Leakage-free compressor technology for the supply of biogas

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Bioenergy in the form of biogas is rapidly gaining importance as a CO_2-neutral energy source. Supplying it directly to the public natural gas supply grid is an efficient way to use biogas. This is also an elegant solution to the storage problem. However, a few steps are required before biogas or biomethane can be supplied to the grid. Leakage-free high-availability compressors as the end point immediately before the grid form the crucial interface for this connection.

Methane is the key component of both natural gas and biogas. Biogas is named for its biotic origins, in contrast to natural gas as a fossil energy carrier. What they both have in common is that their processed form is becoming increasingly important for the energy market. For raw biogas, this essentially means removing water, hydrogen sulphide and carbon dioxide. The methane content can be enriched to almost 99% through purification. It is adjusted to the heating value of the respective natural gas grid before feeding it in. This makes it possible to supply biogas even to remote customers.

Supply versus combined heat and power plant (CHP)

Supplying biogas to the public grid also has a clear physical advantage. When biogas is used exclusively to generate electricity in a combined heat and power plant (CHP), energy utilisation or the efficiency factor is often very low. This is due to a lack of customers for the waste heat. Up to two-thirds of the energy stored in biogas remains unused this way. By supplying it to the public grid, biogas replaces natural gas from fossil sources and can be used with great flexibility to generate electricity, for heating or even as fuel.

Significant investments

Several requirements have to be met in order to produce biogas (biomethane) suitable for the grid out of corn, grain, grass silage, chopped sugar beets, liquid manure or dry chicken manure. Enormous investments are required to actually operate cost-effectively. The lower limit of profitability is approximately 250–500 Nm³/h of biogas production. There is a typical biogas refining plant in Niederndodeleben (Saxony-Anhalt). It has been in operation since 2009. A second, more modern plant has been operating there in parallel since March of 2014, with even higher availability as well as improved systems engineering and control technology. EUR 9 million was invested for the first production line, and another 11 million for the second. Together they supply approximately 1,300 Nm³/h, which means 96 million kWh of energy per year. Since a 4-person household consumes 5,000 kWh/a on average, the plant covers the annual energy demand of approximately 19,200 households of this size with CO_2-natural, renewable energy.

Minimising methane loss

The highest priority for production overall is preventing methane loss, for three reasons:

- To protect the climate. Methane is a powerful greenhouse gas, with a greenhouse gas potential that is 28 times higher compared to carbon dioxide. The regulations for the operator are correspondingly rigorous. The strict limits of the Technical Instructions on Air Quality and the Gas Grid Access Ordinance (GasNZV) apply.
- To maintain safety. Methane is highly flammable and can react explosively with oxygen. Avoiding uncontrolled discharge is therefore essential. For example, the compressors before supplying it to the natural gas grid are in explosion zone 1.
- For economic efficiency. Only processed methane can be used as an energy source. It is sold to the operators of the respective public natural gas grid through contracting. This means it is essential to lose as little as possible within the production process.

Exacting volume flows

Since the bacteria in the bioreactor need a certain amount of time to multiply before the desired target quantity of gas is produced by the microorganisms, the start-up phase is a critical moment in production. Once it is up and running, a biogas plant usually operates as a base load plant since the natural process cannot simply be stopped.

All these prerequisites mean that compressor manufacturers have to meet special requirements. In order to gain a better understanding of these, we are going to follow the various process steps in a bio-refinery based on the parameters of the plant in Niederndodeleben.

Fig. 1: Biogas upgrading plant Niederndodeleben

Fig. 1.1: Biomethane grid injection unit

Niederndodeleben biogas plant

First the surrounding farms supply approximately 49,000 tons of corn silage, 34,500 tons of beet pulp and 11,500 tons of farm fertiliser annually. These 95,000 tons of renewable resources, plant by-products and farm fertiliser are mixed in fermenters to produce a homogenous biomass. In the absence of air and at an ideal temperature of approximately 40° C, the proteins, fats and carbohydrates contained in the plant-based raw materials are broken down. The raw biogas produced during fermentation mainly consists of methane and carbon dioxide. The methane content in this phase is approximately 53 percent. Approximately 18 million Nm³ of raw biogas is produced annually. To close the agricultural substance cycle, the fermented substrate can be spread on farmers' fields again as organic compound fertiliser. This amounts to approximately 72,000 tons annually from the silage volumes delivered to Niederndodeleben as described above.

