ANAEROBIC DIGESTION OF ENERGY CROPS – STATE OF THE ART OF BIOGAS TECHNOLOGY

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ABSTRACT: EU policy has improved the legal framework conditions for energy production from renewable sources. Therefore the number of biogas plants and the application of energy crops increased considerably during the last few years. Still, a big discrepancy can be seen between the theoretically available and the actually utilised biogas potential. An optimisation of the efficiency along the whole process chain from the substrate input over technology, process control, digestate utilisation up to energy conversion is necessary to promote the very promising potentials of biogas. The increased use of energy crops induced adaptations in digester, feeding, and mixer technologies as well as in the process control. A new generation of modern biogas plants is the result of this development. An area-wide monitoring of Austrian farm-based biogas plants assessed the current state of the art. Data on biogas technology, substance and energy flows, economic efficiency, work requirement and management of the biogas plants were collected. From these data, a clear picture on the current state of the art and of the performance of biogas plants can be drawn.

Keywords: anaerobic digestion, farm scale biogas, greenhouse gases

1 INTRODUCTION

The European Union (EU) has improved the legal framework conditions for energy production from renewable sources. Within the directive for promotion of electricity produced from renewable energy sources EU policy implements efforts to strengthen security and diversification of power supply from renewable sources. The directive classifies the following renewable energy sources: wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogas. The Austrian Government transposed the EU directive into national law through the Green Electricity Act 2002. The Act regulates guaranteed prices for electricity generated from biomass until 2015 for all plants licensed by the end of 2004 and operational by mid 2006. The supply compensation determined in accordance with the Eco-Power Act now offers an economic calculability of eco-power generation. Accordingly, increased investment activities in the field of agricultural biogas plants can be observed. The price guarantee is an important basis for the economic calculability of investments into biogas production

The number of farm based biogas plants has increased rapidly since 2002. Biogas plants in Austria nearly doubled between 2001 and 2002 as shown in figure 1. The same trend is observed in Germany [1].

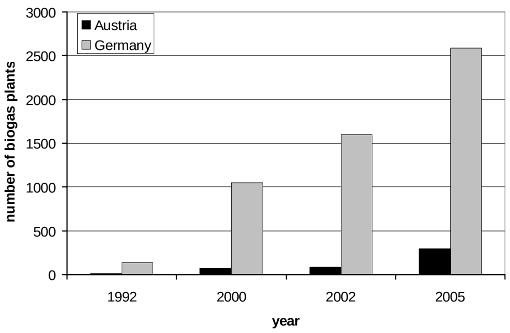


Figure 1: Development of the number of biogas plants in Austria and in Germany

In April 2005, 294 biogas plants were operated in Austria [2]. A net total of 27 MW installed electric capacity or 13.5 kW per 1000 hectares were installed. In Germany, 2600 biogas plants. were operated in April 2005. This corresponds to 450 MW electricity or 26.3 kW per 1000 hectares [3].

Despite of the positive trend, the full potential of biogas production is by far not used. Considering the amounts of animal manures and energy crops available, Austrian biogas plants could produce a total of 180 $MW_{el.}$ [3]. One reason for the discrepancy between the theoretically available and the actually utilised resources lies in the limited knowledge on the optimum technology to be installed on biogas plants that mainly digest energy crops. Guidelines in the building and operation of the new generation of biogas plants are required.

In the last few years, an increasing trend towards anaerobic digestion of energy crops has been observed. The “first generation” of biogas plants mainly relied on animal manures. It was shown, however, that higher methane yields and a better economic efficiency can be achieved through the additional use of energy crops in anaerobic digestion. The „new generation“ of biogas plants mainly or only digest energy crops. The new plants comprises a big variety of fermentation technologies and technical equipments.

The aim of this study is to monitor and benchmark technologies installed on the new biogas plants. Recommendations on optimum technologies and on possibilities for optimising biogas production along the whole process chain shall be worked out.

