



Estimation of AD Process Stability from Biogas Measurements

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Agenda

- Introduction
- Gas transient response
- Measurements & results
- Gas profile analysis
- Development of control method
- Long term simulation & results
- Conclusions

Introduction

- Originally investigating use of Mid-Infrared MEMS sensor for monitoring the AD process.
- VFA sensor performance needs improvement.
- Gas sensor performance is good.
- What is “optimum”? – each biogas plant is different.
- Focused work on using gas data for optimising & control of process.

Gas transient response for optimisation

- Previous work completed by J-P Steyer et al [1].
- Method only suitable for continuously fed systems.
- Principle is that as digester approaches inhibition, digester response to feeding events changes.
- Only uses gas production rate.
- Investigating applicability to batch fed reactors.

[1] J. P. Steyer, P. Buffière, D. Rolland, and R. Moletta, “Advanced Control of Anaerobic Digestion Through Disturbances Monitoring,” *Water Res*, vol. 33, no. 9, pp. 2059–2068, 1999.

Continuous fed to batch fed

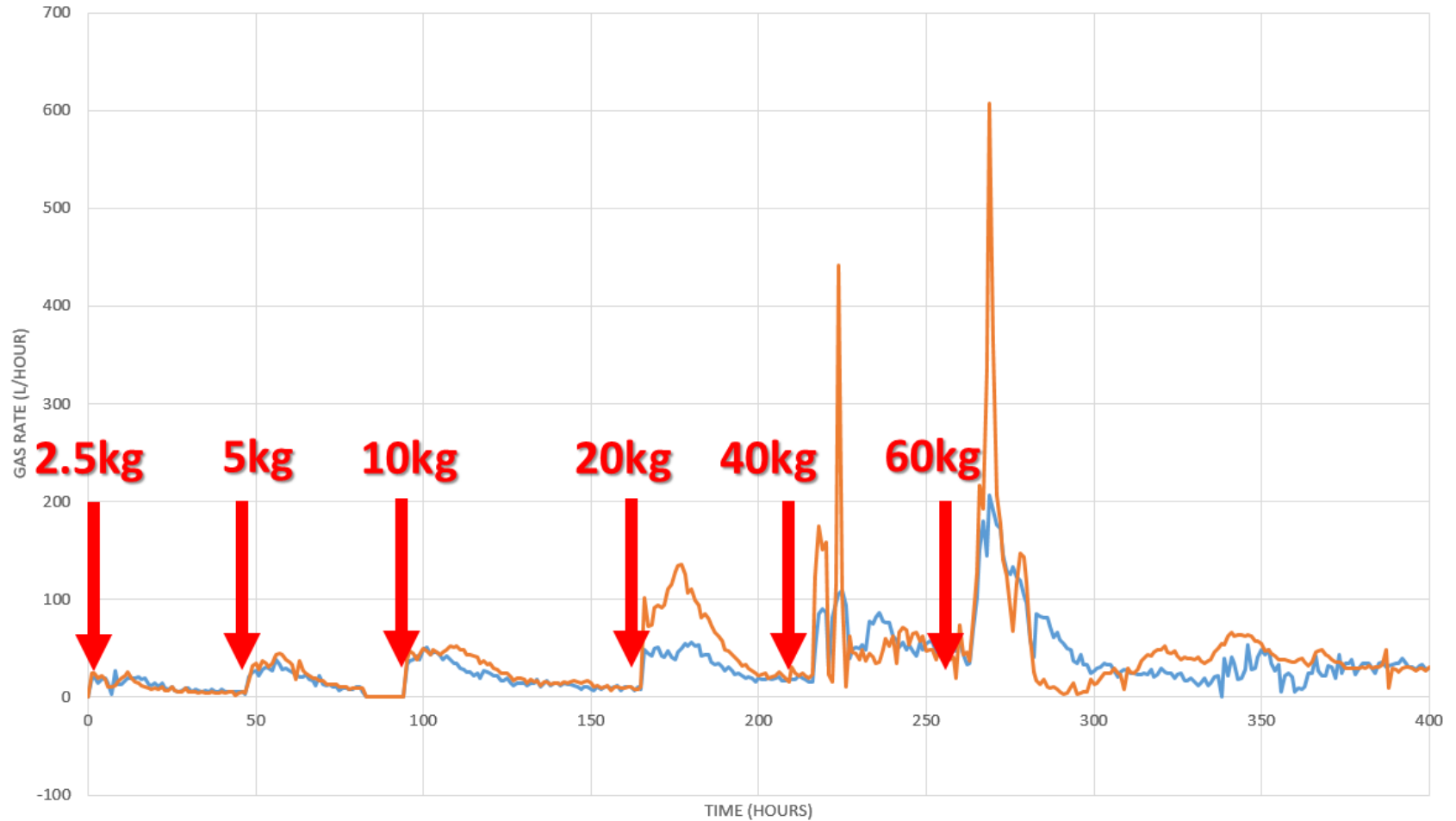
- Currently most reactors fed continuously.
- Produces most biogas, good for subsidies.
- Without subsidies, more profitable to produce on demand to get intraday trading price.
- Energy storage is expensive, and shift to renewables (solar & wind) results in demand changing more dramatically.
- Intermittent feeding can supplement available gas storage [2].

