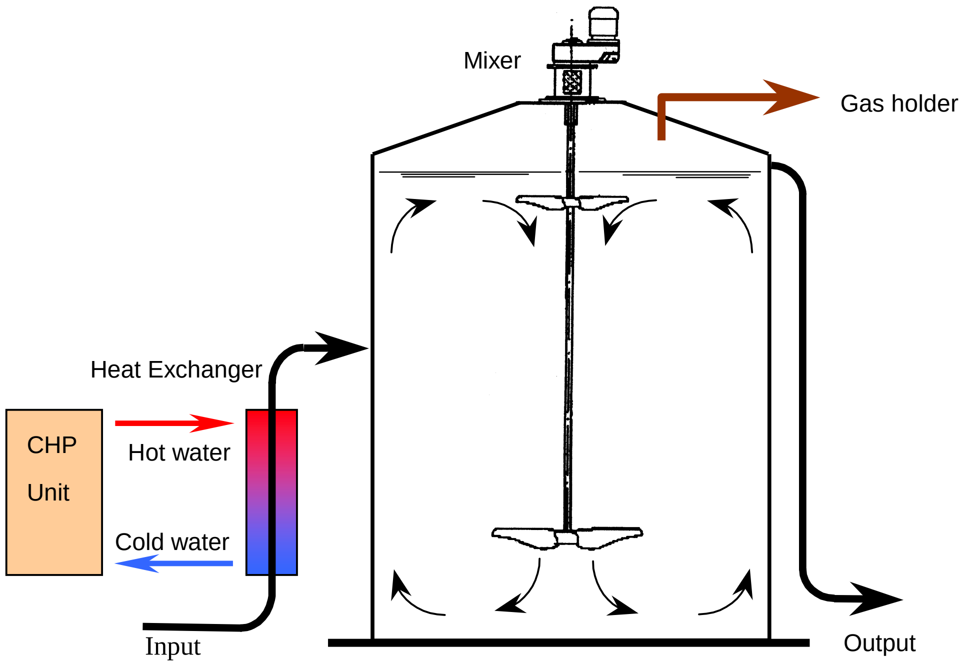

Figure 4. Upright large digester (up to 5,000 m^3 Volume)

7. FIELD APPLICATION IN GERMANY (Krieg & Fischer GmbH)

7.1 BARZ Cofermentation Biogas Plant

To improve economy of biogas plants some owners decide not to digest manure alone but to take other organic substances - so-called coferments - as well. Typical coferments are fats, market wastes, spice residues, residues from food industry and many similar substances. The operator of the cofermentation biogas plant increases his earnings in two ways: first, just by taking the coferments from the person who wants to dispose them and second, through higher biogas production. The standard substrate ratio for cofermentation is about 3:1 to 2:1 for manure and coferments. At first the coferments are ground, hygienized and mixed with manure. Hygienisation is most often performed at 70°C for one hour with a maximum particle size of 1 cm. The homogenization with manure is performed in a mixing tank with strong agitators. After this pretreatment all the organics are pumped into the digester. Standard digestion volumes of cofermentation biogas plants range from 500 m³ to several thousand m³. The biogas produced is used in gas or diesel gas engines. All large-scale cofermentation biogas plants are controlled by an overall process control system. There are many devices for measurement and safety purposes. At night everything is run automatically, during the day there are operators on site - especially for repair and maintenance reasons and for taking the coferments and manure. Figure 5 represents BARZ cofermentation biogas plant digesting manure as main substrate and kitchen waste as coferment.

SPECIFICATION

- Location: Germany
- Time of erection: 1996-1998
- Input: Manure, kitchen waste
- Fermenter: 2-stage-concrete tank, 20 m³ and 230 m³
- Co-generator: Dual fuel co-generator, 45 kW
- Specials: Gas holders above digesters and manure storage tank, hygienisation
- Responsibility: conception, permission planning, detailed planning, erection, start-up

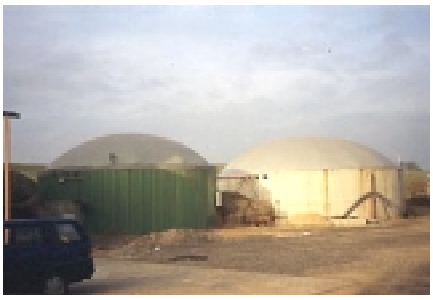


Figure 5. BARZ cofermentation biogas plant and co-generator, Germany.

Table 1. Biogas plant references of Krieg & Fischer GmbH in 2001.