2 MATERIALS AND METHODS

An area-wide monitoring was carried out on 40 new biogas plants in Austria that went into operation between 2003 and 2005. The monitoring included technical, economic and management parameters. Data on biogas technology, substance and energy flows, economic efficiency, work requirement and management were collected. From these data, a clear picture on the current state of the art and of the performance of biogas plants can be drawn. Possibilities for the optimisation of biogas production can be concluded.

In addition to the area-wide monitoring, a very detailed monitoring was carried out on two biogas plants for eight months. The detailed monitoring includes daily biomass input, digester temperatures, time requirement for substrate input and mixing, biogas production and utilisation, biogas quality and composition of substrate inputs and of the digestate.

The results given in this paper include data from 32 biogas plants that were included in the area-wide monitoring. The data were gathered through on-farm visits between February and July 2005. The on-farm visits guarantee a good data quality. Samples of the input substrates and of the digestate were taken in course of the on-farm visits.

3 RESULTS

3.1 Electric capacity installed

During the last two years, more than one hundred new biogas plants were built in Austria. The performance of 72 % of these new biogas plants ranges between 100 and 500 kW electricity installed. 15.5 % of the new biogas plants have less than 100 kW electricity installed, and 12.5 % have more than 500 kW electricity installed.

About 50 additional biogas plants will go into operation this year. Their average size is 500 $kW_{el.}$.

3.2 Substrates

Three types of biogas plants can be differentiated:
I. Digestion of energy crops II. Digestion of energy crops and animal manures, and III. Digestion of energy crops, animal manures and organic wastes.

About 10 % of the new biogas plants only digest energy crops. About 65 % digest energy crops and animal manures, with 61 % of these being fed with pig slurry, and 39 % with cattle slurry. The Green Electricity Act 2002 encourages the digestion of energy crops and/or animal manures, because when organic wastes are co-digested in so called “cofermentation plants”, biogas plant operators in Austria receive a 25 % lower guaranteed price for the produced electricity.

About 25 % of the monitored biogas plants digest animal manures and organic wastes. The organic wastes that are anaerobically digested mainly come from the food and agro-industry, from markets, canteens and from the municipal sector.

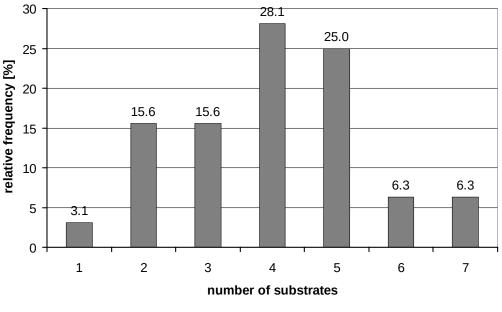


Figure 2: Frequency distribution of substrates digested in modern Austrian biogas plants

Most biogas plants digest a multitude of contrasting substrates as shown in figure 2. Only 3.1 % digest only one substrate. Most of the monitored biogas plants use two to five different substrates as input material. About 13 % even digest six or seven different substrates.

Many different types of energy crops are suitable for anaerobic digestion. Still, maize is the most widely used energy crop. However, additional energy crops become more and more important: grass silage, maize corn silage, alfalfa, clover, sunflowers, sugar millet and sudan grass.

3.3 Direct feeding systems

The digestion of energy crops and the increase in the capacity of biogas plants require the application of technologies that can feed solid substrates directly into the digester. A stable fermentation process and a high methane yield can only be achieved if the input substrates are well mixed, chopped and fed at a as much as possible constant rate.

With animal manures and other liquid substrates, a preparation pit had been used from which the viscous substrates were pumped into the digester. This technology is not very suitable for the digestion of considerable amounts of energy crops. Thus, a range of technologies for feeding solid substrates directly into the digester was installed on the new biogas plants. Figure 3 shows the distribution of direct feeding systems on the monitored plants.

