MONITORING OF AGRICULTURAL BIOGAS PLANTS IN AUSTRIA – MIXING TECHNOLOGY AND SPECIFIC VALUES OF ESSENTIAL PROCESS PARAMETERS

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ABSTRACT: The increase of renewable energy production is of great interest today. Biogas technology can contribute an essential part to a sustainable energy system. Therefore the efficiency of technology has to be improved continually. The increased use of energy crops in modern biogas plants induced adaptations in digester and feeding technologies and especially in mixer technologies as well as in the process control. After finalisation of an Austria wide monitoring on 55 modern biogas plants, this paper shows detailed final results. The focus lies on one of the central elements of modern biogas plants: the mixing technology. The monitoring revealed a strong trend towards slow moving mixers with large agitating wings, which can be operated almost continuously. In addition to the technical data, detailed results of the substrata input and specific values of essential process parameters are presented. A stable biological process is a necessary condition for the efficient operation of biogas plants.
Keywords: anaerobic digestion, biogas, energy crops

1 INTRODUCTION

This paper is a continuation of the work presented on the 14th European Biomass Conference & Exhibition in 2005. It includes an update on the current state of legal framework conditions in Austria and the finale and more detailed results of the monitoring on modern biogas plants.

The increase of renewable energy production is of great interest today. The European Union (2001/77/EC) has improved the legal framework conditions for energy production from renewable sources. EU policy implements efforts to strengthen security and diversification of power supply from renewable sources. According to Directive 2001/77/EC Austria should increase the share of electricity derived from renewable energy sources from 70% of gross inland consumption in 1997 to 78.1% in 2010. The Austrian Government transposed the EU directive into national law through the Green Electricity Act 2002 and the amendment of 2006. The Act 2006 regulates the legal framework conditions and guaranteed prices for electricity generated from biomass for the years 2006-2011. 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 as shown in figure 1.

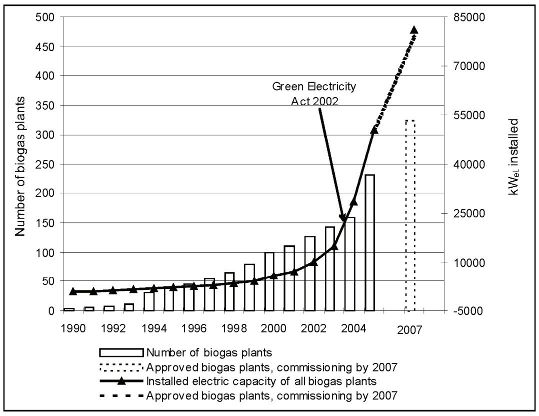

Figure 1: Development of the number of biogas plants in Austria [1]

Current study shows that in December 2005, 231 biogas plants were operated in Austria [2]. A net total of 50.67 MW installed electric capacity were installed. The number of approved biogas plants with a commissioning date by the year 2007 constitutes 323 with a net total of 80.96 MW installed electric capacity [2]. The average installed electric capacity of biogas plants increased from approximately 80 $kW_{el.}$ in the year 2002 on approximately 180 $kW_{el.}$ in the year 2004 and could amount approximately 240 $kW_{el.}$ at the end of 2007 [1].

At the same time 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. Modern biogas plants mainly or only digest energy crops. The new plants comprise a big variety of fermentation technologies and technical equipments with adapted feeding and mixing systems.

In modern biogas plants increased requirements develop over the original functions of mixing techniques. The intensified use of energy crops means higher dry matter and fiber contents in the fermenting substratum. Substrata with higher contents of dry matter have a slower-acting flow behaviour, why a decrease of the rotation speed of the mixer wings is necessary. On the other hand a reduction of the rotation speed makes the use of larger mixer wings possible. They are also necessary, in order to ensure a good mixing.