[2] E. Mauky, H. F. Jacobi, J. Liebetrau, and M. Nelles, "Flexible biogas production for demand-driven energy supply - Feeding strategies and types of substrates.," *Bioresour. Technol.*, Sep. 2014.

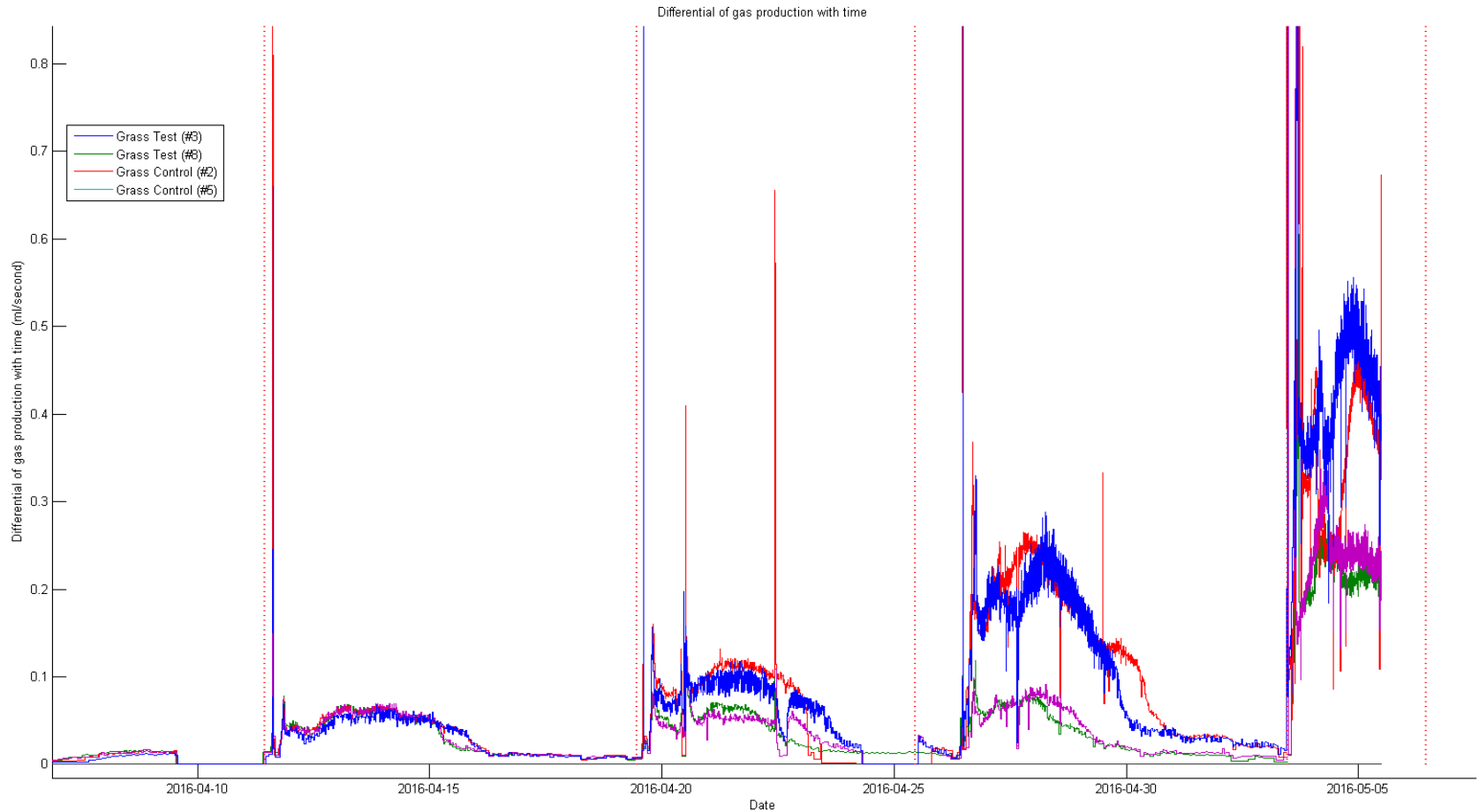
Test Setup



Gas Production Rate – Pilot Plant Results



Gas Production Rate – 5L CSTR Results



Gas Production Profiles

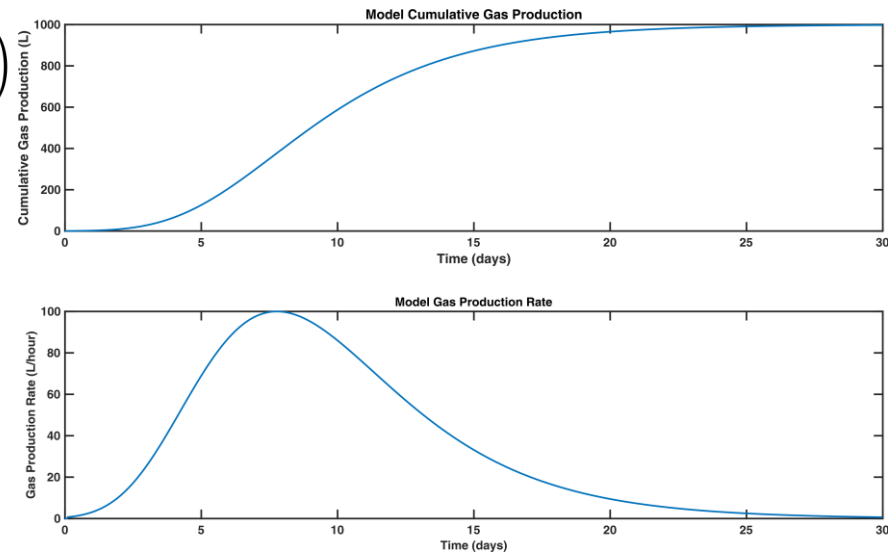
- Different gas production profile as digesters approach inhibition.
- Goal - create analysis method that works with existing sensors (i.e. total gas volume, possibly methane concentration).

