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Analysis of the anaerobic fermentation process by online spectroscopic measurements

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Introduction

Biogas production as a renewable energy source is facing challenges due to reducing government subsidies making it challenging for biogas plant operators to continue operating profitably. There is another problem; overfeeding a biogas plant can result in the process becoming inhibited and halting production of biogas. This is very expensive and must be avoided at all costs. As a result, biogas plants are typically fed very conservative amounts. A further complication is that each biogas plant is unique and can tolerate different feeding rates. This project is using MEMS (MicroElectroMechanical Systems) based spectroscopy for online analysis of the anaerobic fermentation process, to achieve a greater understanding of the reactor performance on an individual basis, and to allow the optimization of the plant operation, maximizing profitability. The work performed as part of this project is focused in 4 main areas.

1. Mid-Infrared Spectroscopy

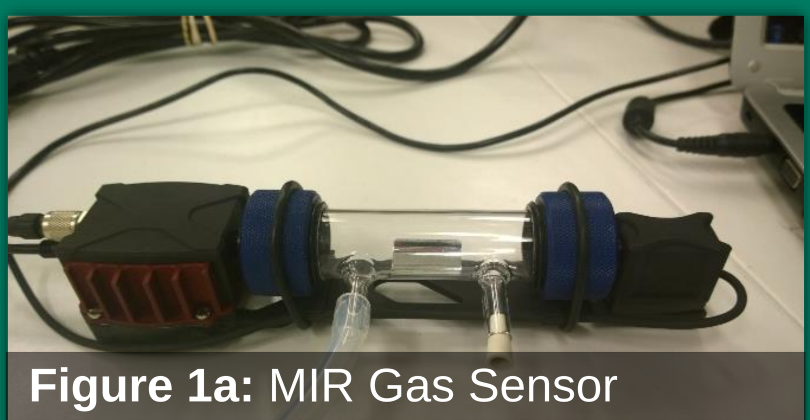

Figure 1a: MIR Gas Sensor

Figure 1b: MIR VFA Sensor

Mid-Infrared spectroscopy has been tested and evaluated for it's suitability for online measurements in the biogas process. Two sensors have been used, one for the online measurement of biogas composition (Fig. 1a), and the second for the online measurements of volatile fatty acid (VFA) concentrations (Fig. 1b). The sensors cover different wavelength ranges, chosen to correlate with the maximum absorption peaks for the parameters to be measured.

2. Spectral Data Analysis

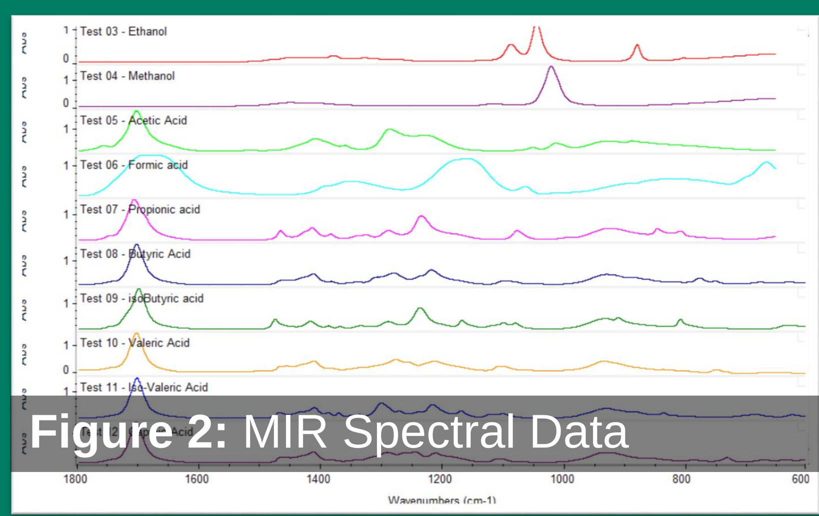

Figure 2: MIR Spectral Data

The spectral data which is produced by the spectrometer sensors (Fig. 2) does not give a direct value for a specific parameter. To calculate process parameters, the spectral data must be processed using machine learning methods. There are multiple different methods, which can be linear or non-linear, and furthermore prediction can be either classification, or regression. In addition, a combination of techniques can be used, called an ensemble. Machine learning is required as this allows determination between different substances, even in the case of overlapping absorption peaks. In cases of low concentrations where regression has high prediction errors, classification has resulted in improved results.

