Mono-fermentation of Energy Crops - Experience from the Biogas Plant in Obernjesa

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Abstract:

The concept for this Agricultural Biomass biogas plant originated with Prof. Konrad Scheffer from the Institute of Plant Utilization at the University Kassel/Witzenhausen, Germany. The input consists entirely of energy crops such as corn stalks and grass. The fresh crops are processed and stored as silage in concrete bins. The silage process preserves the energy value of the plants until needed in the digester. The silage is fed into the digester throughout the year resulting in a supply of electricity to the power grid. The biogas plant is located on the Hans-Walter Körber-Harriehausen farm, in Obernjesa nearby Goettingen, Lower Saxony, Germany. Financing was supported by a significant subsidy from the Dr.Volker-Reimann-Dubbers foundation. The plant was under construction from autumn 2002 until spring 2003 and start-up occurred in March 2003.

1. Introduction

The idea behind the mono fermentation biological gas facility introduced here is to create a closed cycle within a single agricultural enterprise. The valuable end products are electrical and heat energy. Essentially, this biogas project aimed at showing that agricultural land can be put to an optimal use with a two-crop system if the principles of closed loop recycling management as well as economical and ecological conditions are taken into account.

Fig. 1: Biological gas facility OBERNJESA

At this site the connection between the biological gas facility and agriculture goes far beyond what is known so far. For many years now it is common for a farm to have a biological gas plant utilizing liquid manure available, organic wastes and perhaps some crops. With the biogas plant in Obernjesa the development team wanted to create a facility, which would be an equal part of the farm, meaning that is has the same economic weight as the crop farming itself. By having two equal businesses on his farm the farmer would depend less on the crop market and would thus broaden his business opportunities. The biological gas facility in Obernjesa was planned and built to meet these objectives. This is not an „end of the pipe waste treatment system“, rather it is a process which is an important part of the Obernjesa agribusiness and has strong implications on the farm’s agricultural decisions.

2. The biological gas facility

The OBERNJESA biological gas facility involves one central container (Fig. 2) with a top mounted mixer, an external heat exchanger and a secondary fermenter. The plant is operated as a single step process at mesophilic temperatures.

Various crops are used as input material. After harvesting these materials are placed in a silage bunker (Fig 1) alongside the fermenter. From there the silage is placed in a solids input device (Fig 3.) using a rubber tired front end loader throughout the year.

