CASE STUDY HIGHLIGHTING THE BENEFITS OF MONITORING AND CONTROL FOR IMPROVING THE PERFORMANCE OF AN ANAEROBIC DIGESTION PLANT

SITE: BRUCK/LEITHA BIOGAS PLANT, AUSTRIA

PRODUCED AS PART DELIVERY OF:

Promotion of bio-methane and its market development through local and regional partnerships
A project under the Intelligent Energy – Europe programme

Contract Number: IEE/10/130
Deliverable Reference: D2.2
Delivery Date: May 2012

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1.0 INTRODUCTION / OVERVIEW

The biogas / biomethane plant is located in an arable region approximately 40km to the east of Vienna in the federal state of Lower Austria in the eastern part of Austria. The biogas plant is operated as a co-digestion plant and utilizes organic waste material to a high extent for the production of a high-quality biogas. The plant has been commissioned in the year 2004 and initially produced electric power and heat for the local district heating grid using CHP-gas-engines. In the year 2007 the biogas plant has been complemented by the erection and commissioning of a biogas upgrading plant producing biomethane for natural gas grid injection. A part of this gas is consumed in the local low-pressure grid; the remaining part (especially in summer and during the night) is compressed to 60bar and injected into the regional high-pressure gas grid. The manufacturer of the upgrading system was Axiom Angewandte Prozesstechnik GmbH, the complete biogas/biomethane production facility is operated by Biogas Bruck/Leitha GmbH.

2.0 PLANT DESCRIPTION

Feedstocks for the anaerobic digestion plant are basically organic residual materials of varying origin. These comprise organic residues from agricultural processes and food production, expired packed and unpacked food, lecithin fractions from biodiesel production, organic waste material from separated collection at households and local commerce, fat separator residues, cooking oil and fat, dairy wastes and slaughterhouse wastes. Total feedstock consumption is approximately 28,000 tonnes per year.

2.1 Pre Treatment

Depending on the type of feedstock different pretreatment steps and storages are used. Liquid material is stored in two medium size buffer tanks. Solid organic material is stored in a clamp silo at the plant. Packed material (expired and refused food) is unpacked mechanically and washed to the liquids buffer tank. Surface water runoff from the digestion plant is collected in a tank to provide all necessary process water for the digestion plant. The feedstock is mashed up together with this water in one out of two mashing tanks and the dry matter content is adjusted. During the automated pumping to the two primary fermenters, the solid fraction is chopped to approximately 10 mm particle size. Around 100 t of feedstock is transported to the fermenters per day.
2.2 Anaerobic Digestion and Digestate

The feedstock is directly pumped from the mashing tanks to the primary digesters. Currently, three digesters of 3,000 m³ each are operated at the site. Two of these vessels are of dual seam stainless steel construction; the third one is significantly newer and is made of seal concrete. All digesters are operated at a temperature of 38 °C constantly, which requires a vessel heating (around 200kW mean value over the whole year). Mechanical stirring is performed both by slow agitation via a central propeller as well as high speed agitation at three points around the tank perimeter. Micronutrients as well as iron salts for H₂S reduction are added to the digesters on a daily basis.
Each primary digester is followed by a secondary digester (5,000 m³ each) which are also heated to 38 °C and mechanically mixed. Both vessels are fitted with a flexible dual membrane gas storage roof system. Additionally, these vessels act as digestate storage. Digestate is not fractionated into solids and liquids and is utilized by local farmers as a fertilizer (only approximately from April to November). It is estimated that 2-3 % of overall gas production is via biogas generated within the secondary fermenters.

Overall retention time within the total system (primary digester – secondary digester – digestate storage) is approximately 50 to 60 days.
2.3 Biogas Production and Utilisation

The anaerobic digestion plant produces biogas at a rate of approximately 800 m$^3$/hr and has a typical methane content of 60 - 64%. The main part of this biogas is utilized in 2 CHP gas engines (GE Jenbacher, 836 kW$_{el}$ each) producing 12 GWh electricity and 15 GWh process heat on an annual basis. Electricity is injected to the grid at a (green energy) feed-in tariff of around 8.5ct/kWh (yearly average value). The heat (around 1.2 MW) is delivered to the local district heating system of the city Bruck/Leitha (length around 11 km) supporting the heat generated by a local biomass combustion plant (6 MW). Thus, around 800 households are provided with heating energy covering approximately one third of the heating demand of the city of Bruck/Leitha. A small amount of the heat produced by the CHP gas engines is directly utilized at the anaerobic digestion plant to heat up the digesters to operating temperature (around 200 kW as a yearly averaged value). The overall electric demand of the biogas/biomethane production site is around 1 GWh per year.