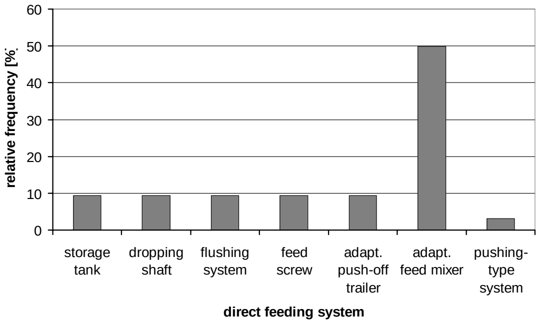


Figure 3: Frequency distribution of direct feeding systems

In the first run, mainly dropping shafts, flushing systems, and systems with feed screws were used to directly fed solid substrates into the digester. These did, however, not offer the possibility of continuous feeding of the digesters and of weighing the amount of input. Thus, nowadays mainly adapted feed mixers and adapted push-off trailers with weighting machines are applied. These systems ensure a constant and exact supply with organic matter, which is the basis for a stable digestion process with a good biogas quality.

3.4 Digester systems

The digester is the core of a biogas plant. There are two principal types of digesters: vertical and horizontal digesters.

The vertical digester is a completely mixed digester usually made of reinforced concrete. The substrate is continuously mixed during the digestion process in order to keep the solids in suspension. Biogas accumulates at the top of the digester. The standard size of vertical digesters is between 500 and 2,000 m³. In horizontal or so called plug flow digesters the substrate flows semi-continuously through a horizontal tank. Plug-flow digesters are in most cases made of steel and have a volume between 50 and 150 m^3.

As figure 4 shows, in Austria more than 80 % of the new biogas plants have vertical digesters. Less than 20 % have a combination of horizontal and vertical digesters. In this case plug flow digesters are used for the first stage of fermentation and a complete mixed digester for secondary stage. Horizontal digesters alone were not found in the investigated plants.

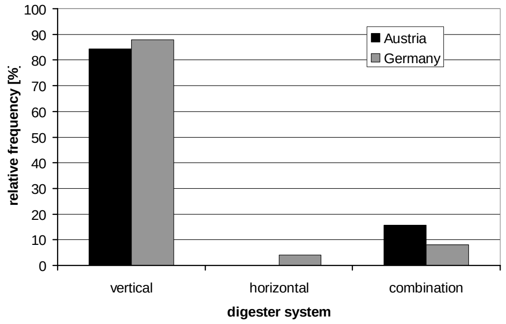


Figure 4: Frequency distribution of digester systems in Austria and Germany

A monitoring of biogas plants in Germany gave similar results [1]. Nearly 90 % of the biogas plants had vertical digesters. On a small percentage of biogas plants, only horizontal digesters were found.

It is to be assumed that vertical digesters will be most important in the future. Their volume can be up to 6,000 m³, they are competitive to construct and more easy to operate than horizontal digesters. Horizontal digesters will only be installed on small biogas plants, because this digester type cannot be transported in large sizes. But our monitoring also shows new developments. In some cased, horizontal digesters were made of reinforced concrete with on-site fabrication. They then had a volume of 400 m³.

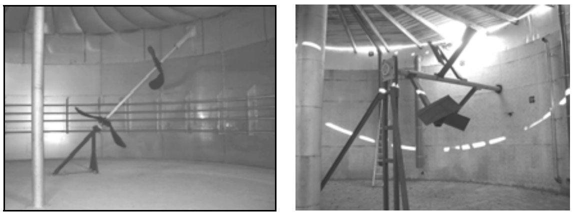
3.5 Mixing technologies

The mixer is a very essential part of an agricultural biogas plants. Digestion of energy crops requires a sophisticated mixing technology. Only then have the micro-organisms in the digester the possibility to get an evenly access to the whole digestate. A thorough mixing is a pre-requisite of a stable digestion process, a good degradation of the organic substrates, a high biogas yield and a good biogas quality. A good mixing is especially important when digesting energy crops and/or animal manures as these substrates have a strong tendency to unmix.

The changes in substrate inputs strongly influenced the mixing technologies. Earlier, rapid velocity submersible-motor propeller mixer were most commonly applied. The monitoring of the new biogas plants revealed a strong trend towards low velocity mixers, that keep energy consumption at a low level and can be operate continuously.

More than 54 % of the new biogas plants have installed slowly moving paddle mixers in completely mixed digesters. About 9 % of all mixers are slowly moving long-shaft mixers and only 7 % are rapid velocity submersible-motor propeller mixer.