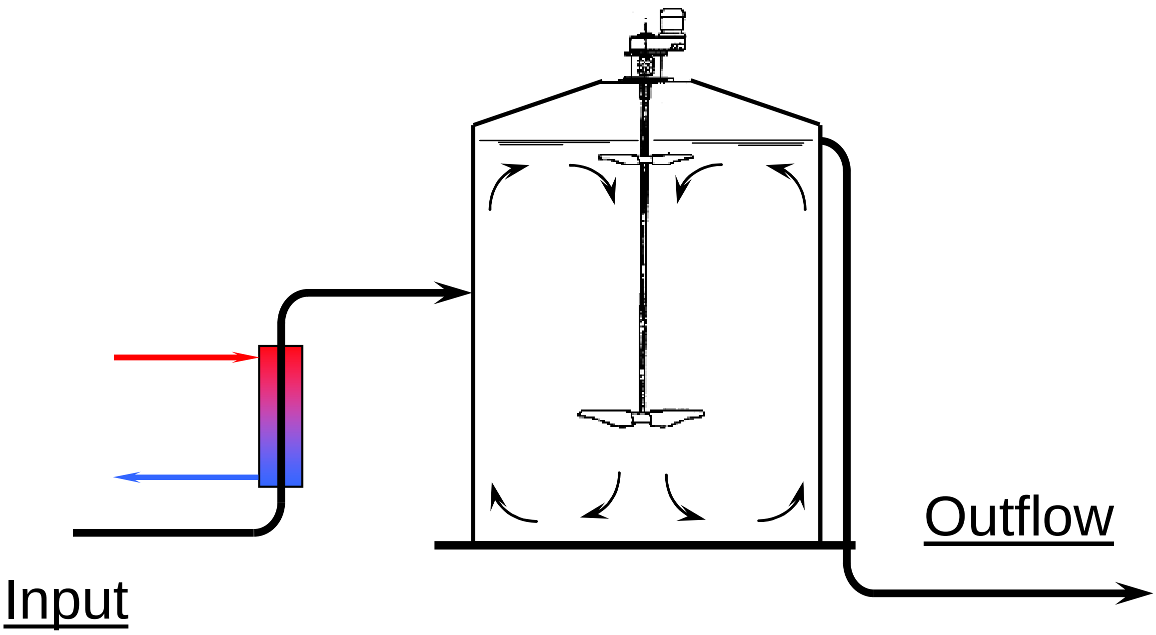

Fig. 2: Process engineering biological gas facility OBERNJESA

Heat is provided to the process by an external heat exchanger located in the building between the primary and secondary fermenter. Liquid is removed from the container, heated in a controlled manner and returned to the fermenter. This means that no other equipment needs to be installed inside the digester. The fermenter is a concrete tank with a volume of approximately 600 m³. A primary goal was to apply optimal mixing and substrate heating technologies allowing the fermenter to run on high organic loading rates Also, the equipment had to contend with fibrous input material which has a strong tendency to create a floating mat or swimming layer. To contend with these issues robust technologies were selected which are usually reserved for larger scale installations.

Fig. 3: Primary fermenter, solid input device in the foreground. Notice the inflated gasholder roof on the secondary digester behind the left side of the primary digester and the dual fuel CHP to the right.

The secondary fermenter is a larger concrete tank with a volume of approximately 1,000 m^3 equipped with a double membrane gas holding roof. From this flexible gas holder, biogas is supplied directly to a combined heat and power (CHP) plant. This containerized plant (Fig. 4.) includes a dual fuel engine and generator with an electrical output of 110 kW. Heat from the engine is transferred to the process through the heat exchanger and to the farm house and office building.

Fig. 4: (Combined Heat and Power (CHP) Plant alongside the fermenter. Biogas-Blockheizkraftwerk = BHKW)

3. The enterprise

Between March and May of 2003 the biological process was started, initially with pure liquid manure. In April and May manure was replaced gradually with silage as the input material. The graphs below show the operating results from this period. Figure 5 begins with week 23 (beginning of June) when the power output in kW had stabilized and runs to the end of the year. The graph on Fig. 6 covers the same period comparing the daily input in tons to methane content in the raw gas. The wide swings shown on the graphs reflect the problems and challenges an operator faces when he starts running a new biological gas facility.

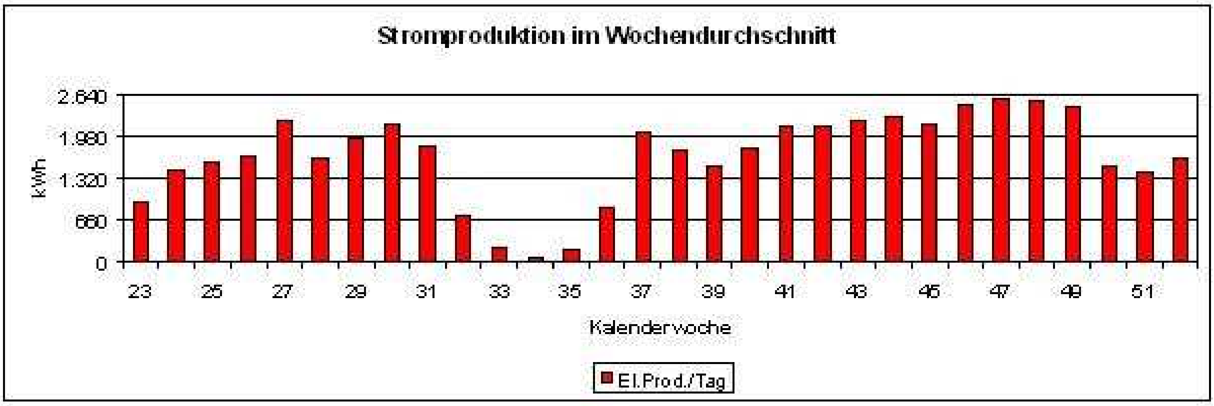

Fig. 5: Current production in the week average, June - December 2003

It was not until week 27 that it could be said the facility achieved full utilization of the engine generator. The theoretical output of the 100 kW_{el} dual fuel jet ignition engine/generator is 2,640 kWh per day. In week 27 the output reached 2,237 which corresponds to the basic utilization factor of 85%.

Then, there was an incident in the period of calendar week (CW) 32 to 36. In this period the biogas facility was substantially over fed by the operator's vacation replacement - see fig. 6.