Bio methane potential model

- Modified Gompertz model for biomethane potential [3]:

$$y = y_{max} \times \exp\left(-\exp\left(U \times \frac{e}{y_{max}} \times (\lambda - t) + 1\right)\right)$$

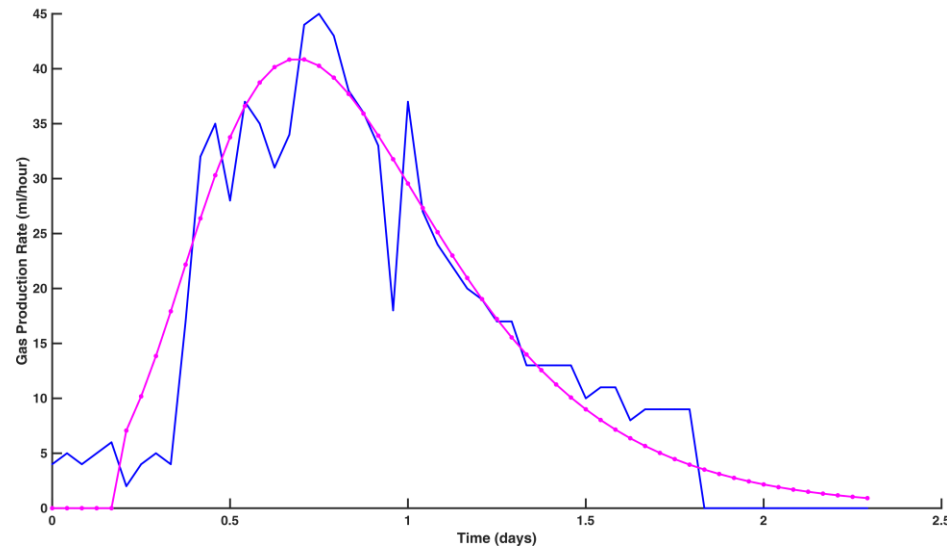
- y : cumulative amount of methane at time t .
- y_{max} : BMP.
- U : The maximum gas production rate
- λ : The lag phase before the maximum rate is reached.
- t : The time at which the values are calculated.



[3] D. M. Wall, P. O’Kiely, and J. D. Murphy, “The potential for biomethane from grass and slurry to satisfy renewable energy targets,” *Bioresour. Technol.*, vol. 149, pp. 425–431, 2013.

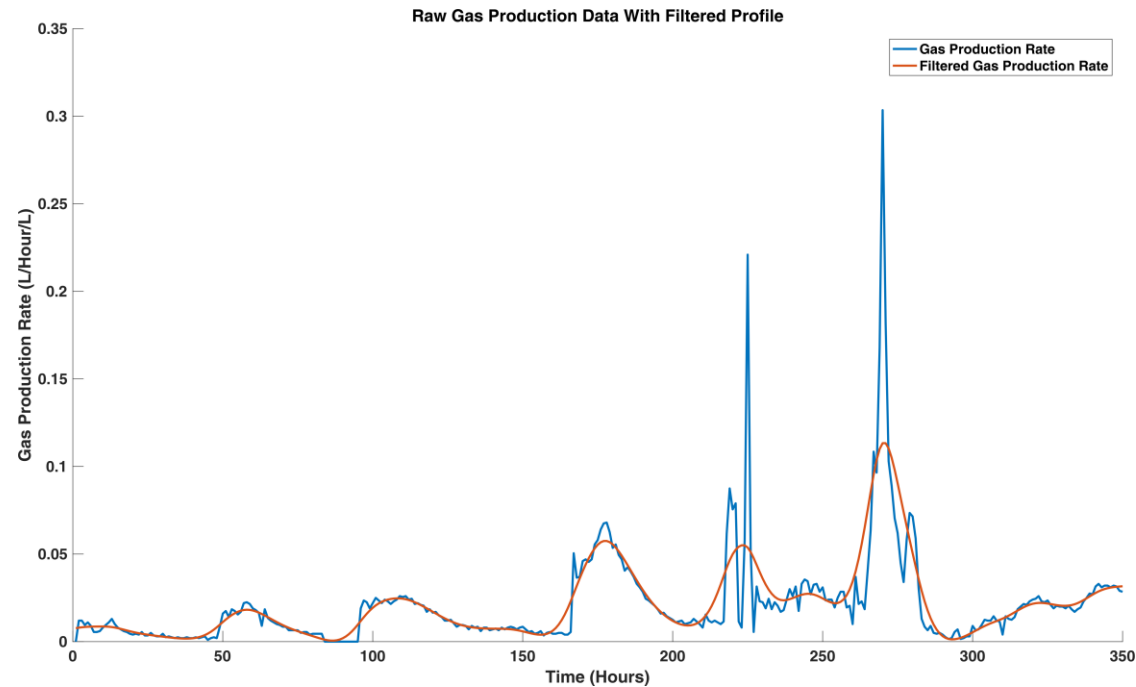
Curve Fitted With Genetic Algorithm

- GA attempts to simulate evolution to create solutions to problems.
- Worked well in cases with no inhibition.
- Modified to include model for combinations of feedstocks & inhibition.
- Became too computationally intensive.
- With inhibition present, GA converged on solution similar to curve fitting.



