NEW TECHNOLOGY ENABLES BIOGAS PLANT OPTIMISATION

Governments around the world are seeking to lower greenhouse gas (GHG) emissions in the fight against climate change, to reduce waste to landfill, and to increase their utilisation of renewable energy in compliance with international agreements. Consequently, in many countries, subsidies have been made available to encourage the growth of the biogas sector.

According to the International Renewable Energy Agency (IRENA) a third of global power capacity is now based on renewable energy, and nearly two-thirds of all new power generation capacity added in 2018 was from renewables. Much of the recent growth was provided by solar and wind energy, but global bioenergy capacity has roughly trebled in the last 10 years.

The generation of biogas from wet putrescible wastes and crops produces a more reliable and predictable source of renewable energy than wind or solar. However, as these technologies become more efficient and subsidies are reduced, the biogas sector will have to focus on process optimisation if it is to maintain profitability, compete with other forms of energy generation and become sustainable in the long term. In the following article, Antti Heikkila from Vaisala explains how a new in-line biogas monitoring technology enables the effective optimisation of several processes at plants handling biogas from anaerobic digestion and landfill.

Background

Waste management presents a significant challenge to societies, with wastes increasingly being viewed as resources. Organic wastes are a particular concern because of their potential to produce methane – a powerful GHG. However, the gases from the anaerobic digestion (AD) of organic wastes can be contained and utilised as a source of renewable energy. Combustion of the gas produces renewable heat, or in a combined heat and power (CHP) engine it produces both electricity and heat. Biogas can also be upgraded to biomethane (>99% methane) for compression and injection into the natural gas grid or for use as a transport fuel. AD plant operators can also generate income by exporting electricity to the grid, by selling heat or biogas to local businesses or communities, and by charging a gate fee for incoming waste materials. The digestate produced by such plants is rich in nutrients and can be used as a soil fertiliser and conditioner.

Irrespective of the process, all plants need to optimise the production of biogas, whilst minimising costs, waste and down time. However, biogas is a corrosive and potentially explosive gas so in the past it has not been possible to conduct in-line monitoring. Until now, the only solution has been to extract samples for analysis outside of the process, but this method has inherent flaws that will be discussed later.

Seeking to enable effective process optimisation, Vaisala developed the MGP261, the world's first in-situ 3-in-1 biogas monitoring instrument, for the simultaneous measurement of methane, carbon dioxide and humidity. Importantly, the instrument is Ex certified up to Zone 0/1, which enables in-line installation in pipes and ducts where explosive atmospheres exist, with the area surrounding the pipes classified as Zone 1.

Anaerobic digestion – the process

Four main processes take place inside the digester to produce biogas. All of these processes are mediated by different groups of bacteria, and a key feature of effective biogas process optimisation, is the maintenance of a healthy balance of these microorganisms. The four main processes are:

1. Hydrolysis – complex organic matter such as proteins, carbohydrates and fats are broken down by bacterial enzymes into sugars, fatty acids and amino acids.
2. Acidogenesis – various fermentation reactions convert larger molecules into organic acids, alcohols, ammonia, carbon dioxide, hydrogen and hydrogen sulphide.
3. Acetogenesis - the fermented products are oxidised into simpler forms such as acetate and carbon dioxide.
4. Methanogenesis – Archaea (single cell organisms) convert hydrogen and acetic acid into methane and carbon dioxide.

Any disruption to the last two processes will result in a lowering of biogas yield and can be detected by changes in the methane:carbon dioxide ratio. Hence the requirement for continuous monitoring.

Process monitoring for improved efficiency

Biogas is typically 50 to 75% methane with the majority of the remainder being carbon dioxide and water vapour with small amounts of other gases such as those mentioned above. Clearly, by monitoring methane it is possible to measure the successful operation of the plant, and by monitoring the methane:carbon dioxide ratio, the plant operator is provided with a continuous real-time indicator of digester behaviour, and with the status of the digester's micro-organisms.

Data on methane and carbon dioxide can be used in a number of ways. Firstly, this information can be used by the operator to adjust loading rate and feedstock type if possible, in order to improve the status of the bacteria. Secondly, where the biogas is being used by an engine, the measurements can be used to optimise engine performance, and thirdly, where the biogas is being refined for injection into the grid, the data can be used to inform the biomethane upgrading process.

Of course, it is also possible to extract samples from the reactor for subsequent laboratory analysis. This can provide an accurate indication of process conditions, but the delay (and cost) of doing so means that timely or automatic action to optimise the process is not possible. In-line monitoring of biogas methane and carbon dioxide therefore helps to reduce the requirement for costly laboratory analysis.

Why monitor biogas humidity?

Humidity in biogas represents a potential problem for a number of reasons. Humidity in gas may condense with changing pressure or temperature – in the pressure regulator or in transfer pipes for example. Such condensation can cause serious damage and must be avoided. Similarly, excessive humidity in biogas fed to the CHP engine increases moisture in engine oil and results in a need to replace engine oil more frequently.