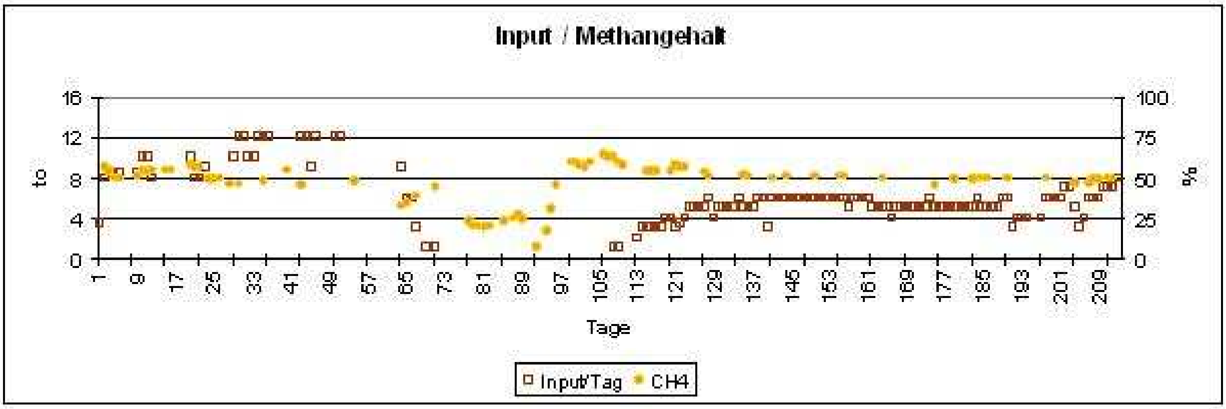

Fig. 6: Input quantity tons per day and methane content, June - December 2003

The facility was designed for an input quantity of 6 metric tons of fresh fodder per day. This level was clearly followed in the right half of fig. 6. In contrast to this 10-12 tons per day were fed in the period between day 30 and 50. The process can handle this overfeeding for some time which demonstrates the high level of process stability; it finally reacted about day 60 when the gas content dropped.

At that point silage feeding was stopped and the fermenter was restarted using active liquid manure from a neighboring farm. Starting in the autumn of 2003 the operator was experienced and the facility really began the full operation of the business. At the end of 2003 the solid input technology was replaced by a system with a larger storage capacity. Essentially the stable and now current production period began in the second half of 2003.

4. Field-operational influences on the enterprise of the biological gas facility

As previously discussed the underlying design concept for the facility was that the biological gas facility would be fed with various and changing arable crops. For example during 2004, the first full year of operation, the input material was changed six times. At the beginning of the year a residual quantity of triticale/rye silage was used. Then in February it was changed to a corn/sunflower silage mix. The affect of this change can be clearly seen in fig 7, as a sharp increase in the week's daily average power output. Then in the early summer a slow transition from the corn/sunflower to green rye then later to supplementary wheat silage. Over this same period the power production decreased. As a counter measure the operator fed a larger quantity as well as supplemented with freshly harvested green crops. However it was not until the feed was supplemented with corn in October that the power production increased to a satisfactory level. From this data it is clear that there are different qualities of silage when it comes to feeding a biogas plant. The biogas plant operator will gather experience that is similar to the cattle business in the quality of the feed having a direct result on the product. It is questionable, though, whether they have similar flexibility when it comes to comparing a biogas plant to livestock.