In contrast to other mixing technologies, paddle and long-shaft mixers have no electrical parts inside the digester. This is an important factor for a trouble-free operation. Figure 5 shows two examples of these modern mixer technologies.



long-shaft mixer paddle mixer

Figure 5: Mixing technologies

Figure 6 shows that on more than 50 % of the new biogas plants only one mixer is installed. However, the tendency goes towards digesters with two or three mixers installed. The increasing volume of completely mixed digesters goes along with the installation of two or more mixers. As the mixer is a key factor for a smooth digestion process, the installation of several mixers increases the reliability of the process.

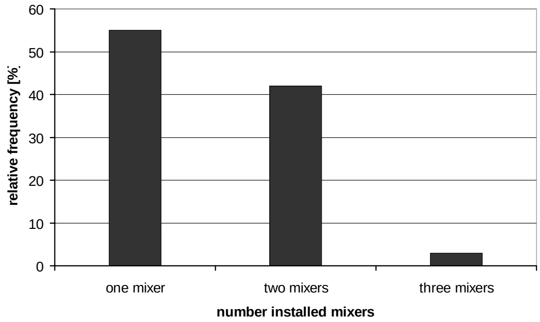


Figure 6: Frequency distribution of the number of mixers installed on new biogas plants

3.6 Process benchmarks

Anaerobic digestion can be performed at mesophilic temperatures between 35 and 38 °C or at thermophilic temperatures of more than 55 °C. Most of the methane producing bacteria prefer mesophilic temperatures. Anaerobic digestion at mesophilic temperature enables and guarantees a stable digestion process and high biogas yields. Thermophilic temperatures enable greater loading rates due to the faster degradation of the organic substrates, but at the same time require a higher energy input for the digester heating and may cause an increase in process instability.

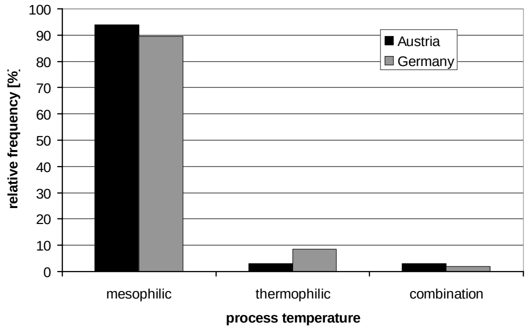


Figure 7: Frequency distribution of mesophilic, thermophilic and combined digester temperatures

The monitoring in Austria and in Germany [1] revealed that about 90 % of all biogas plants are operated at mesophilic temperatures. Only a small number of new biogas plants are operated at termophilic temperatures or at a combination with termophilic temperatures in the first and mesophilic temperatures in the second stage of fermentation (Fig. 7).

The average retention time is an important influence on the economic efficiency of biogas plants and on the methane yield that is produced. The average retention time must be high enough to enable the degradation of the biomass. On the other hand, it must be kept as low as possible, because a high retention time always means an increase in the necessary digester volume.

The average retention time is defined as digester volume divided by the volume of daily substrate input. It is dependent on the type of digester. Vertical digesters require a slightly higher retention time than horizontal digesters.

The monitoring on the new biogas plants showed average retention times between 42 and 50 days in the main digester and 55 days in the secondary fermentation tank (Fig. 8). These retention times are high. Normally, the horizontal digester is planned to have an average retention time of 20 – 25 days. The high retention times are most likely to be due to an over sizing of the digesters. Walla & Schneeberger [4] found that the average rate of capacity utilisation of biogas plants implemented since 2000 is only 70 %.

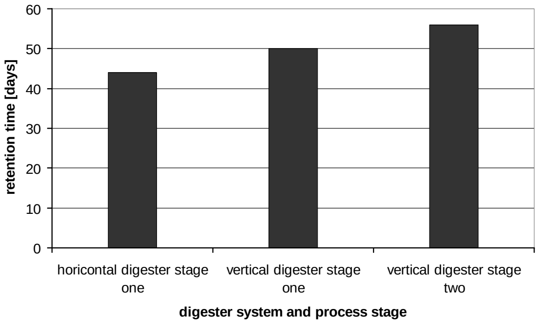


Figure 8: Mean average retention times in horizontal and vertical digester and in the first and in the second stage of digestion

The average volume load is defined as the amount of volatile solids that enters the digester related to the digester volume.