The increase of the installed electric capacity implicated larger digesters up to a volume of 2,700 m³. Thus additionally the requirements rise to the mixing technology, in order to achieve an evenly access of digester content and to prevent effectively the formation of sedimentary layers and surface crusts. Usually in large digesters the number of inserted mixers is increased.

The results represented in this paper originate from the research project "Analysis and optimisation of new biogas plants" that aimed to point out the current state of the art on modern biogas plants as well as to identify possibilities for their optimization. In this paper the focus rests upon the performance of the mixing techniques currently used and the specific values of essential process parameters.

2 MATERIALS AND METHODS

Within the project "Analysis and optimisation of new biogas plants" 55 modern biogas plants in Austria were analysed that went into operation between 2003 and 2005 and digested increasingly or exclusively energy crops. 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.

The results given in this paper include data from all 55 biogas plants that were included in the Austria wide monitoring. The data were gathered through on-farm visits between February and March 2006. The on-farm visits guarantee a good data quality. Samples of the input substrata and of the digestate were taken in course of the on-farm visits. From the collected data a picture of currently used mixing techniques and their operation modes is made as well as an overview of key process parameters.

3 RESULTS

3.1 Substrata

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

About 10.9 % of the new biogas plants only digest energy crops. About 65.5 % digest energy crops and animal manures, with 61 % of these being fed with pig slurry, and 39 % with cattle slurry. The Green Electricity Act 2006 encourages the digestion of energy crops and/or animal manures, because biogas plants which use organic wastes, so called "cofermentation plants", have a 30 % lower guaranteed price for the produced electricity to those which digest only agricultural feedstock.

About 20 % of the monitored biogas plants digest animal manures, energy crops and organic wastes and only 3.6 % 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.

Within the project the main interest was based on the use of energy crops. The consideration of the quantity of daily substratum input (kg of fresh matter) by including data from all 55 biogas plants showed that 63% energy crops, 34% animal manure and 6% organic wastes were digested. More than half of the used substrata represented energy crops and over 90% of the substrata originated from agricultural primary production.

Most biogas plants digest a multitude of contrasting substrata. Only 3.1 % digest only one substratum. Most of the monitored biogas plants use two to five different substrata as input material. About 13 % even digest six or seven different substrata.

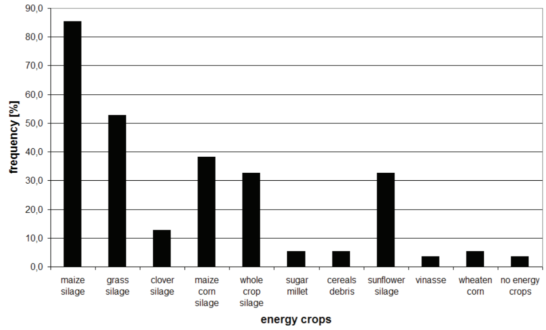

Figure 2: Frequency of used energy crops

The intensified use of energy crops extended the spectrum of substrata. Many different types of energy crops are suitable for anaerobic digestion. Still, maize (85.5 %) is the most widely used energy crop. However, additional energy crops become more and more important: grass silage, maize corn silage, clover, sunflowers, sugar millet and whole crop silage (fig. 2).

3.2 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 substrata directly into the digester. A stable fermentation process and a high methane yield can only be achieved if the input substrata are well mixed, chopped and fed at a nearly constant rate.

In the first run, mainly dropping shafts, flushing systems, and systems with feed screws were used to directly feed solid substrata 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 (57.4 %) and adapted push-off trailers (9.3 %) 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.

The majority of the examined biogas plants supplied fresh substratum to the digester every second hour or more frequently. Approximately 18 % of the plants fed substratum into the digester once per hour.