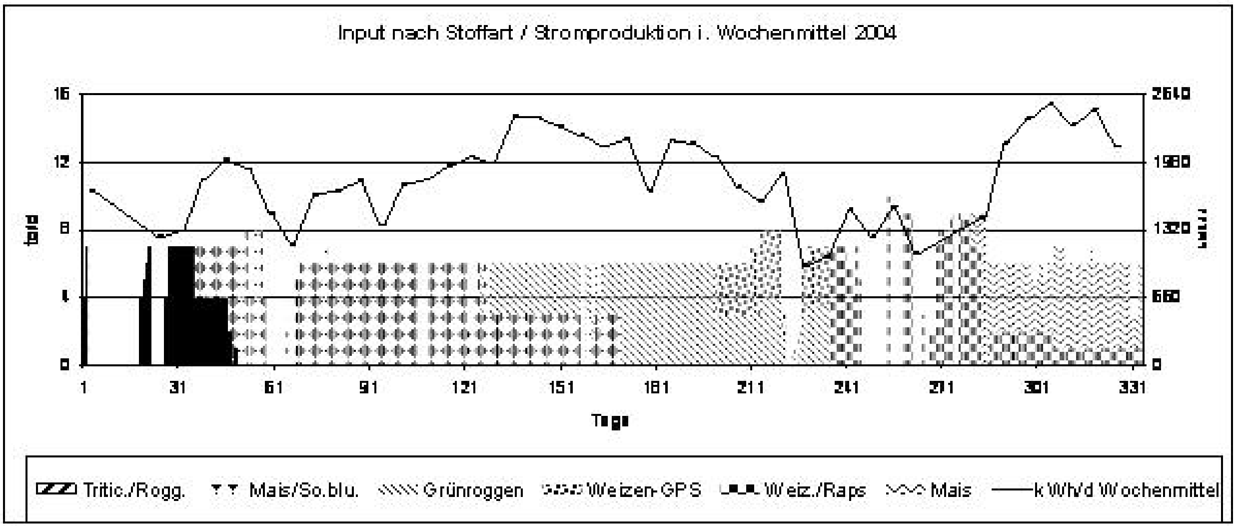

Fig. 7: Input after kind of input, current production in the week means 2004

During 2004, the production curves indicate that something happened every few months affecting the steady flow of energy from the facility. In order to evaluate these breaks additional data must be considered. In Figure 8 the input quantities as well as current energy production are shown. Also shown are the down times of the CHP (BHKW), the additions of liquid manure, and the removal of digested liquid. The spent substrate or digestate is removed from the secondary fermenter and distributed to the farm fields through a dragging hose irrigation system. Digestate was removed six times during the year respectively 450 m³, 460 m³, 460 m³, 300 m³, 520 m³ and 360 m³. This digestate is removed from the secondary digester (this plant has only two tanks – primary digester and secondary digester) as part of the normal operation. As a consequence biogas expands to fill the additionally available space. The withdrawal rate of the digestate is higher than the gas production rate and the volume withdrawn exceeds the capacity of the flexible gasholder roof. Therefore less gas is available for the engine and the electricity production drops immediately after effluent removal. Also, at other times gas production exceeded the 1,100 m³/day capacity of the dual fuel engine and significant volumes of gas had to be vented. These incidents explain the breaks in energy production although the process in the biological gas facility ran perfectly stable.

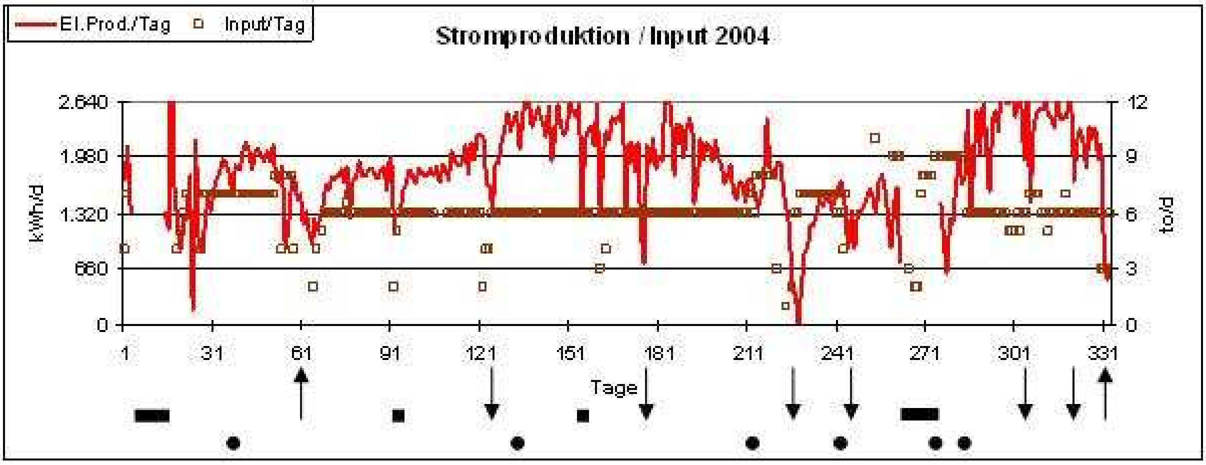

Fig. 8: Daily production of el energy / input of fodder 2004, ■ indicate BHKW down-times, ● to changes of substrate, ↑ liquid manure additions, ↓ fermenting substrate withdrawals.

