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Application of Near Infrared Spectroscopy, Acoustic Chemometrics, and Process Sampling for On-line Monitoring and Control of Biogas Processes

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Applied **C**hemometrics
Analytical **C**hemistry
Acoustic **C**hemometrics
Applied **B**iotechnology
Bioenergy
Sampling

Abstract

Biogas plants represent versatile biological processing plants that can be implemented for various reasons. For the purpose of energy production, biogas plants are capable of treating many different types of organic wastes, energy crops, and agricultural residues aiming at producing renewable energy (biogas) and organic fertiliser (digestate) for use in sustainable crop cultivation. In the context of wastewater treatment, biogas technology can for instance be applied for removing persistent organic pollutants and thus secure the water environment. In order to be able to operate the biogas process optimally, reliable, fast, and comprehensive process monitoring is needed. Otherwise the process might be imbalanced leading to process failure and severe economic losses.

Despite having a long and well-documented history, the biogas process is still considered a black box phenomenon. Many biogas plants are equipped with simple classical univariate sensors (e.g. pH electrodes, temperature transmitters etc.), which makes reliable process monitoring and control difficult.

The biogas processes

Biogas production (i.e. anaerobic digestion) is a complex system of reactions occurring simultaneously in the same reactor vessel (the digester). It involves interaction between many different microorganisms, so-called consortia. Each consortium thrives optimally at a given set of chemical and physical conditions. The consortia responsible for degrading organic matter grow faster than the consortia producing methane. Hence, the process must be operated in such way that the methane producing bacteria are favoured. Otherwise accumulation of intermediate compounds or washout of the methanogens will occur leading to process imbalance. A simple degradation scheme outlining the four main steps in anaerobic digestion is presented in figure 1.