3.3 Digester systems

The digester is the core of a biogas plant. There are four principal types of digesters: I. vertical completely mixed digester with cylindric design II. vertical completely mixed digester with ring-shaped design III. horizontal completely mixed digesters, and IV. horizontal plug-flow digesters (fig. 3)

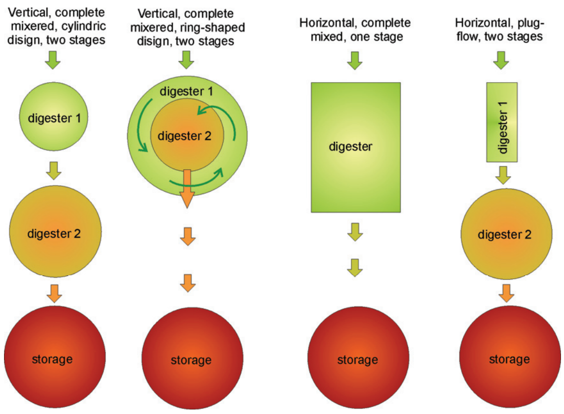

Figure 3. Different digester systems

The vertical digester is a completely mixed digester usually made of reinforced concrete. The substratum 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 3,000 m³. In horizontal plug flow digesters the substratum 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. Horizontal completely mixed digesters are usually made of reinforced concrete and have a volume between 1,000 and 2,000 m^3.

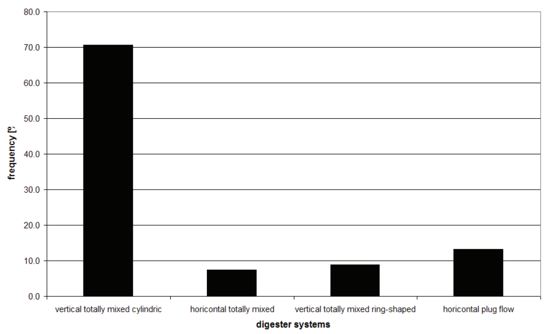

Figure 4: Frequency distribution of digester systems

As figure 4 shows, in Austria more than 80 % of the new biogas plants have vertical digesters. The preferred digester system was the vertical completely mixed digester with cylindric design, with a use frequency of 70%. The special form of the vertical completely mixed digester with ring-shaped design was used in 8.8 % of the biogas plants. Horizontal digesters were employed in the first process step in roughly 20% of the plants, although ferroconcrete polygon plug-flow digesters were used with preference. This sort of digester is manufactured on site, and can hold up to 800 m³. The plug-flow digesters made of steel, which had been used often formerly, were only seldomly used, due to their restricted volume. In 7.4 % of the biogas plants, horizontal completely mixed digesters were used.

For the second stage of fermentation, vertical, completely stirred ferroconcrete containers were used exclusively.

3.4 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 substrata, 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 substrata have a strong tendency to unmix.

The changes in substratum inputs strongly influenced the mixing technologies. The intensified use of energy crops in biogas plants leads to higher dry matter and fiber contents in the digestate. The increase of the digester volume with up to 2,700 m³ rises the requirements on the mixing technology, in order to achieve an even mixing of the digestate and to prevent the formation of sedimentary layers and surface crusts effectively. Earlier predominantly rapid velocity submersible-motor propeller mixers with small propellers were most commonly applied. The monitoring of the new biogas plants revealed a strong trend towards low velocity mixers with large agitating wings, which keep energy consumption at a low level and can be operated continuously. Pneumatic and hydraulic mixers are used only in few individual cases mostly as additional mixing unit to mechanical mixers.

Number of installed mixers

A further trend appears at the number of installed mixers for each digester. The investigations showed that on approximately 46% of the biogas plants only one mixer is installed. However, the tendency goes towards digesters with two or three mixers installed. Only one mixer came particularly into operation on biogas plants with an electric capacity under 250 $kW_{el.}$. On biogas plants with an electric capacity over 250 $kW_{el.}$ mainly two or three mixers were set in. In digesters with a volume up to 500 m³ only in 7.7% two or three mixers were installed. However, starting from a digester volume of 501 m³ 54% of the biogas plants installed two or three mixers, and with a digester volume > 2,000 m³ approximately 85,7%.