5. The technology

The biogas facility has operated continuously since the late summer/ early autumn of 2003 with the exception of a two week loss of the engine caused by a maintenance error made by the supplier's mechanic. During that time the operation continued with the biogas burning in a temporary mobile flare.

Altogether there were two pieces of equipment which developed technical problems during the start up phase - the central agitator and the CHP:

A) The roof mounted central agitator in the primary fermenter operates continuously. The agitator consists of an electric motor a gearbox transmission and a shaft dropping down into the container mounted with paddles. Within three months of starting a problem developed in the gearbox. The manufacturer replaced it within a day and the agitator ran trouble free to the end of 2003. Then the gearbox started to fail again. As it turned out, the transmission had not been sized properly for the substrate. Obernjesa was the first silage fed digester ever starting operation. Initially selecting the wrong size gearbox can be considered part of the learning or development process of this innovative approach. Since the more robust transmission was installed in the winter of 2003-2004 the fermenter has been mixed continuously and perfectly for over a year without a problem.

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B) The working reliability of the CHP is in contrast to this. To understand refer to figs. 8-11 which cover the CHP (BHKW) down times during the year 2004. Unfortunately there were other interruptions and only the longer interruptions are shown on the graphs. It is worth noting that the operator was extraordinarily careful with maintenance and followed the manufacturer's recommendations in all ways. This makes it all the more incomprehensible as to why in September-October there was a second total failure. At this time the engine was removed and replaced completely after only approximately 1.5 years of operation.

The quality of the gas with respect to CH_4 is around 50% as shown in fig. 11. The concentration of hydrogen sulfide in the raw gas was lower than gas produced from liquid manure and waste plants due to the crop based input material. In addition the desulfurization system functioned perfectly. Therefore the second engine failure cannot be explained from by biological gas production quantity, gas quality or engine maintenance.

6. Anaerobic biology

The total solids (TS) content of the input material runs between approximately 25 and 35%. Soon after start up a stable biology was established in the fermenter and has been maintained at 6-7% dry substance content. This is a level that can be mixed well.

All together the figures provide a set of data which represents the actual operation of the biological gas facility in 2004. This data is in accordance with common theory of anaerobic digestion. More information on this biogas facility can be found in [1, 2 and 3].

All of this valuable data, however the following fact is more important: since the starting phase in July 2003 the fermenter did not require any heat with the exception of periods of time when the system was upset. At the end of 2003 the records indicated that during the summer the temperature in the primary fermenter exceeded 45 ℃. In the winter the temperature dropped although remaining at mesophilic values. From this it can be surmised that biogas fermenters fed only with silage develop their own heat in amounts sufficient to allow the process to proceed year round.