Obviously engine down-time, for service maintenance or repairs, should be minimised because this may result in flaring which can cost €3k to €5k per day in lost revenue.

Humidity is also a serious consideration in the operation of activated carbon filters, because they are designed to work within specific humidity ranges. Carbon filters are commonplace because biogas impurities such as hydrogen sulphide, siloxanes and a range of other organic gases need to be removed to prevent damage to the engine, or to generate biomethane of sufficient purity to be suitable for gas-to-grid (G2G) applications. Excessive humidity causes carbon filters to wear out prematurely, resulting in a costly requirement for refilling. Some plants need to change the carbon filters several times a year which can result in an annual cost of more than €10k. However, too little humidity can also be a problem for some filters, resulting in the inefficient operation of the carbon filter.

Why measure in situ?

In the past, the only option was to employ biogas analysers which extract a sample for subsequent measurement by electrochemical or fixed wavelength infrared instruments. These technologies require frequent re-calibration which is costly, labour-intensive, and potentially harm the plant's capability to monitor continuously. Pumps and gas tubing are required and it is necessary to dry the sample to prevent the errors and potential damage incurred by condensation. These instruments are therefore unable to measure sample humidity. This also means that the measurements from extractive instruments are given on a dry basis. Such readings, by definition, will be higher than those from an in situ probe measuring on a wet basis, although Vaisala's MGP261 can provide measurements on either basis.

Sample extraction in cold climates also risks freezing of the sample line, which inhibits flow and leads to erroneous data. This problem could be rectified by Ex-certified trace heated lines, but they are prohibitively expensive.

Electrochemical and fixed wavelength infrared extractive gas analysers have a relatively short working life, so this is important when considering whole-life cost of ownership. In addition, these technologies have a short calibration interval and require frequent sampling system maintenance, so the running costs can be high.

The launch of Vaisala's MGP261 is a major step forward because it overcomes the disadvantages of the older extractive technologies.

New technology

As the world's first 3-in-1 in-situ biogas analyser, the MGP261 relies on CARBOCAP® technology that has actually been in operation in a wide variety of other industries for many years. However, uniquely, this instrument combines second generation CARBOCAP-technology for measuring methane, carbon dioxide and humidity into a single compact probe that is EX-certified for operation directly in corrosive, potentially explosive biogas streams.

The Vaisala CARBOCAP® sensor features an electrically tunable Fabry-Pérot Interferometer (FPI) filter. In addition to measuring the target species, the micromechanical FPI filter enables a reference measurement at a wavelength where no absorption occurs. When taking the reference measurement, the FPI filter is electrically adjusted to switch the bandpass band from the absorption wavelength to a non-absorption wavelength. The reference measurement compensates for any potential changes in the light source intensity, as well as for contamination in the optical path, which means that the sensor is highly stable over time.

Other manufacturers of infrared gas analysers employ a filament lamp in their instruments, but Vaisala has developed a patented 'microglow' infrared source which is low power, extremely stable and benefits from a 15 year lifetime. It also has a fast startup (<2 mins) and is ideal for inclusion in an Ex-certified measurement instrument.

Within the MGP261, humidity and carbon dioxide are measured with the same optical filter, and a second optical channel measures methane. In many ways, this combines the analytical power of a laboratory spectrometer with the simple, rugged design of an industrial process control instrument.

From a user's perspective, the key advantages of this technology are:

- In situ measurement – direct measurement of process conditions without the cost, problems and delays associated with alternative methods
- Long term stability – maintenance is minimal; just a change of probe filter if it becomes dirty (usually undertaken during engine maintenance)
- Self-calibration – the measurement technology effectively self-calibrates, but an annual calibration check is recommended
- Minimal operational costs – no requirement for frequent service or calibration by technical staff
- Lower CHP engine maintenance and downtime - through reliable humidity control

Where to monitor

Applications for this technology include anaerobic digestion and landfill gas monitoring, activated carbon filter monitoring in biogas treatment processes, and CHP engine feed gas monitoring. The typical monitoring points for methane, carbon dioxide and humidity at biogas plants would therefore be:

- within or after the digester - to optimise the digestion process by monitoring the $CH4/CO_2$ ratio and adjusting waste loading rate accordingly
- after the heat exchanger – measuring humidity to optimise drying
- prior to the activated carbon filter - measuring humidity to optimise filtration
- prior to a CHP engine – measuring humidity to protect the engine and methane concentration to optimise engine performance
- prior to a methane upgrading plant – to optimise the process

Summary

Effective biogas process optimisation requires in situ monitoring of the key parameters, methane, carbon dioxide and humidity. In the past, this has not been possible with the monitoring technology available, but with the launch of Vaisala's MGP261, a new world of opportunity has been created to derive more value from waste; improve the profitability of biogas plants; help reduce waste; lower GHG emissions and recycle agricultural nutrients.

Author Contact Details

VAISALA CORPORATION • Head Office P.O. Box 26, FI-00421 Helsinki, Finland

Web: www.vaisala.com • Email: comms@vaisala.com

Antti Heikkilä