Frequency distribution of the type of mixers

The results with regard to frequency of use of the different mixer types showed that for the processing of large portions of energy plants especially low speed motors with low rpm and large paddles dominated. The most widespread in vertical digesters were paddle mixers with 36.6 % of biogas plants surveyed. Submersible-motor propeller mixers were used in 34.7% of the plants, followed by long-shaft mixers (17.8 % of the plants) and paddle mixers in horizontal digesters (8.9 %). Stick-type propellers played only a minor role, with 2 % of the biogas plants.

In examining the proportional distribution of the wattage classes for frequency of the use of mixers, it was shown that submersible-motor propeller mixers were more often used in biogas plants under 250 $kW_{el.}$, while larger plants (over 250 $kW_{el.}$) tended to use low speed motors. Long-shaft mixers were only used in biogas plants > 100 $kW_{el.}$.

Figure 5 shows the frequency distribution of the various mixer types dependent upon substratum input.

Biogas plants that used as substratum 100% energy crops usually combined low speed paddle mixers with submersible-motor propeller mixers. In biogas plants whose substrata mix showed a more than 50% portion of energy crops in the substratum mixture, all types of mixers occurred. Special waste biogas plants used submersible-motor propeller mixers in vertical digesters. The special paddle mixers were employed as standard mixers in the horizontal digester system in all substratum groups.

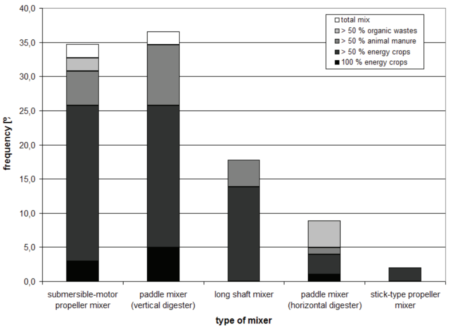

Figure 5: Frequency of the different mixer types dependent upon substratum input

Characteristics of the different mixer techniques

Which characteristics the individual mixer types employed, and how the average running time and intervals were structured, is shown in table 1 for rapid moving mixers and in table 2 for slow moving mixers.

Table 1. Characteristica of rapid moving mixers

	submersible-motor propeller mixer	Stick-type propeller mixer
Ø delivery rate [kW]	13.4	15.0
Ø wings [cm]	71	60
Ø rpm [rev. min.$^{-1}$]	400	400
Ø start-up interval [d^{-1}]	26.0	12.0
Ø runtime per interval [min]	9	11.5
Ø runtime per day [h d^{-1}]	3.9	2.3

Table 2: Characteristica of slowly moving mixers

	paddle mixer vertical digester	long-shaft mixer	paddle mixer horic. digester
Ø delivery rate [kW]	14.8	11.2	1.4
Ø wings [cm]	379	275	190
Ø rpm [rev. min.$^{-1}$]	18.0	36.0	5.0
Ø start-up interval [d^{-1}]	34.0	28.0	42.0
Ø runtime per interval [min]	12.5	10.9	24.2
Ø runtime per day [h d^{-1}]	7.1	5.1	17.0

Rapid mixers displayed an average connected wattage of between 13.4 and 15.0 kW, and their construction was characterised by small paddles of 71 cm (submersible-motor propeller mixers) and 60 cm (stick-type propeller mixer). Accordingly high was the average rpm of the paddles at 400rpm. The results indicated a good suitability of low speed motors for constant usage. Due to the need for such high starting current, the high speed mixers were, on the average, started less frequently, and the running time per starting interval was distinctly less than that of low speed mixers. The whole running time of the high speed mixers came to 3.9 hours a day (submersible-motor propeller mixers) and 2.3 hours a day (stick-type propeller mixer), only half of that of low speed paddle mixers.