Pressurised water scrubbing

Pressurised water scrubbing is the next step in the gas processing plant. Desulphurisation and separating the carbon dioxide (CO_2) and methane (CH_4) are the key objectives. Biogas contains sulphur in the form of hydrogen sulphide (H_2S). Biological, chemical and adsorptive processes are possible for separation in principle. Pressurised water scrubbing is an absorptive method. The basic and acidic components are relatively easily soluble in water. Therefore the scrubbing solution primarily binds carbon dioxide and hydrogen sulphide from the biogas. Since pressure increases solubility, the biogas is compressed. Water is sprayed from above into the absorption column with a height of 17 metres while raw biogas flows in at the bottom. The water falling into the counter flow absorbs CO_2 and H_2S. The loaded scrubbing solution flows into a flash tank where it is decompressed to atmospheric pressure, causing the bound carbon dioxide to be released and discharged to the outside through an exhaust air purification system. Minimal residual methane is first removed by means of flameless regenerative thermal oxidation at 800° C. In the downstream desorption column, the scrubbing water is purified and then returned to the absorption column where the cycle begins anew. Moisture is extracted from the scrubbed gas in an adsorption dryer before it is routed to the supply system as biomethane at about 40° C. A small amount of methane is always dissolved in this process as well and released during decompression. This is returned from the flash tank to the raw biogas supply as lean gas. During pressurised water scrubbing in the Niederndodeleben biogas refinery, the supply volume flow is approximately 2,500 Nm³/h and the discharge volume flow of biogas is approximately 1,300 to 1,400 Nm³/h with methane enrichment up to 98.5 %.

The Magdeburg biogas refinery uses a total of 4 compressors for this process, which are operated respectively as redundant pairs: a first generation with 75 kW and a volume flow of 365–780 Nm³/h and a second generation with 200 kW and a volume flow of 960–1987 Nm³/h.


Fig. 2: Compressor station for biomethane supply

Leakage-free supply

Now the final and crucial step in the biogas supply follows. First an analysis of the processed gas is performed, the pressure is raised to match grid conditions, odorisation is performed if applicable and the heating value is adjusted according to the Wobbe index with the help of propane. This is required to meet the quality requirements of the public grid operator as "high gas".

The chosen compressor technology is of particular importance in this phase. A machine with no gas leaks for installation in explosion zone 1 is the basic requirement.

Gas-proof crankcase

The redundant compressor installations have a gas-proof crankcase, which is essential for leakage-free operation. A leakage gas compressor can be used in the petrochemical sector to prevent gas leaks. This is usually not the case in biogas plants. From the perspective of the operator, a compressor system without leakage gas compressor is advantageous since it eliminates an additional machine as a potential error source. In terms of cost, the acquisition cost for the leakage-free compressor is equivalent to systems with a separate leakage gas compressor. However, the operating costs for the leakage gas compressor version are higher since maintenance, wear parts and energy are required for another machine component. Not to mention the need for more space. In terms of the total cost of ownership (TCO), a hermetically sealed compressor is therefore more favourable for biogas plant operators without any fear of technical disadvantages.

The compressors in the new Niederndodeleben line have a motor power of 200 kW. A slide ring seal replaces the conventional shaft seal for the crankshaft in this application. Together with the pressure-resistant crankcase, this achieves a hermetic seal to prevent gas loss.

Direct drive preferred

The directly coupled machine has no belt drive. Instead this task is handled by a jaw clutch coupling, which works with no bothersome belt tension. Finite Element Method (FEM) studies have clearly shown that the service life of the crankshaft is extended when only one force – torque – is acting on it. The belt drive exerts dual forces, bending moment and torque. It is never possible to achieve identical belt tension and the belts are also of different lengths. This produces oscillating forces that affect the drive system as well. The power requirement at the shaft is approximately 45 to 150 kW. Belt oscillations are eliminated when a direct drive is used. It is also possible to design a more robust coupling bell to encapsulate the direct drive compared to the belt drive casing. As a rule, the latter is more for protection against contact and tends to oscillate as well. Overall, the directly coupled machine exhibits significantly reduced vibration behaviour, which is why this power transmission method is preferred.