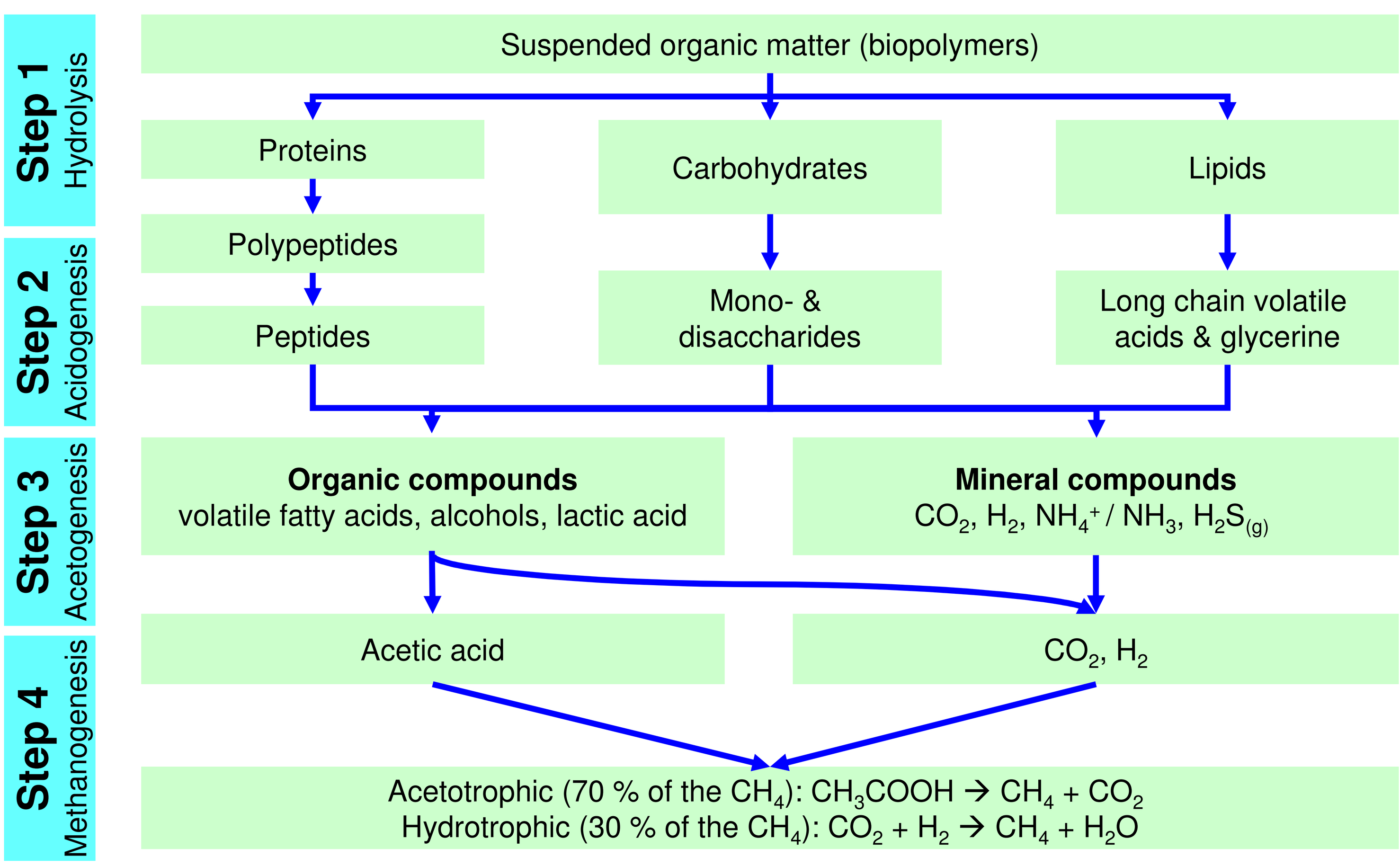

Figure 1. Anaerobic degradation of organic matter

The intermediate compounds volatile fatty acids (VFA) and ammonia have been proposed by several authors as the most suitable control parameters for describing the state of the anaerobic digestion process. These analytes can be quantified using near infrared spectroscopy. Many biogas plant operators use the concentration of solids as a control parameter. The concentration of solids can be assessed using acoustic chemometrics. Introducing Process Analytical Technologies in the biogas sector therefore carries a great potential for stabilising and optimising the biogas yield, which is absolutely necessary if biogas is going to be one of key elements the in the future energy supply.

The biogas plant investigated, LinkoGas A.m.b.A.

The work was done in cooperation with one of the largest centralised biogas plants in the world, LinkoGas A.m.b.A., Denmark. The daily flow of biomass is approximately 470 t of manure and 137 of industrial organic waste. The plant is operated at thermophilic conditions (51ºC). Three uniform reactors each having a volume of 2400 m³ are operated in parallel. The hydraulic retention time is approximately 14 days. The infrastructure at LinkoGas is illustrated in figure 2. Figure 3 displays a typical daily variation in the biogas yield and thus also justifies introduction of Process Analytical Technology.

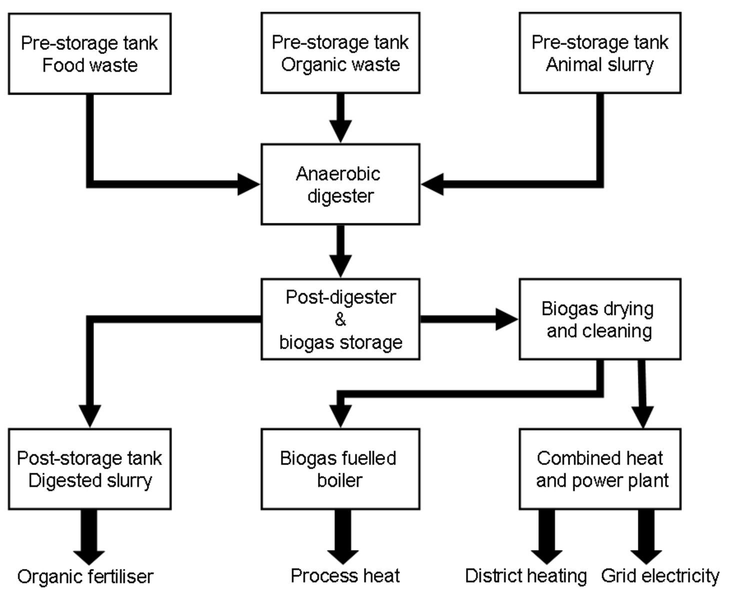

Figure 2. Main infrastructure at LinkoGas A.m.b.A.