Simpler Curve Fitting

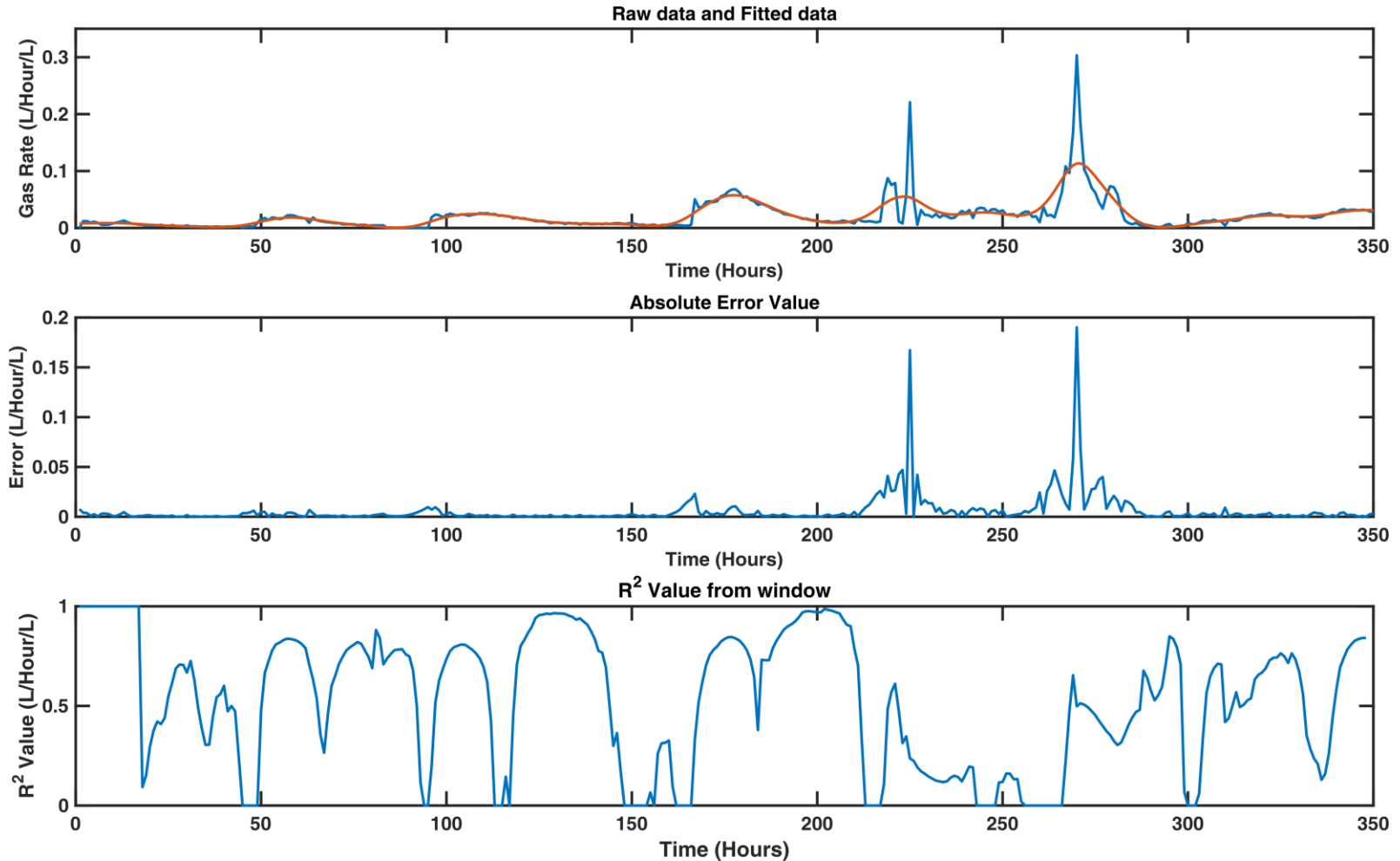
- Results very similar to GA approach.
- Need another method to estimate inhibition.



