Funded by the European Union

Fachhochschule Köln
Cologne University of Applied Sciences
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Analysis of anaerobic fermentation process by online spectroscopic UV/Vis, NIR and MIR-measurement

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Introduction

The aim of this project is to develop an innovative online-measurement system for biogas plants. The system will use new MEMS based spectroscopic sensors and will perform measurements of anaerobic digester substrates and the produced biogas. Machine learning methods will be applied to the measured spectral data to estimate the concentrations of various process parameters from the measurements. At present, work is being performed using a spectrometer for the estimation of methane concentration and relative humidity in the gas phase.

Theory

The MEMS based spectrometer performs measurements in the region of 3µm - 3.7µm. In this region, both methane and carbon dioxide will absorb light. Furthermore, water is also absorbent in this region. The light passing through the measurement cell will experience attenuation dependant upon the wavelength and gas composition. From this absorption profile, an estimation of the biogas composition will be made. For infrared absorption to occur, It is necessary that either a dipole moment is present, or that asymmetric vibrations occur as a result of IR radiation [1]. Neither of these are true for N2, O2, and H2, and hence it is expected that these gases will have no effect on the measured output, and so this work is focusing on the measurement of CH4, and CO2.

Laboratory Testing

Laboratory testing has been performed with the MEMS sensor to asses the variation of the measurement results based on differing gas compositions and relative humidity. In order to vary the gas composition, the measurement chamber was flushed with one type of gas, and then a second gas was introduced using a gas syringe through a bung. To increase the relative humidity, the gas was bubbled through water in a closed chamber, and the resulting gas was used for testing. For this reason, it was difficult to closely control the relative humidity, and measurements were made with either dry gas, or gas near saturation. All measurements were performed at room temperature.

The laboratory testing showed that the sensor is sensitive to methane, and that CO2 and relative humidity also produce a smaller variation in the output. Furthermore, the variation with methane concentration appears to be linear, with a clear absorption profile visible, as shown in Figure 1. The absorption profile for CO2 is much more flat over the entire range of wavelengths measured by the spectrometer. In Figure 2, the changes due to relative permittivity to spectra for CO2 and CH4 can be seen.

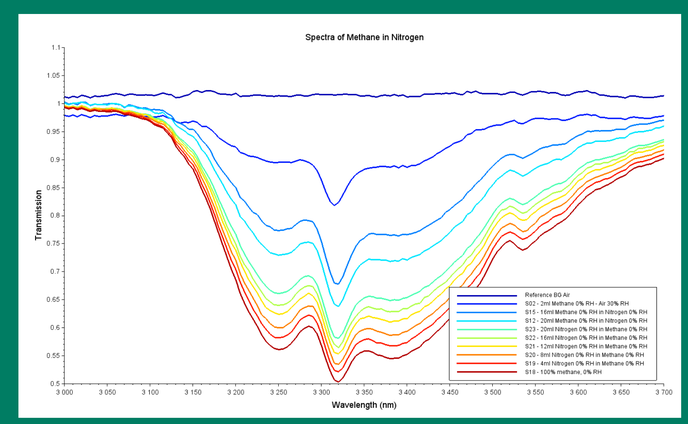

Figure 1 – Methane absorption profile for differing concentrations

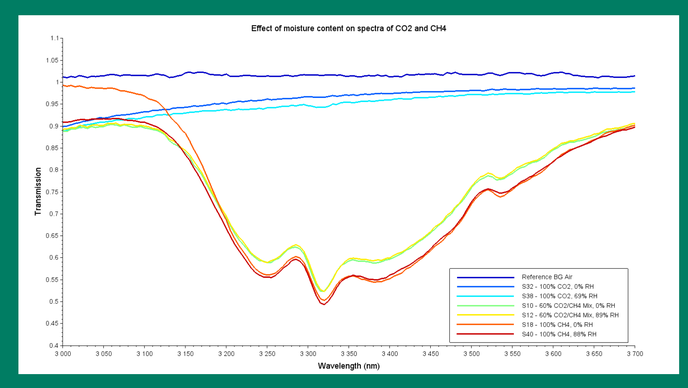

Figure 2 – CO2 and CH4 spectra for dry gas, and nearly saturated gas.

Figure 3 – Installed gas spectrometer

Pilot Scale Biogas Digester Monitoring

The gas spectrometer has been installed on a pilot scale digester, and is presently collecting spectral data continuously. The installed gas spectrometer can be seen in Figure 3. The equipment fitted inside the enclosure can be seen in Figure 4. In addition to the gas spectrometer, there is a further gas measurement unit, which performs measurements of Methane, Carbon Dioxide, H2 and H2S concentration, with measurements being performed approximately once per hour. Once data has been collected, machine learning techniques will be applied in an attempt to estimate the gas concentrations from the spectral data.

Potential Issues

There is a potential anticipated problem with the pilot scale plant testing, which is that the biogas is much warmer than room temperature, and so it is expected that moisture will condense in the glass measurement chamber, resulting in dispersion and diffraction of the infrared beam. If this is found to be a problem, two possible solutions for this issue would be either first cooling the gas, or alternatively to heat the glass measurement chamber. An additional challenge would be the measurement of H2S, laboratory testing has not yet been performed and so it is not yet known if the concentrations are sufficient for detection with this measurement setup.

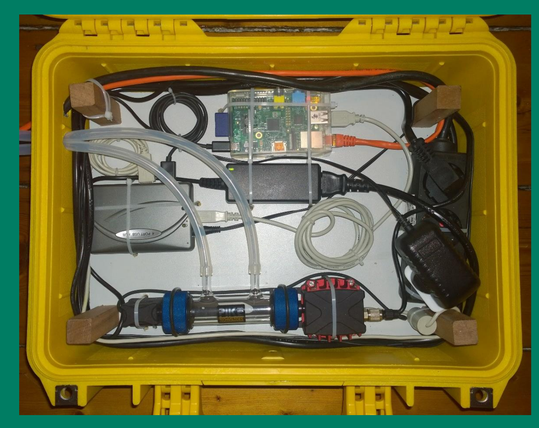

Figure 4 – Inside enclosure showing electronics and MEMS spectrometer.

References

[1] Smith, B.C., 1998. Infrared Spectral Interpretation: A Systematic Approach. CRC Press.