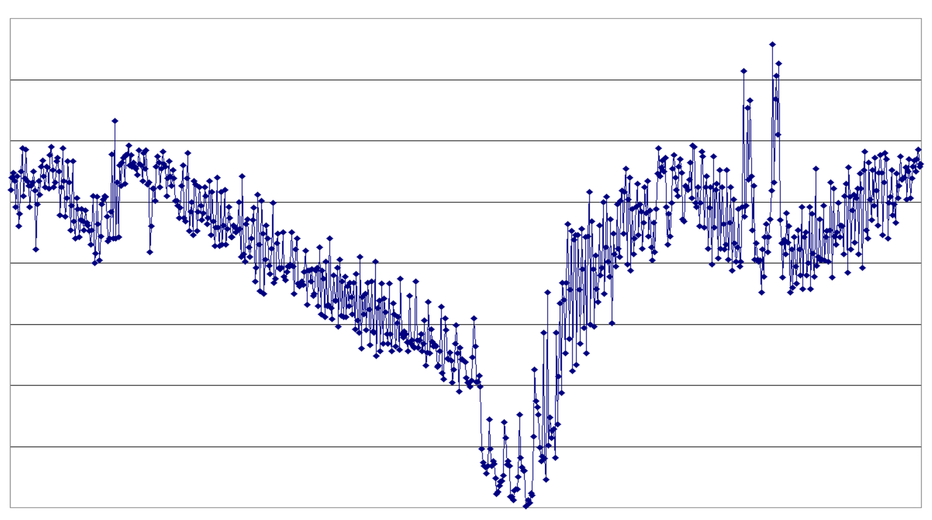

Figure 3. Typical variation in the daily biogas production at LinkoGas A.m.b.A.

Methods

The recurrent loop concept developed by ACABS Research Group was applied in this project. Briefly explained, the loop integrates Process Analytical Technologies (PAT) and representative sampling (according to the *Theory of Sampling, TOS*). It is of utmost importance that the process samples used for building the calibration model are representative of the flow analysed by the PAT-sensors in order to establish maximum correlation between the multivariate data and the chemical reference analyses. The recurrent loop concept is depicted in figure 4 along with the actual implementation in figure 5.