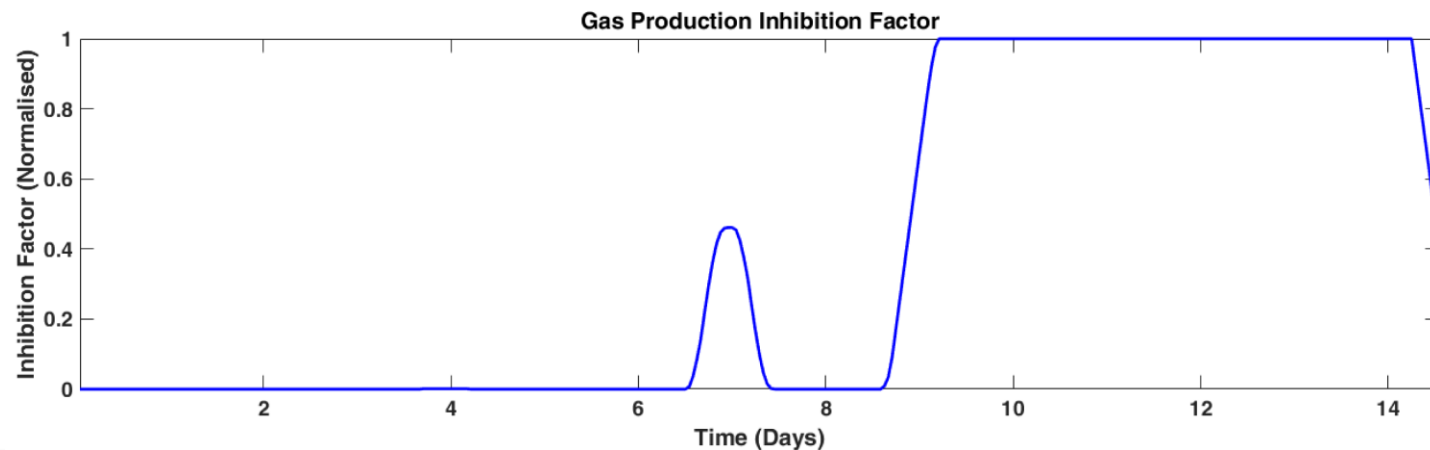
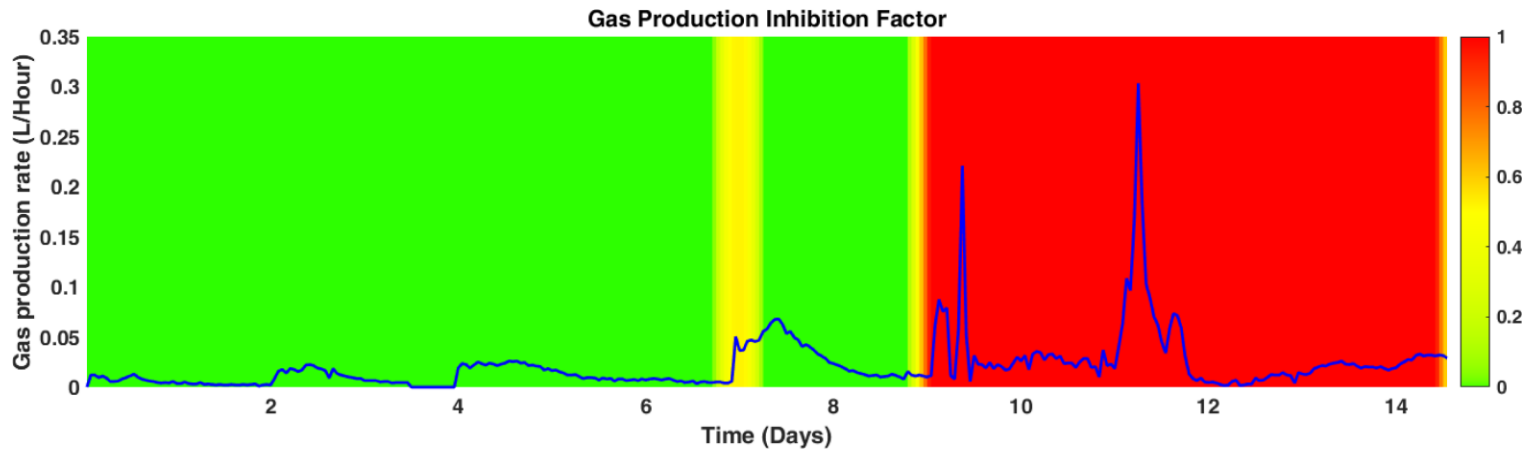
“Inhibition” metric

- Combination of absolute error and R^2 gave good performance.
- R^2 value from previous 18 hours of data.
- Added slow decay of inhibition value, as once process was inhibited, then the R^2 & absolute error drop again.
- Estimates system stress level.
- Thresholds are defined per L of reactor volume.