In the year 2007 a biogas upgrading plant has been installed and commissioned having a production capacity of 100 m$^3$/h of biomethane to be injected to the adjacent natural gas grid. For this purpose a partial flow of 170 m$^3$ biogas is taken per hour in parallel to the installed CHP engines. The biomethane facility was Austria’s first industrial scale upgrading plant with grid injection and is in regular operation since 2008.

The biogas upgrading plant has been designed and erected during a huge research project (“Virtual biogas”: www.virtuellesbiogas.at) under the cooperation of leading gas companies, universities (Vienna University of Technology, University of Natural resources and Life sciences Vienna), the AD-plant operating corporate body and the plant constructor. This plant applies the innovative technology of membrane separation (gaspermeation) for the main task of carbon dioxide removal and gas drying. It has been designed and constructed by the company AXIOM Angewandte Prozesstechnik GmbH and is operated since 2008 by the AD-plant operator Biogas Bruck/Leitha GmbH. The whole upgrading plant has been mounted inside a standard 30foot-container by the plant constructor and has been transported as a whole to the final location in Bruck/Leitha. A number of plants also applying this technology have been commissioned in Austria and Germany by the plant constructor since then, the technology is commercially available.

The applied technology of membrane gaspermeation has its advantages in a stable and continuous operation and thus is easy to control. Furthermore, no expensive regeneration or chemicals are needed. The whole process becomes very simple, straight-forward and compact. The separation technique uses a dense polyimide-membrane with different solubilities and diffusivities for the various gas species contained in the raw biogas feed. As a result, the driving force for separation is the difference in the partial pressures of the various species between the feed phase and the permeate phase. A high flux through the membrane can be realized with high pressure on the feed side and a low pressure (near to atmospheric pressure) on the permeate side of the membrane. Using this membrane material, most unwanted gas species are quantitatively removed from the feed stream and transported through the membrane to the permeate stream. Only nitrogen shows similar behavior as methane and therefore cannot be removed by this technique but remains in the product gas stream, the so-called retentate. Sufficient product gas quality and quantity can easily be reached if only enough membrane area and adequate operation conditions are provided. The great advantages of this process compared to others are the continuity, compactness, simultaneous drying and the removal of the traces of hydrogen sulphide and ammonia. Since the mixture of NH$_3$, H$_2$S and very humid gas can jeopardize the membrane material, some gas processing before the gaspermeation is necessary.
The membranes are constructed as hollow fibres with the high pressure feed/retentate stream on the inner side of the tube and the low pressure (almost atmospheric) permeate on the outside of the tube. Many of these fibres are collected to form a membrane module that is fed with pressurized biogas.

In the upgrading plant Bruck/Leitha the raw biogas from the fermentation vessels is mixed with the permeate of the second membrane stage, it is subsequently compressed and water is condensed at gas temperatures of lower than +7°C. Afterwards, the biogas is heated up again using waste heat from the compressor in order to obtain the optimum temperature for the subsequent separation steps. After that, the hydrogen sulphide is removed by means of adsorption and the pretreated gas is fed to the two-staged membrane separation process.

In order to minimize the methane losses, two stages of membrane modules have been suggested. The permeate stream from the second stage, which contains significantly higher amounts of methane compared to the permeate of the first stage, is brought back for recompression. Due to the recycling of this permeate, a nonlinear dynamic behavior of the process is expected. The methane quality of the produced gas from the retentate of the second stage is controlled by a proportional valve that is located at the retentate outlet of the second stage. The position of the valve is adjusted by a PID controller, which influences the pressure in the feed channels and, in the same time, the methane content of the produced gas. Using this control strategy a gas with various methane contents can be produced (e.g. from almost raw gas composition 70% to 99% or more). Additionally, the volume flow of the produced biomethane can easily be adjusted with an enhanced PID controller manipulating the rotating speed of the compressor using a frequency converter.
Like any other separation technique, gas permeation cannot transfer all of the methane in the raw biogas feed to the produced biomethane. As a result, the carbon dioxide-rich Offgas still contains little amounts of methane (usually 2 to 3% of the produced biomethane) and other separated substances. In order to achieve a zero-emission strategy regarding methane the upgrading plant is perfectly integrated into the existing biogas plant and the Offgas is delivered back to the existing gas engines (CHP with raw biogas). Thus, the remaining methane is not emitted to the atmosphere, but is burned and its chemical energy is used to produce heat and power.