Biogas plant	Location	Input	Digester	Go-generator	Time of erection
HINNEMANN	Germany	Manure, corn, other organic waste	Stainless tank, 1000m^3	Dual fuel go-generator, 60kW	2001
WINTER/RIGGERT	Germany	Manure, corn, agricultural residues	Concrete tank, 1250 m^3	Gas engine, 100kW	2001
FABEL	Germany	Manure, corn, agricultural residues	Concrete tank, 1000 m^3	Gas engine, 100kW	2001
PRATO allo STELVIO	Italy	Manure, straw, other organic wastes	2 concrete tanks, 735 m^3 each	Integration in central energy system	2001
EICHHOF	Germany	Manure, other organic wastes	Concrete tank, 600 m^3	Dual fuel co-generator, 22kW, gas engine, 5kW	2001
BEKKAI	Japan	Manure, other organic wastes	Steel tank, 1500 m^3	Turbine, 37kW, 2sets	2001

* and many other reference plants are installed.

8. FIELD APPLICATION in KOREA (Kolon Eng. & Const. Co., Ltd.)

8.1 Sung Hwan Biogas Plant

At the pig farm in the National Institute of Livestock Research, Sung Hwan, Kyungki, Korea, a farm-scale biogas plant for generating energy from manure of approx. 2000 pigs was built (Figure 6). The process was developed and built by Kolon Engineering and Construction Co., Ltd., and sponsored by the Korean Ministry of Agriculture and Forestry as a demonstration project. Construction of the plant started in summer 1999, and it is in operation now. This farm-scale biogas plant (200m^3) was designed to process 10 m^3/day of pig slurry under mesophilic conditions at 35℃. Its major components are an anaerobic digester (a semi-continuous, single stage, completely stirred AD) to produce biogas and combined heat and power station (CHP) to generate heat and electricity. The digester temperature was controlled less than 0.8℃ deviation per day from setting temperature. Input pig manure is blended with circulating sludge upstream of the heat exchanger. This allows the manure to be heated before being fed to the digester. Mixing is important to the high-rate digester because it maintains uniformity within the digester and prevents scum and grit accumulations. For this biogas plant, gas recirculation with draft tube and external recirculation pump were used to maximize the mixing efficiency. The draft tube system works like an airlift pump. The biogas used for mixing is within a closed circuit. One of the major advantages of the biogas mixing system is the complete absence of any mechanical part inside the reactor. This allows the process to operate in high-solid conditions without any hindrance and without maintenance of mechanical devices. For the purpose of digester heating, external heating system was used in this biogas plant. It recirculates digester sludge through an external heat exchanger (tube in tube type). The inlet and outlet temperatures of the heat exchanger were monitored since the significant difference indicates the reduced heat transfer.

During anaerobic digestion of pig manure in the biogas plant, 50% of volatile solids (VS) reduction (in average) was stably achieved. However no further VS reduction was occurred due to its inherent hardly biodegradable materials. The varying input VS amount resulted in the significant fluctuations in the biogas production. The average biogas yield was 0.79 m^3 (0.22 m^3 - 1.77 m^3) per kg of added volatile solids. The biogas composition was relatively constant throughout the operating period with the 68-73 vol. % methane and 27-30 vol. % carbon dioxide.

8.2 Combined Heat and Power Unit Operation

Specialized gas Combined Heat and Power (CHP) units are very expensive, thus in this plant modified dual fuel engine-generator (diesel generator) was used. Costs are lower because it is a more standard piece of equipment and maintenance costs are also lower than for the specialized CHP units. The purpose of the installation of CHP unit in this work was to supply all energy need on the plants and all electric and thermal energy needed for livestock, machinery, and administration of the farm by the process itself. Furthermore, the surplus of electricity was planed being fed into the public network. The generator used for this is rated at stand-by 37kW (continuous power: 33kW), 380/220Volt, 3-Phase, 0.8 PF(Power Factor), 60Hz at 1800RPM. The dual fuel system allowed up to 85-95% substitution of biogas (in gradient: methane above 65%) for diesel fuel. Produced heat is recovered by both cooling water exchanger system (engine jacket fluid flow) and exhaust heat exchanger system.

Figure 6. Biogas plant digesting pig manure of 10 m^3 /d at Seung Hwan, Korea.

9. RESULTS

Most of the biogas plants in Germany are medium-sized farm-scale biogas plants. The process temperature in general is mesophilic, and the process technology is one-staged. This plant type has been constructed about 1,000 times with digester sizes between 300 and 1,500 m^3. Several hundred biogas plants are equipped with horizontal digesters, mainly for small farm-scale biogas plants in South Germany. A few dozen biogas plants have been constructed with large upright digesters with external heat exchangers and centrally located mixers. There are large differences among all these farm-scale biogas plants. Besides variation in the types of digester, engine and gas holder, there is a great variety of technical solutions for the degree of automation, the mixing procedure, the heat input, the feeding rate, the process temperature, etc. Economic evaluation of these plants reveals that the plants can be economically viable, only if special taxation measures economically favor energy from biogas, compared to energy from conventional fossil fuels. Korean government has a target of 3% electricity from renewable sources by 2010. It has the option of encouraging renewable energy with a fixed high price for electricity. Thus the installation of biogas plant may increase gradually in Korea like European countries.

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