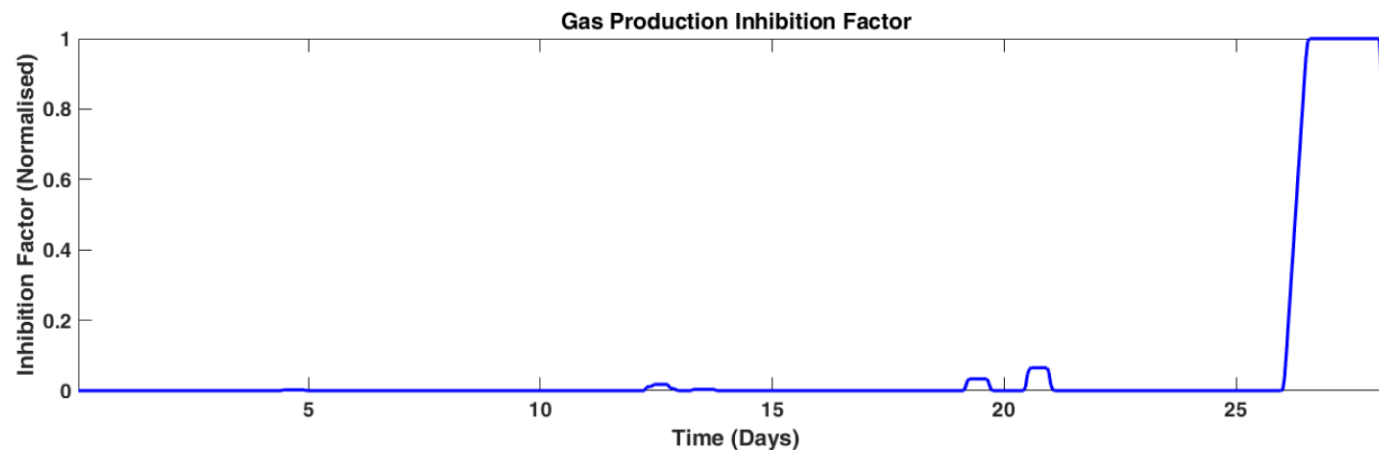
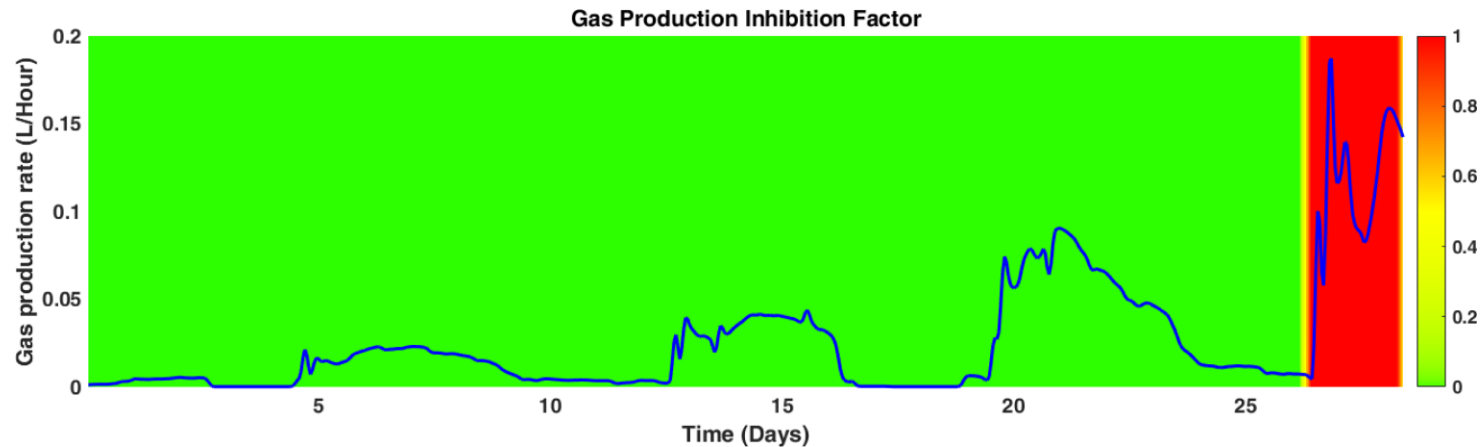
Curve Fitting Statistics