Paddle mixers reached the highest starting frequency with 34 starts of the mixers per day. At a running time of 12.5 minutes per starting interval, the paddle mixers in the completely mixed, cylindrical digester reached the longest stirring times with 7.1 hours a day. Only paddle mixers in horizontal digesters, which displayed the least connection wattage and rpm, mixed horizontal digesters longer (17 hours per day). Paddle mixers in horizontal digesters were developed especially for constant use.

Slow-running mixers better meet the requirements of the microbes, since high rotational speeds of mechanical mixers impair process stability. High shearing stresses can cause a sterical separation of syntropic living micro organisms and reduce so the degradation speed. The direct influence of the mixing intensity on the microbial activity is however still controversial.

Possibilities for combination

Biogas plants that use 100% energy crops as substratum generally combined low speed paddle mixers with submersible-motor propeller mixers. Thus, the advantages of both mixing techniques could be employed optimally. Where only one mixer was used in a vertical, completely mixed digester, paddle mixers were installed horizontally or vertically in a majority of 71.4% of the plants. In 42.2 % of the plants with two mixers in a digester a high speed one and a low speed one were combined. 34.1 % of the plants installed only high speed mixers, and 22.9 % installed only low speed mixers in their digesters.

Power usage

The mixers belong to the biggest power consumers in a biogas facility, for which reason operators often keep the running times of the mixers down to a minimum in order to avoid peak loading. With increased usage of energy crops, the mixers' energy demands can amount to 10% of the facility's power production. Paddle mixers displayed the highest power demands, conditioned by the long running times in combination with high starting current at 105 kWh per day. The average power usage of submersible-motor propeller mixers lay at 52.26 kWh per day, considerably less. The enquiries, however, showed that roughly 60% of all biogas plants with only one mixer installed used paddle mixers. The high speed mixers were usually installed in pairs in each digester, or as one together with a low speed one. From this point of view, two submersible-motor propeller mixers displayed approximately the same mixing effect, and a similar power consumption level to that of a paddle mixer.

Power requirements of the mixers are high. On the average, the mixers used 4.8% of the produced electricity. The percentage of power demand of the mixers in the digester waxes with the size of the plant. While biogas plants under 100 $kW_{el.}$ used 2.7 % of their daily power production, those of the power class 251 – 500 $kW_{el.}$ needed 5.5 % for the agitation in the digester. Biogas plants with electrical connection wattage of over 500 $kW_{el.}$ showed very high values for the demands on daily power production with 20.6%, which would suggest a great potential for improvement in the plants' efficiency.

The reason for it lies in the smaller active volume (m^3 digester volume per $kW_{el.}$ installed) of large biogas plants. Biogas plants over 500 $kW_{el.}$ had to process substrata on the average in smaller digesters in order to achieve the higher biogas yields in comparison to the class 251 – 500 $kW_{el.}$. This led to the necessity for increased stirring to maintain homogeneity of the fermentation substratum.

Stirring technique in the secondary digester

In the secondary digester only one mixer was installed in 65% of the cases, two in 35% of the cases. In 52.5 % of the cases submersible-motor propeller mixers were used, in 35.6 % of the plants, paddle mixers, and in 11.9 % of the plants, long-shaft mixers. Agitation in the secondary digester is not of such great significance as in the digester, since after a fermentation phase, the substratum is already considerably more homogeneous, and also demonstrates less dry matter content. This is also apparent in the average running times of the mixers in the secondary digester which came to 3.9 hours per day.

The mixer as a weak point

In spite of the great significance of the mixing technique, in 44% of the biogas plants, dysfunctions were reported most frequently in the area of agitation. The flaws were various and affected all diverse types of mixer types. Submersible-motor propeller mixers were affected especially by damage to the engines and anchors, and problems with the pull rope. For paddle mixers in horizontal digesters agitators were sometimes broken, and then repaired with additional supports to strengthen them. Low speed mixers in vertical digester also caused malfunctions due to broken axels, false faulty paddle design, or faulty anchoring, stopping operation of the plant for up to three weeks.