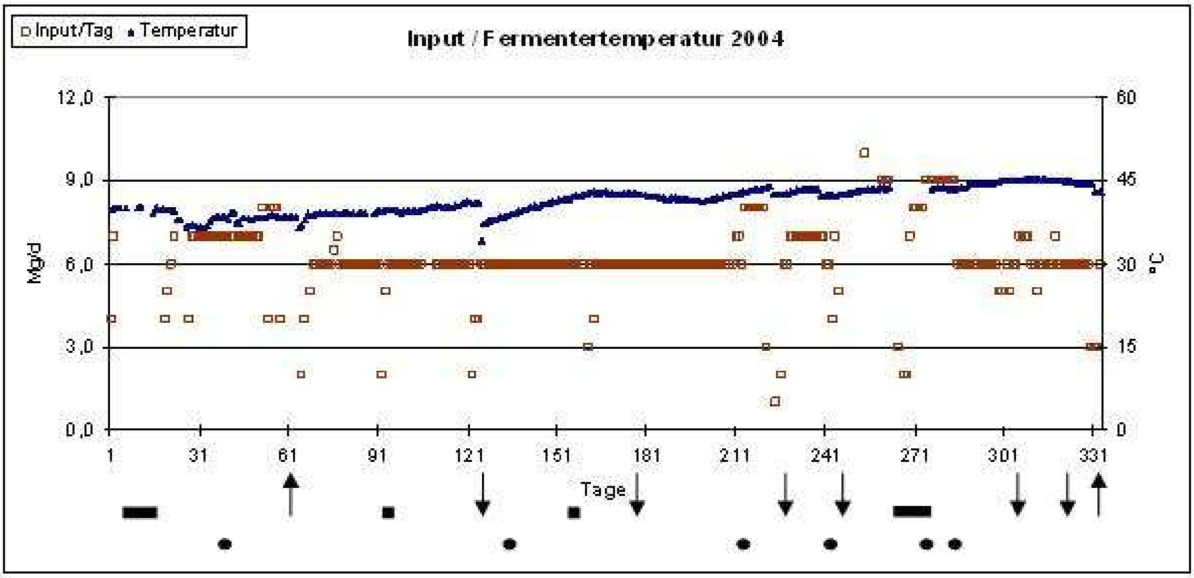

Fig. 9: Input quantity, fermenter temperature 2004, ■ BHKW down-times, ● to changes of substrate; indicate ↑ liquid manure additions, ↓ fermenting substrate withdrawals.

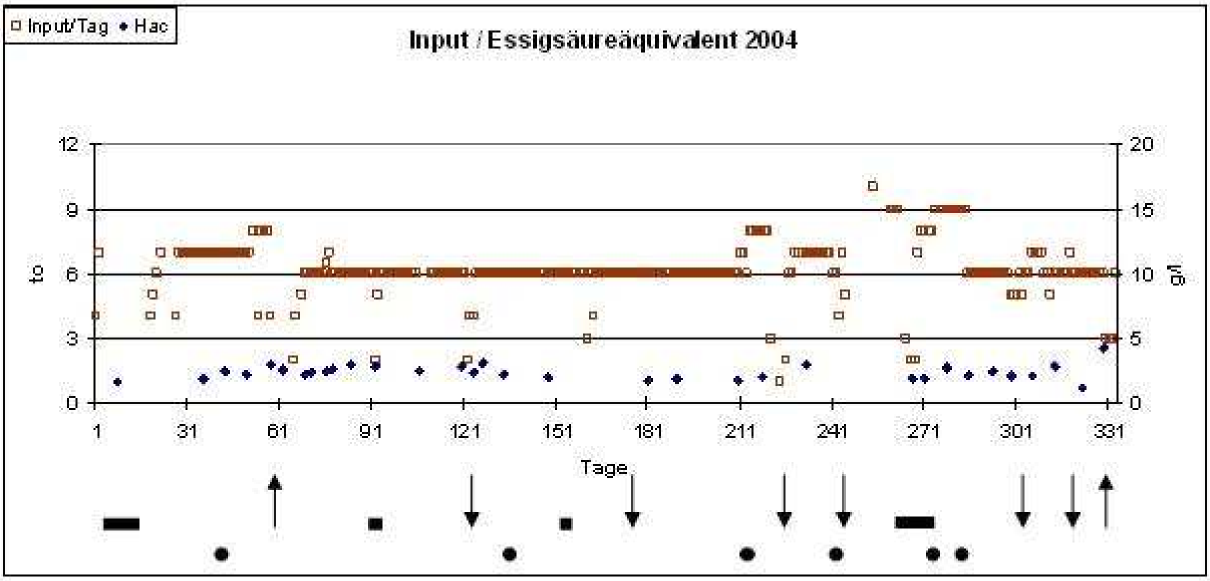

Fig. 10: Input quantity and Acetic acid equivalent vs. days in 2004, ■ BHKW down-times, ● to changes of substrate, indicate ↑ liquid manure additions, ↓ fermenting substrate withdrawals.