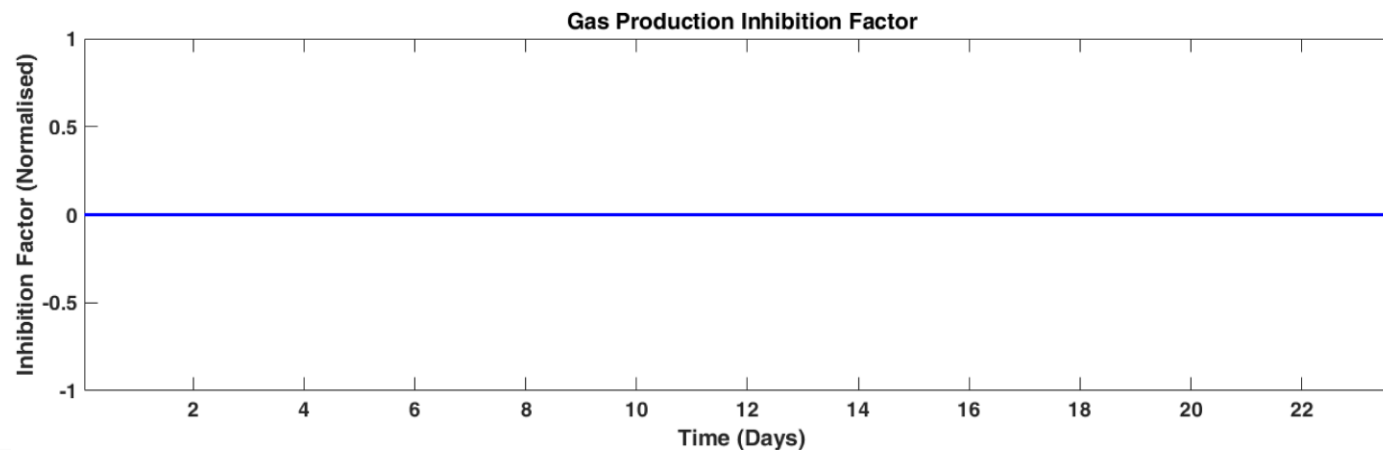
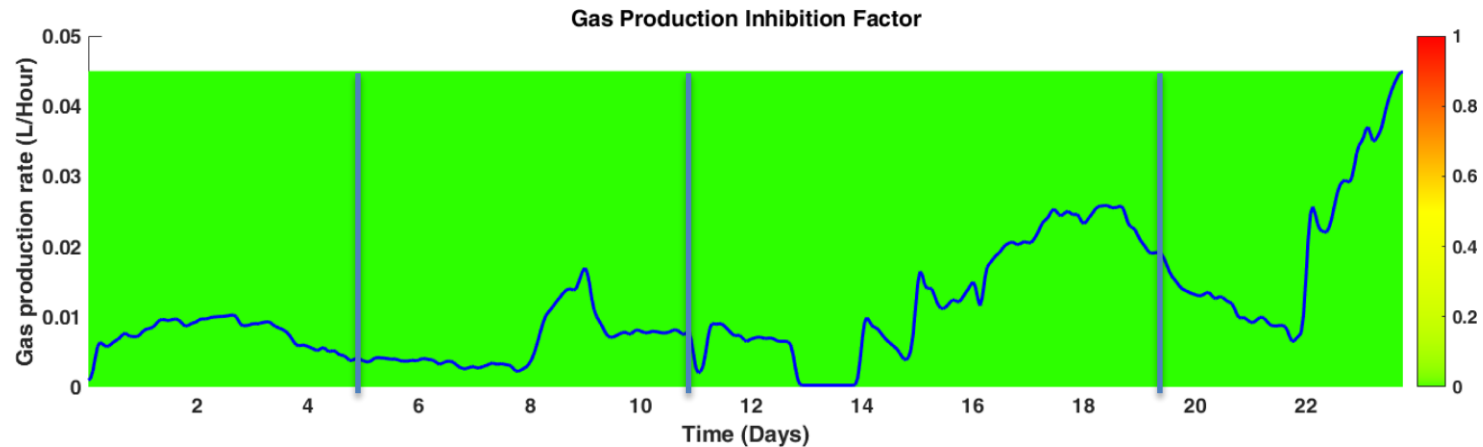
Calculated Inhibition – Maize fed 1000L Pilot Plant