The timely coupling with the direct feeding system is also decisive for the functionality of the mixers. The content of the digester ought to be brought into motion through agitation before solid materials are introduced into the digester. For good mixing, the mixers should continue running for a while after the introduction. The position of the mixer in the area of introduction also plays a central role. If the distance is too great, the tendency for the formation of floating or sedimentary layers is increased.

The functionality of the mixing technique in the digesters is essential for the process stability and security. Hence, dysfunctions and interruptions can cause great trouble and loss of production. Therefore, it is necessary to appreciate the great significance of agitation in the digester, and to optimize the mixing technique via intensive R&D activities.

The effect of insufficient mixing is that installed digester volumes are often insufficiently used, i.e. unfermented substratum leaves the digester almost without degradation. Through insufficient degradation of the organic matter the biogas yield is reduced on the one hand, and on the other, the methane emissions from the unfermented substratum can adversely affect the environment. Furthermore, surface crust and sedimentary layers can often only be destroyed with great effort.

3.3 Process benchmarks

Biogas plants that increasingly digest energy crops often lead to quite sensitive fermentation processes, because the buffer effect of liquid manure on the pH value and on the microorganisms is lacking. Because of this, microorganisms react quite sensitively to slight changes in temperature, to pH variations, or to high volume load. By changing the quantities of additional material, the available micro- and macro-nutrients vary with the volume load, leading to changes in the pH value, to an increase in fatty acids, and further to subsequent decrease in the gas yield. The sensitivity comes from a narrower microorganism spectrum, whence a change in the nutrition supplì cannot be reacted to as quickly. The higher the portion of animal manures, the more various bacteria, and the higher the buffer capacity were.

For this reason it is ever more important for modern biogas plants that the parameters on material and energetical evaluation of the fermentation process be watched over constantly.

Temperature

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 prefers 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 substrata, but at the same time require a higher energy input for the digester heating and may cause an increase in process instability.

The monitoring in Austria 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.

Hydraulic retention time

The average hydraulic retention time is an important influence on the economic efficiency of biogas plants and on the methane yield that is produced. The average hydraulic 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 hydraulic retention time is defined as digester volume divided by the volume of daily substratum input. It is dependent on the type of digester. Vertical digesters require a slightly higher hydraulic retention time than horizontal digesters.

Horizontal plug-flow digesters displayed the shortest hydraulic retention time in the first fermentation phase with approximately 19 days. In the second fermentation phase, which occurred in vertical completely mixed digesters in all plants with plug-flow digesters the average hydraulic retention time amounted to approximately 42 days (fig. 6). The entire hydraulic retention time of 62.8 days corresponded to the guidelines recommended in the literature, and indicated a good capacity utilization in the biogas plants.

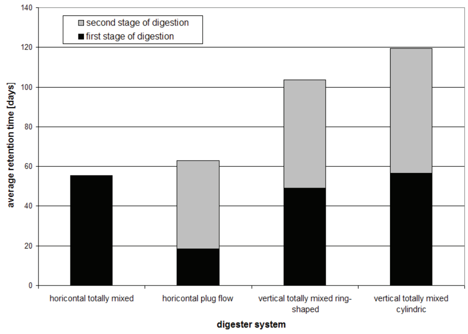

Figure 6: Mean average retention times in horizontal and vertical digester in dependency on the first and second stage of digestion

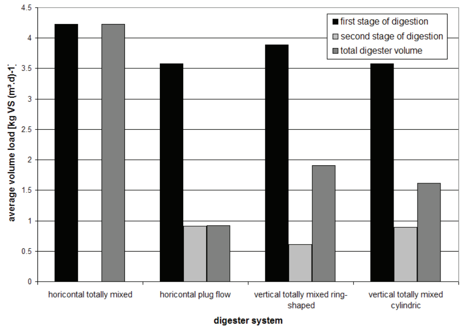

Figure 7: Mean average volume load in horizontal and vertical digester in dependency on the first and second stage of digestion

Biogas plants with horizontal completely mixed digesters were only run with one phase, and had a mean hydraulic retention time of 55.8 days. Considering the possibility of short-circuit, which could mean the pouring out of fresh substratum into the end storage, this retention time could prove too short for sufficient degradation of organic substance.