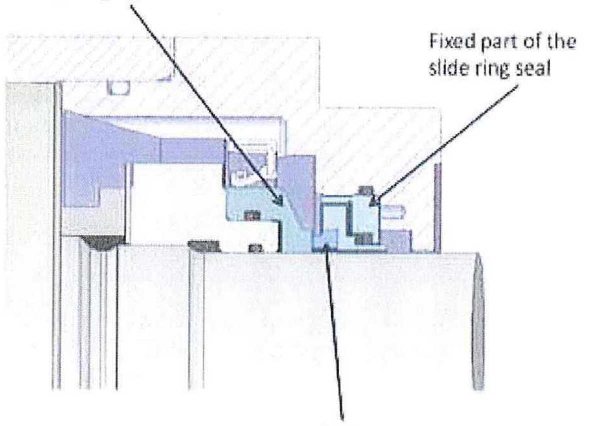

Fig. 3: Sectional draw of a slide ring seal

Fluctuating volume flow

Due to fluctuations in the volume flow, especially in the start-up phase, the compressors are speed-controlled. The suction pressure ranges from 4.5 to 7 bar overpressure. The final pressure range is a special feature. It is between 11 and 26 bar abs. In Niederndodeleben the natural gas grid operator works with PN 25 max., which is why the compressor was laid out for 26 bar abs. Downward pressure fluctuations are explained by seasonal factors. For example, withdrawal from the grid is significantly higher in the heating period during the winter than in the summer. The specified standard volume flow is 1470 Nm³/h, while approximately 1987 Nm³/h would be possible with the compressors being used, so that nothing stands in the way of a possible higher future volume flow.

Water cooler for chilling

A maximum of 40° C is specified for the discharge temperature at the supply point. Since the customer cannot supply cooling liquid, the compressors themselves must be operated with self-contained cooling. The ambient temperature at the compressor installation site was specified as 5° C to 40° C. A maximum ambient temperature of 40° C and an equivalent discharge temperature results in an infinite cooler size which is technically not realisable. This requirement was met with a water cooler or water chiller. It circulates a mixture of water and ethylene glycol, which chills the existing coolant circuit of the intercooler and aftercooler to a configurable 20° C. A sufficient temperature delta is thereby achieved. The water cooler is installed outdoors outside the explosion zone and also output-regulated.

Chiller beats water-based recooling plant

Lower cooling liquid temperatures can be provided with this type of cooling compared to a water-based recooling plant, which is limited by the ambient temperature because it can only realise a ΔT of 15° to 20° K. Therefore a water-based recooling plant at an outdoor temperature of 40° C results in a gas temperature of approximately 55° to 60° C, which would be too high for the grid injection in this case. This design means the aftercooler also has to be chilled with a water cooler to avoid exceeding the 40° C limit. Two cooling circuits would have to be operated in this case, with the corresponding disadvantages in terms of cost and susceptibility to errors. At an outdoor temperature of 40° C, the circulating temperature of 20° C is readily achievable with a simple chiller solution, leading to a gas discharge temperature of 30° C at the aftercooler. A comfortable 10° Celsius reserve is available in addition.

More flexible with bypass

A bypass is essential for the compressors in the measurement and control system of a biogas plant. Gas production during anaerobic fermentation is determined by bacteria and subject to natural fluctuations. Attempting to optimise the conditions in the fermenters in order to produce the most consistent possible volume of gas is a matter of course, and this is usually given once a plant is up and running. But as mentioned above, the gas volume is much lower during plant start-up in particular. Yet the compressors have to work with this reduced quantity as well. They would simply extract everything from the upstream scrubbing stage without control. A bypass valve was installed in order to prevent this. In Niederndodeleben, the bypass starts regulating when the volume flow falls below 970 Nm³/h. The speed-controlled compressor system is designed for a minimum volume flow between this lower value and 1,230 Nm³/h. Below that, the controlled bypass valve simply reroutes part of the flow from the pressure side to the suction side. The volume flow is first depressurised again and flows through the bypass until the control system detects that the normal values are reached again. While a bypass return is not optimal from an energy perspective, this function is indispensable for a biogas plant. With the quick and simple solution of a bypass valve to compensate for the falling suction pressure, additional investments in the plant are avoided and frequently turning the compressors on and off, which would be undesirable, is prevented. Since this control system allows 0–100 % of the biogas supply to be compressed, it offers maximum flexibility.

Mandatory availability

Just like bacterial gas production cannot just be switched on, it cannot simply be switched off either. Once the fermentation process is going, the compressor has to reliably transport the produced gas and therefore needs to be continuously available. The com-