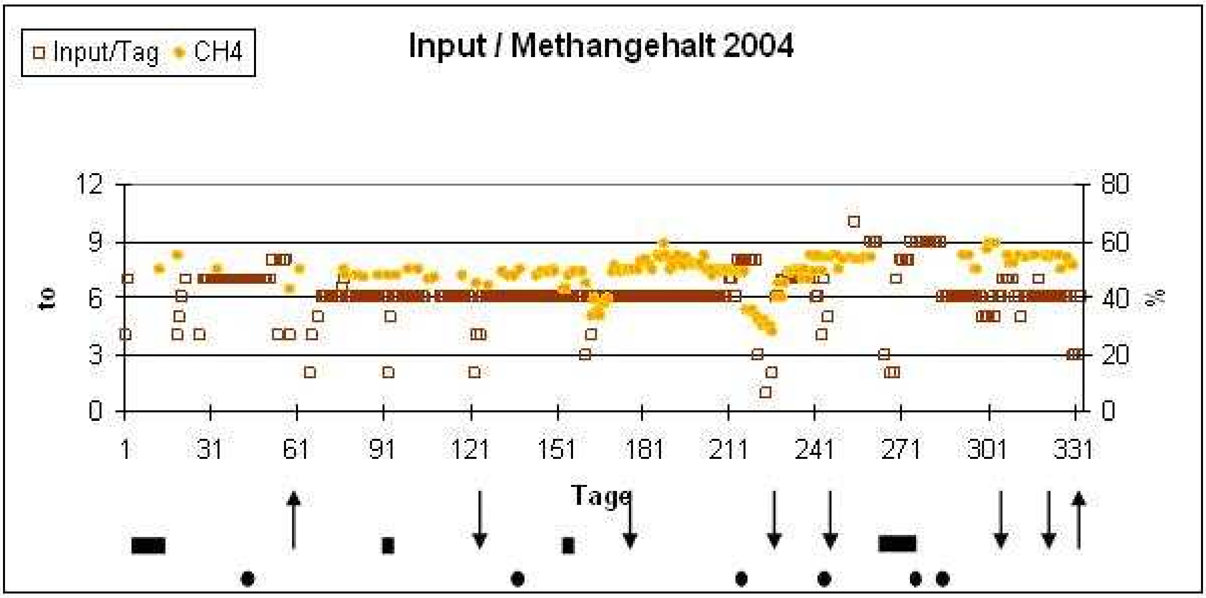

Fig. 11: Input quantity, methane contents vs. days in 2004, ■ BHKW down-times, ● to changes of substrate; indicate ↑ liquid manure additions, ↓ fermenting substrate withdrawals.

In anaerobic fermentation the concentration of volatile fatty acids defines the health of the biological process. In fig 10 the values are higher than those usually observed in stable liquid manure biological gas fermenters. Even at these higher levels the process was extremely stable. This was proven when the process continued in spite of extreme over feeding during day 30-50 in 2003 (see fig 6.) when it took weeks for the buffer capacity to be exceeded.

Although liquid manure was added to the fermenter twice during 2004 the subsequent two year operation has proven beyond doubt that the biological gas facility can operate on silage alone. The ten month continuous operation between liquid manure supplementation means that multiple generations of microorganisms must have survived and flourished after being added with the manure. This evidence supports the viewpoint that liquid manure would only need to be added just once into a pure silage based biogas fermenter. The data also supports that whenever the plant gets sick a prescription of liquid manure will put it right again in short order.

Due to the input substrate the methane concentration settled at the lower edge of the usual range of values for agricultural biogas fermenters. Concentrations of approximately 50% CH4 are typical for silage fed systems and the values represented in fig. 11 correlate well with the input quantities represented in fig. 7. For example, as the input volume was increased in the period from day 211 to about 220 to compensate for the poorer silage quality, the methane percentage steadily reduced. This is to be expected as it can be explained by the increased hydrolysis effects. Hydrolysis, the first step in the digestion process produces only carbon dioxide gas. The increase in input substrate volume would therefore produce a related increase in carbon dioxide and as a consequence a reduced methane concentration. When the operator noted this, the feed rate was sharply reduced on day 220 which allowed the methane concentration to recover.

7. Summary

The technology provided for the Obernjesa biogas facility provided a good solution. After less than one year the solids input device was replaced with a larger model which now fulfills the requirements of the agricultural enterprise regarding operability. In addition, the problem which affected the top mounted mixer's gear box was solved by installing a more robust version. The last fundamentally technical problem remains a concern. The dual fuel engine in the Combined Heat and Power unit was vexed with serious problems and resulted in low availability. This presented the operator with repair cost and down time resulting in loss of income for the biogas enterprise. Unfortunately, the supplier of the CHP unit is not in a position to provide a solution. Thus the burden remains with the operator.

The biological process has and is working to a large extent trouble free. In addition, considering that this is the first pure silage fed biogas facility of its kind, the overall process has been able to operate for more than two years as a stable process proving the viability of the pure silage facility.

8. Literature data

[1] Fischer, T. and H. - W. Körber Harriehausen, Fermentation gas from grass - bio energy yard Obernjesa, conference volume for meeting „Holistic energy production from NaWaRos", Hildesheim, 26. June 2004

[2] www.KriegFischer.de/Ver öffentlichungen

[3] www.Bioenergiehof.de