In contrast, vertical complete mixed ring-formed or cylindrical digesters displayed quite long hydraulic retention periods (fig. 6), which could indicate an over dimensioning of the digesters. An exact assignment of hydraulic retention times, however, can only occur in connection with the raw materials used in qualitative and quantitative respect. The hydraulic retention time must therefore always be seen in connection with the resulting volume load.

Volume load

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

The monitoring in Austria showed that the average volume load is connected with the digester type. The volume load of the biogas plants examined, with respect to the whole volume load was between 0.5 for two phase biogas plants and 6.8 kg VS per m^3 volume load and day for one-phase plants. The mean volume load in horizontal completely mixed digesters came to 4.3 kg VS m^{-3} day^{-1} (fig. 7). Since these digester systems are operated on a one-phase basis, the volume load, with reference to the entire volume load, which disperses the daily substratum input to all digesters, yields likewise a mean of 4.3 kg VS m^{-3} day^{-1}. In connection with an average retention time of approximately 55 days (fig. 6) it is to be assumed that these systems display a lesser degree of degradation of the organic substance, and a considerable potential in remainder gas.

In the horizontal plug-flow digester the average volume load amounted to 3.58 kg VS m^{-3} day^{-1} in the digester and 0.9 kg VS m^{-3} day^{-1} in the secondary digester. The low volume load in the secondary digester showed the good degradation rates in the digester. It would also have been due to the much greater volume in the secondary digester, since all secondary digesters were vertical completely mixed containers, and no more fresh substratum was added. Consequently, the net total volume of 0.91 kg VS m^{-3} day^{-1} was quite low for this system.

In vertical completely mixed digesters, the volume load in the first process phases in cylindrical digesters on the average 3.58 kg VS m^{-3} day^{-1} and in ring-formed digesters, 3.89 kg VS m^{-3} day^{-1}. The low volume loads in the second process phase also demonstrated a high degradation of organic substances. However, the results raise the question of whether biogas plants with two process phases really operated at full capacity. The rather low sum volume load in combination with the long retention times suggest rather a too large dimensioning of the digesters (fig. 7).

Specific methane yield

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 substrata, 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 substrata.

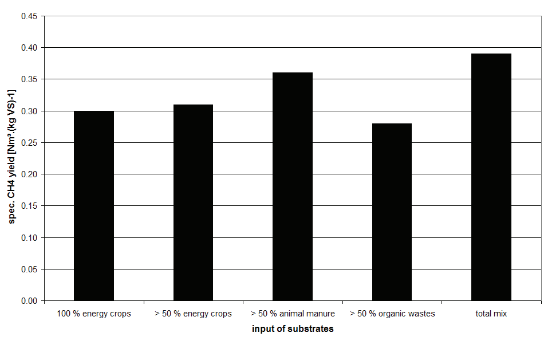

Figure 8: Mean specific methane yield in dependency on the digested substrata

Figure 8 shows that through the addition of organic dry matter, biogas plants that digest 100% energy crops yielded somewhat less specific methane (0.30 m^3_N methane $(kg\ VS)^{-1}$) than those that fermented with additionfertilizer of animal manures. The range of values yielded for energy plant plants was 0.26 – 0.34 m^3_N methane $(kg\ VS)^{-1}$). With an increase of the animal manure portion, the specific methane yield also rose at an average of 0.36 m^3_N CH_4 $(kg\ VS)^{-1}$. The co-fermentation of energy crops and animal manures effected a stable fermentation process and a high methane yield. The highest rates of methane production were had in those biogas plants that fermented energy plants together with organic waste and animal manures. At 0.39 m^3_N CH_4 $(kg\ VS)^{-1}$, though, the figure for specific methane yield was quite high, and needs to be rechecked.