Calculated Inhibition – Milled Grass fed 5L CSTR

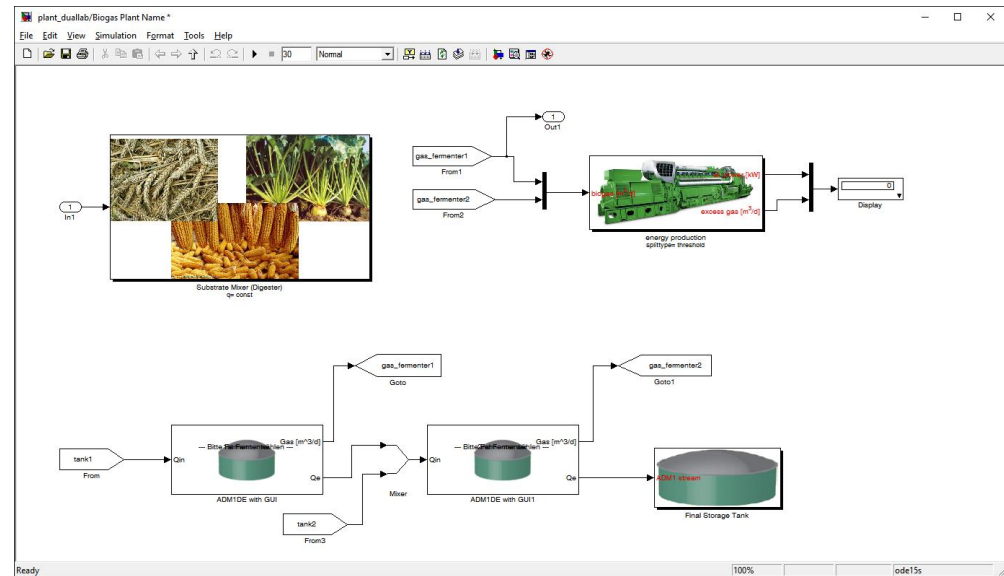


Calculated Inhibition – Cattle Slurry fed 5L CSTR



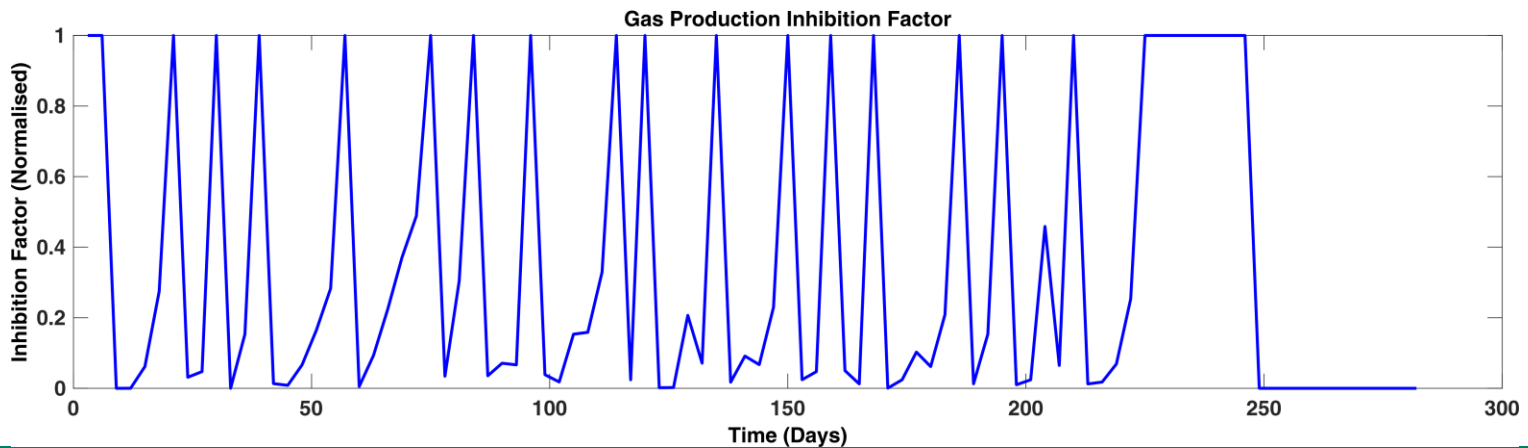
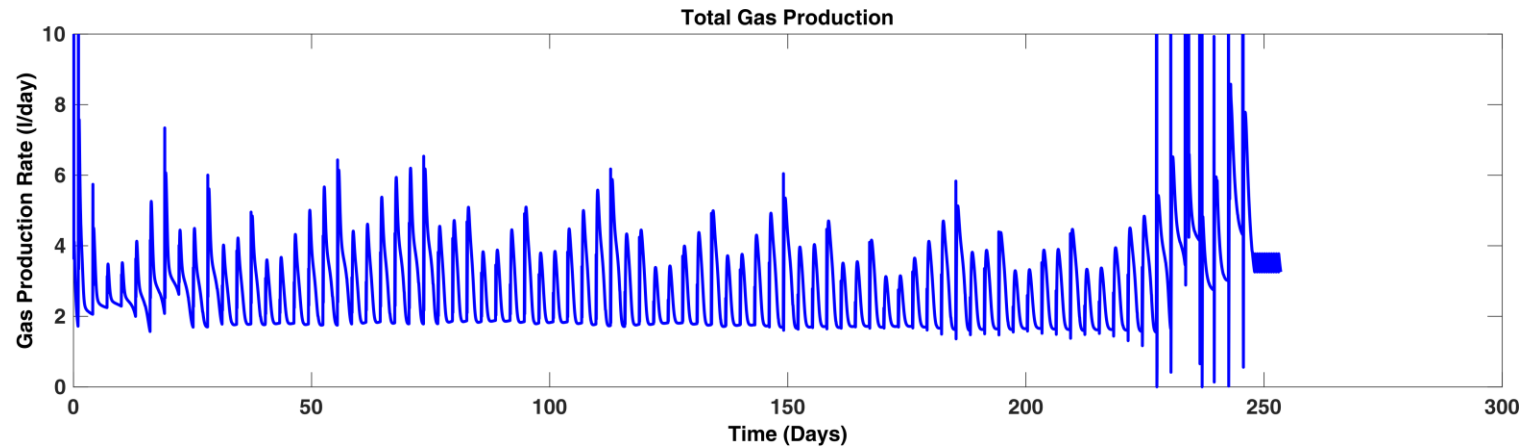
Long Term Simulation

- Ran on ADM1 toolbox for Matlab[®] created by Daniel Gaida [4].
- Simulated laboratory 5L CSTR tests.



[4] D. Gaida, "Dynamic Real-time substrate feed optimization of anaerobic co-digestion plants," Leiden University, 2014.

Long Term Simulation Test



Conclusions

- Changes in gas production as digester approaches inhibition have been observed in tests.
- Curve fitting & error analysis performed well for estimating digester inhibition.
- More complex models to match feed parameters still needs work.
- Using Genetic Algorithm to estimate feedstock parameters works only when there is no inhibition.
- Approach is limited to inhibition from overfeeding – washout isn't detected.
- Control of simulated plant also works well for preventing overfeeding.
- Intermittent feeding for on-demand power production provides additional information on digester condition.
- Next step: implement PID controller for better control of simulations.

References

- [1] J. P. Steyer, P. Buffière, D. Rolland, and R. Moletta, “Advanced Control of Anaerobic Digestion Through Disturbances Monitoring,” *Water Res*, vol. 33, no. 9, pp. 2059–2068, 1999.
- [2] E. Mauky, H. F. Jacobi, J. Liebetrau, and M. Nelles, “Flexible biogas production for demand-driven energy supply - Feeding strategies and types of substrates.,” *Bioresour. Technol.*, Sep. 2014.
- [3] D. M. Wall, P. O’Kiely, and J. D. Murphy, “The potential for biomethane from grass and slurry to satisfy renewable energy targets,” *Bioresour. Technol.*, vol. 149, pp. 425–431, 2013.
- [4] D. Gaida, “Dynamic Real-time substrate feed optimization of anaerobic co-digestion plants,” Leiden University, 2014.



Thanks for listening



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