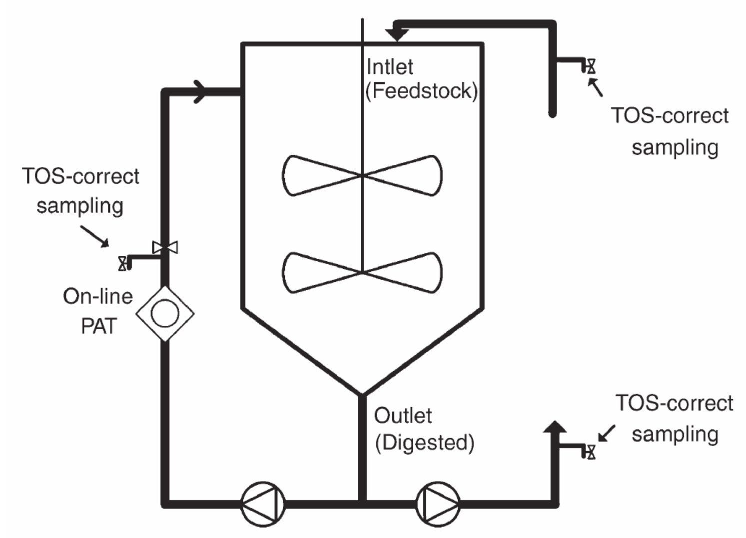

Figure 4. Recurrent loop concept for PAT-applications

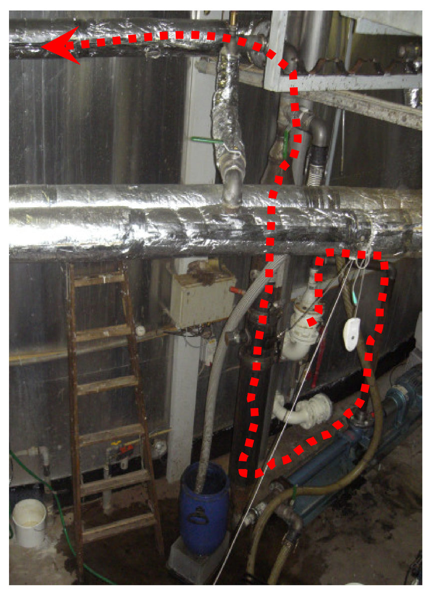

Figure 5. The implemented recurrent loop at LinkoGas

Current results

So far, only the natural variation of the biogas process has been investigated using a reflective NIR-sensor and a passive acoustic sensor. Hence, no deliberate action has been taken to provoke the process and by this obtaining a wider span in the calibration reference data. NIR spectra were pre-treated using the α-MSC algoritm in order to remove light scatter effects from suspended particles. Models were build using the PLS-1 algoritm validated through two-segment cross validation due to lack of a test set. Figure 6 shows an example of one of the PLS-1 models. The normal level for the parameter total VFA is in the range from 0,3-1,5 g L^{-1} with few samples exceeding 1,5 g L^{-1}.

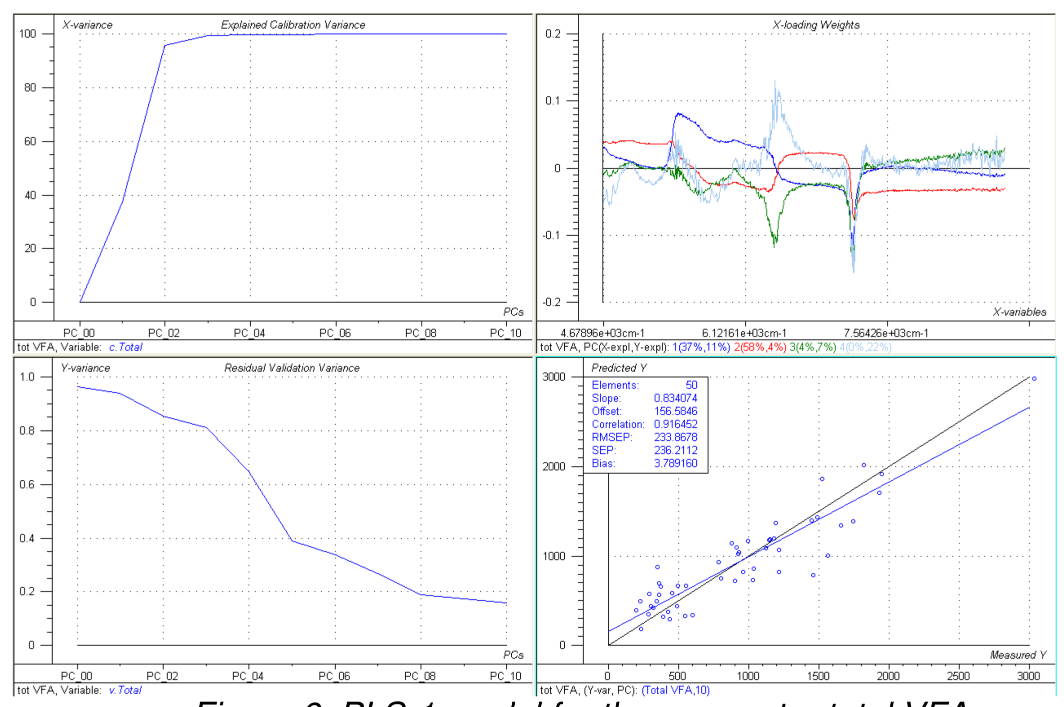

Figure 6. PLS-1 model for the parameter total VFA

Conclusion

Removal of a large portion of outliers (~30 %) was necessary due to large sampling errors introduced from manually taken increments from the sampling valve and subsequently using shovelling methods for mass reduction. In addition, the complexity of the bioslurry and the critically low concentrations of the analytes results in weak calibration models.

The span in the calibration data for solids was not large enough to establish a useful model based on acoustic sensor data (data not shown).

Ongoing work and perspectives

Several sources of error have been identified and the ongoing research and development-work focuses on reducing these errors as much as possible. The primary sampling and subsequent mass reduction is being automated fully in accordance with the Theory of Sampling. The options for building global calibration models at-line in a laboratory and transferring them to biogas plants for use on-line is also being investigated.

Acknowledgements

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