3. Simulation for Optimisation

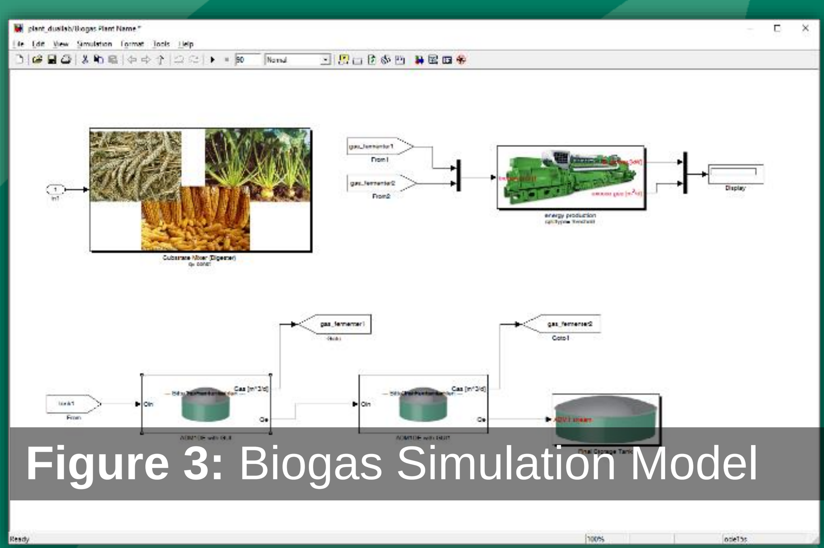

Figure 3: Biogas Simulation Model

Any measurements performed on a biogas plant only become valuable once the information is used for decisions on how to operate the plant. Simulations allow much faster iterations of different scenarios that would not otherwise be possible to test using laboratory testing. A MATLAB® implementation of the ADM1[1] (Fig. 3), is used to test different scenarios, and to investigate the changes in the output due to feeding events, which is performed at different loading levels of the digester. Then as the digester approaches inhibition and the response changes, the feeding regime can be altered, and specific targets can be set for the process parameters which are specific to the individual reactors and not just generic levels taken from literature.

4. Laboratory Verification of Simulations

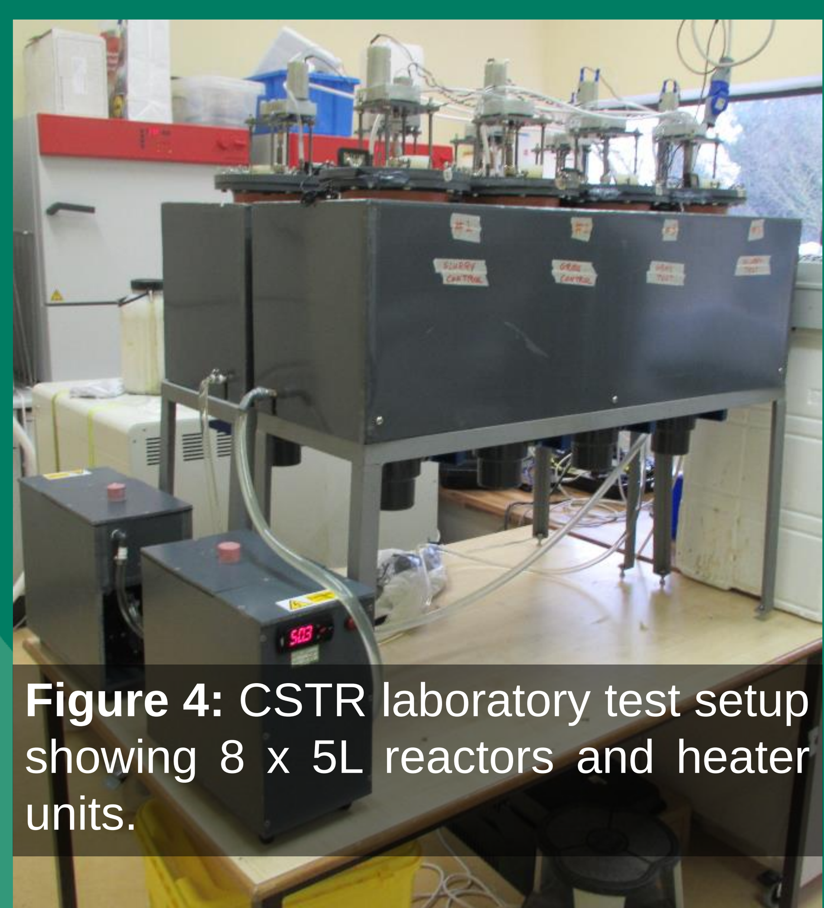

Figure 4: CSTR laboratory test setup showing 8 x 5L reactors and heater units.

To ensure that the results from the model are accurate and representative of real life, the simulations are replicated using a Continuously Stirred Tank Reactor (CSTR) setup (Fig. 4), consisting of 5L reactors. The reactors are simulated using the model and then a control model has been developed for the model. Finally, the control model is then implemented and tested on the laboratory reactors to validate the performance of the control method in reality. Testing with laboratory scale reactors provides the possibility to evaluate multiple control models simultaneously and evaluate their performance as they approach the reactor limits, before testing on larger systems.

Acknowledgements

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References

[1] Batstone, D. J., et al, 2002. The IWA Anaerobic Digestion Model No 1 (ADM1). Water Science and Technology 45(10):65-73.