After a concise online analysis of the relevant gas species (methane, carbon dioxide, oxygen, hydrogen sulphide, humidity) the produced gas is transported to the gas distribution station via a 2.8km long pipeline. If the quality of the gas regarding any parameter mentioned in the Austrian laws does not meet the statutory obligations for feed-in operation, the grid supply is interrupted immediately and the gas is transported back to the gas engines of the biogas plant. The control system will then try again to improve the quality of the produced gas and to readapt the supply to the grid. The calorific value of the injected gas equals to about 10.86 kWh/m³ and is compliant to the Austrian gas grid standard. Therefore, additional LPG dosing for increasing the calorific value is not necessary. The “green” natural gas is sold to the grid operator on a virtual basis.

![Fig. 15 Outside view and internal view of the biogas upgrading plant Bruck/Leitha showing compressor, heat exchangers (right) and membrane modules (left)](image)

The supplied bio-methane is transported to the nearby city of Bruck/Leitha (Population: 7600) via the public natural gas grid having a pressure of up to 3bar. The annual demand of approximately 800 households is covered by the injected amount of biomethane. During the winter months the entire amount of bio-methane is used to satisfy the gas demand of this city (additional natural gas is required). During the summer months the gas demand is only a fraction of the produced gas and the excessive biomethane is compressed to 60bar and fed into the regional natural gas grid. This approach enables a constant operation of the biogas upgrading facility over the whole year and therefore optimized workload and cost structure.

A very important cleaning step during biogas upgrading is the removal of hydrogen sulphide which is specially treated at the biomethane production site in Bruck/Leitha. The raw biogas produced at this AD-plant typically contains up to 1,000 ppmv of hydrogen sulphide, peak concentrations of up to
2,000 ppmv are also be monitored frequently (depending on the utilized type of feedstock). Also, high gradients in hydrogen sulphide content have been reported. Due to its toxicity and corrosive effects only a very small amount of hydrogen sulphide is allowed in the gas. The current process design incorporates four technologies for desulphurization for individual purposes. The first one is the in-situ-desulphurization by addition of special chemical substances (liquid mixtures of metal salts) directly into the fermenter (sulphur precipitation). As a result the produced biogas typically contains 100 to 500ppmv of hydrogen sulphide at the exit of the gas storage tanks.

The second is the microbiological treatment of the gas by means of the chemoautotrophic bacteria Thiobacilli. It results in reduction of hydrogen sulphide to around 50ppmv. The microorganisms use the H$_2$S for their metabolism and convert the gas to water and elemental sulfur or sulfurous acid which is discharged and treated together with the waste water stream. The microorganisms need oxygen for this oxidative conversion of the hydrogen sulphide. Before the biogas upgrading plant was included this biological desulphurization has been operated with air as an oxidizer. Due to the fact that air consists to four fifth of nitrogen and nitrogen cannot be removed with the upgrading technique from the biogas stream, this desulphurization step has been retrofitted with a pure oxygen injection.

It has been shown that the biological system is not able to guarantee stable desulphurization (especially constant H$_2$S content in the sweetened gas stream) during phases of highly fluctuating raw biogas quantity and quality as the microorganisms need time to adapt to the changed conditions. Therefore, an additional desulphurization technology has been applied especially for the gas flow used for biogas upgrading. This novel technology involves a chemical-oxidative scrubbing step, where the sour gas is washed with a caustic solution (NaOH) to absorb the H$_2$S from the gas. Subsequently, the absorbed H$_2$S is oxidized with hydrogen peroxide in order to enhance the removal selectivity against carbon dioxide and the loading capacity of the scrubbing liquid. The application of this concept to biogas desulphurization is new and a pilot plant of a raw gas capacity of 300 m$^3$/h has
been designed, erected and optimized during a two-year research phase. The plant is in regular operation mode since 2010 and is commercially available now. It also has been applied to another Austrian biogas upgrading and grid injection plant.

The final decrease in hydrogen sulphide is done in the third stage where adsorption by means of iron oxide or zinc oxide is implemented. This is used for final removal of H₂S only (from 70 ppm to lower than 3.3 ppmv required by the grid injection).

Fig. 18 Outside view of Chemical-oxidative scrubber for raw biogas desulphurization
Fig. 19 Scrubbing column
Fig. 20 Sodium hydroxide dosing pump

Fig. 21 Schematic showing the plant site, the grid injection point and the grid connection layout (Google Earth 2012)
An enclosed gas flare is present on site for use in the event that the produced biogas stream cannot be utilized in the CHP engines (e.g. maintenance periods) and the biomethane production is also unavailable.