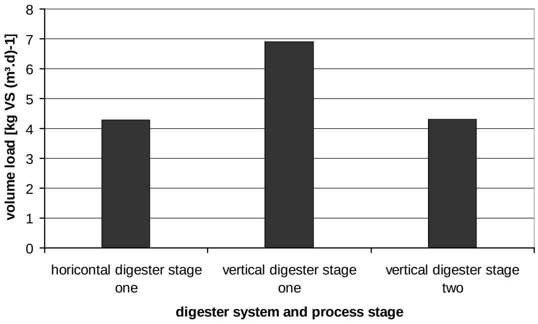


Figure 9: Mean average retention times in horizontal and vertical digester, and in the first and in the second stage of digestion

The monitoring in Austria showed that the average volume load is connected with the digester type. In horizontal digesters (first stage), an average volume load of about 4 kg VS per m³ and days was found. In vertical digesters (first stage), an average volume load of nearly 7 kg VS per m³ and days was found. In the secondary fermentation tanks, the volume load averaged about 4 kg VS per m³ and day (Fig. 9).

A key influence of the economic efficiency of biogas plants is the specific methane yield. The specific methane yield is defined as the amount of methane that is produced per kg of volatile solids.

Our monitoring included the measurement of the amount of input substrates, their VS content, the biogas production and the methane content in the biogas on each biogas plant. With these data it was possible to calculate the average specific methane yields in dependency on the digested substrates.

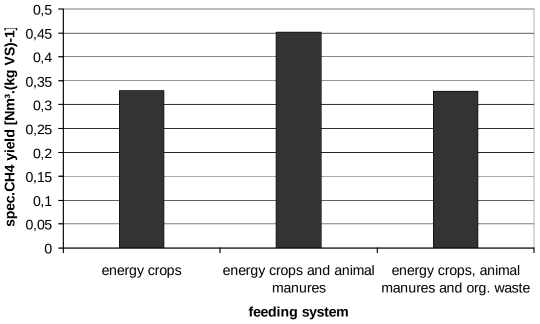


Figure 10: Mean specific methane yield in dependency on the digested substrates

As figure 10 shows, the co-digestion of energy crops and animal manures resulted in the highest specific methane yield. When energy crops were mono digested or when organic wastes were added, the specific methane yield was lower. The co-digestion of energy crops and animal manures guarantees the best stability of the digestion process which results in high methane yields. With mono digestion of energy crops or with the addition of organic wastes, instabilities in the digestion process may easily occur. It is thus essential to provide guidelines on the optimum feeding of digesters and on the optimum use of organic wastes. This is another focus of research of the Division of Agricultural Engineering. Results can be found in Amon, T. et al. (these proceedings).

4 OUTLOOK

This paper presents a first analysis of the data monitored on 40 new biogas plants in Austria. Further research will work on a detailed analysis of the data and on an optimisation of economic efficiency, sustainable crop rotations and fertiliser management.

The increased use of energy crops induced adaptations in digester, feeding, and mixer technologies as well as in the process control. An optimisation of the efficiency along the whole process chain from the substrate input over technology, process control, digestate utilisation up to energy conversion is necessary to promote the very promising potentials of biogas technology and to establish viable biogas plants.

Currently, only 3 – 5 % of the available organic substrates are used for biogas production in Austria. For better exploitation of the available potentials, it is important that the legal framework conditions given under the Green Electricity Act 2002 are further guaranteed. Guidelines must be provided on the optimum feeding of digesters and on the optimum use of organic wastes. Sustainable crop rotations must be proposed that do not rely on the digestion of maize silage alone.

It is also necessary to investigate new ways of the utilisation of biogas like vehicle fuel, gas grid and fuel cells. Currently, biogas is mainly burned in combined heat and power plants.

ACKNOWLEDGMENTS

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