Degree of degradation

The degree of degradation indicates the percentage of substratum organic dry matter that has been degraded after the hydraulic retention time in the digester.

A complete degradation of the organic substance unto mineralization is not possible, as a part of the degraded substratum (ca. 3 – 10%) is converted into biomass, and is unavailable for the production of biogas. For animal fats and carbohydrates, conversion rates of c. 85% are realistic, and for vegetable oils and proteins, conversion rates of 50 – 70% [4]. Modern energy crop biogas plants, with sufficient digester volume, achieve degradation rates of over 80 % [5]. An almost complete degradation of organic dry matter would require extremely large digester volumes, which is not practically feasible from a financial perspective.

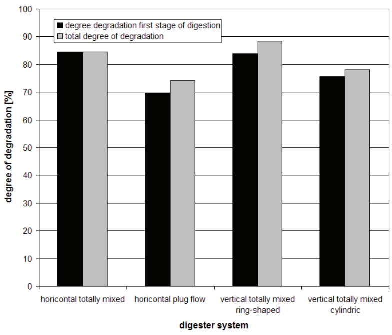

Figure 9: Mean degree of degradation in horizontal and vertical digesters in dependency on the first and total degree of digestion

Among the plants examined, in biogas plants with horizontal completely mixed digesters the range of the degradation rate was 78.6 – 84.5 % (fig. 9). Biogas plants with horizontal plug-flow digesters displayed the least degradation rate, with a minimum of 44.3 %, although one plant also achieved a degree of 89.4%. The highest degrees of degradation were had in plants with vertical completely mixed ring-formed digesters with a maximum of 96.4 % degraded VS and a minimum of 96.4%. The broadest range was had with vertical completely mixed digesters in cylindrical alignment, although this is also a case of N = 26, the highest sample. The range was 54.6 – 90.9 %.

The results show that in all biogas plants, independent of the digesters' construction, degradation rates of approximately 90% can be reached, although these require an optimum fermentation process and sufficiently long hydraulic retention times. Long retention times must be attended to especially with less degradable substrata such as protein- and fat rich materials.

Figure 9 shows the high degrees of degradation distinctly that were achieved in completely mixed digesters systems. It also shows that over 95% of organic dry matter was degraded in the digesters, and only a small portion in the secondary digesters. This was also to be expected, due to the low volume load in the second phase.

4 SUMMERY

- Modern biogas plants mainly or only digest energy crops.
- The intensified use of energy crops extended the spectrum of substrata.
- The increased use of energy crops induced adaptations in digester, feeding, and mixer technologies as well as in the process control.
- The changes in substratum inputs strongly influenced the mixing technologies. The intensified use of energy crops in biogas plants leads to higher dry matter and fiber contents in the digestate.
- The monitoring of the new biogas plants revealed a strong trend towards low velocity mixers with large agitating wings, which keep energy consumption at a low level and can be operated continuously.
- Paddle mixers, employed at 36.6% of all biogas plants examined, enjoyed the broadest distribution.
- The timely coupling with the direct feeding systems of solids was decisive for the functionality of the mixers.
- A stable biological process is a necessary condition for guaranteeing the efficiency of biogas plants.
- Due to the rapid increase in the number of biogas plants, extant concepts for biogas plants whose techniques mainly use liquid manure have not been adapted to the increased use of energy crops, and no adapted system improvements have been integrated into the planning of modern biogas plants. One effect of this rapid development is that some digesters have been over-dimensioned, and the substrata have had hydraulic retention times of up to 350 days.
- An optimisation of the efficiency along the whole process chain from the substratum 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.

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