2.4 Emissions Treatment (Water, Wastewater, Exhaust Air)

The CO₂ rich offgas from the biomethane production plant still contains approximately 2-4% CH₄ and is not allowed to be directly released to the environment. As already mentioned this offgas is mixed with raw biogas and piped to the CHP gas engines. Since the biogas upgrading is only applied to a partial flow of the produced biogas, this option is viable and the most cost effective. If no CHP engines would be available at an AD-plant and the biogas upgrading would cover the whole produced raw biogas, a special offgas treatment plant (typically combustion, low-calorific burner or catalytic oxidation) would be applied. The generated heat would be used to cover a part of the thermal heat demand of the digesters.

2.5 Visual / Local Impacts

No adverse visual impacts of the plant have been described. It is noted that the majority of ancillary plant is located within ISO standard steel containers. Additionally, the distance from the AD-plant to occupied areas is relatively high.

3.0 ENERGY USE, COST AND ECONOMICS

3.1 Mass and Energy Balance

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<th>Produced biogas</th>
<th>Biomethane grid injection</th>
<th>Electricity demand of AD-plant</th>
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<th>Electricity produced by CHPs</th>
<th>Heat Demand of AD-plant</th>
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3.2 Cost & Economics

First of all, it has to be mentioned, that currently no regulated feed-in tariff for biomethane is existent. Plant operators injecting biomethane to the grid have to set up individual contracts with individual tariffs and contracting durations with the relevant grid operating company. There is still no system comparable to the green electricity tariff (2012).

The plant has been erected during a research project with a 50% funding by national and federal agencies and the remaining 50% have been contributed by three big gas and energy companies of eastern Austria. The injected biogas has been delivered to these companies by the AD plant operator.
free of charge during the research project lifetime. Afterwards, the upgrading plant has been transferred to the property of the AD-plant operator without any additional costs for this company.

The investment costs for the AD-plant including the CHP gas engines have been calculated to be in the range of 6.5 Mio. €, the operational costs have not been reported and are difficult to assess. The overall specific production costs have been estimated to be in the region of 0.30 €/m³ of raw biogas.

The investment costs for the biogas upgrading plant are in the range of 800,000 €. Specific production costs considering investment of the biogas upgrading unit only (equivalent annual cost), complete operational costs of the upgrading, maintenance and personnel have been calculated to be around 0.25 €/m³ of biomethane.

As the production of 1 m³ biomethane requires 1.7 m³ of raw biogas the total specific production costs including raw biogas production and upgrading sum up to 0.76 €/m³ (67 % raw biogas production, 33 % biogas upgrading). If the calorific value of the produced biomethane is taken into account, the overall specific production costs are in the range of 7 €ct/kWh. All costs are based on calculations using the stable plant operation in 2012.

Customers do not physically purchase the gas produced at the Bruck/Leitha plant, but can buy the green gas virtually as mentioned before. To make sure the balance between injected and sold biomethane is even, the biomethane quantities are certified by TÜV Austria Services GmbH. Customers therefore have the option to purchase a certain value, or a certain percentage of their gas consumption, as biomethane.

Local maintenance of the AD-plant and the upgrading facility is undertaken by one employee. After the optimization phase of the applied biogas upgrading systems no significant operational problems have been reported.

4.0 DISCUSSION AND CONCLUSION

This case study demonstrates a number of points. Firstly, it shows that the technology is readily available to generate raw biogas and upgrade it to biomethane, in this case using membrane separation gaspermeation. It is shown that applying this technology for biogas upgrading allows for an economic natural gas grid injection operation even at smaller scales. Nowadays, typical operative grid injection plants have a production capacity several times higher than the described plant in Bruck/Leitha. Also the membrane technology benefits from the effects of economy of scale; it has to be analysed individually, which technology suits best for each case of biomethane production. Nevertheless, one has to be aware that biomethane is not directly competitive with imported natural gas and the prices for this renewable product have to be higher.

The operators of the biogas/biomethane plant in Bruck/Leitha are very satisfied with the operative plants and the operational behaviour. Currently, they assess the possibility of extent the biogas upgrading capacity to 800 m³/h of raw biogas. This would be the complete amount of biogas produced, thus making the CHP gas engines obsolete and decommission the machinery. The reason for this is the ending of the contracted green energy feed-in tariffs.

ACKNOWLEDGEMENTS

The authors would like to thank the plant owners and operators at Biogas Bruck/Leitha GmbH (DI Gerhard Danzinger and DI(FH) Wolfgang Allacher for allowing access to the plant and for providing additional information included within this case study.