Deutsches Biomasseforschungszentrum
gemeinnützige GmbH

DBFZ

Thermodynamic modelling of gas storages for optimized demand-driven operation of anaerobic digestion plants

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IV. CMP – 26.03.2019

Development of a renewable energy system

DBFZ

- This needs an further increase of renewable energies (especially fluctuating RE)
- necessary are new ways to guarantee grit stability in future energy systems

Opportunity: **demand driven operated biogas plants**

- A more holistic control and monitoring of biogas plants is necessary
- → Reliable gas storage filling level

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Project Manbio 03KB094A

Projektträger Jülich Forschungszentrum Jülich

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

DBFZ

Development of technical measures for improving gas management on biogas plants

- Investigation and Comparison of different storage filling level measurements
- technical improvement of the storage filling level measurement
- Development of adapted gas extraction strategies
- Support of measurement in dead zones by model approach
- Forecast of gas storage filling levels supporting substrate management strategies

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Experimental setup

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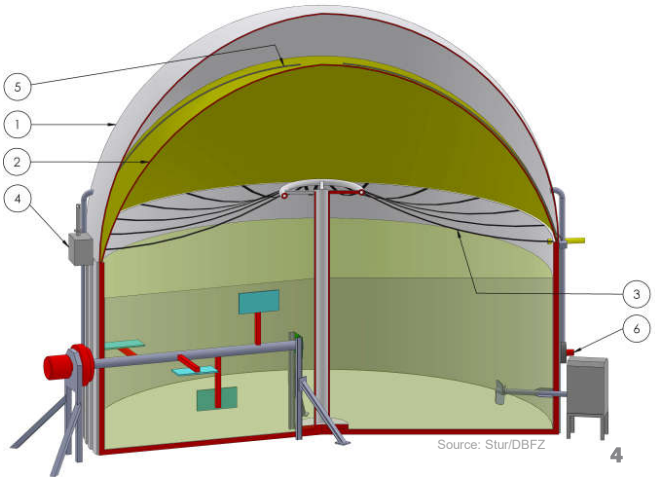
Fermenter volume 215 m³ with 150 m³ double membrane gas storage

- Temperature sensor located north approx. 15 cm inside

Pos.	Bezeichnung / *description*
1	Schutzmembran *outer air membrane*
2	Gasspeichermembran *inner gas membrane*
3	Gurthaltesystem *brace system*
4	Über- /Unterdrucksicherung *positive / negative pressure control*
5	hydrostatisches Gasspeicher-füllstandmesssystem *hydrostatic filling level measurement*
6	Stützluftgebläse *support air blower*



Source: Stur/DBFZ

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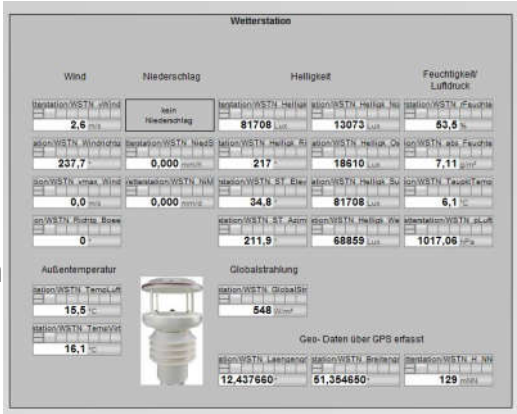
Weather measurements

Weather station (wind speed & direction, humidity, rain, pressure, temperature)

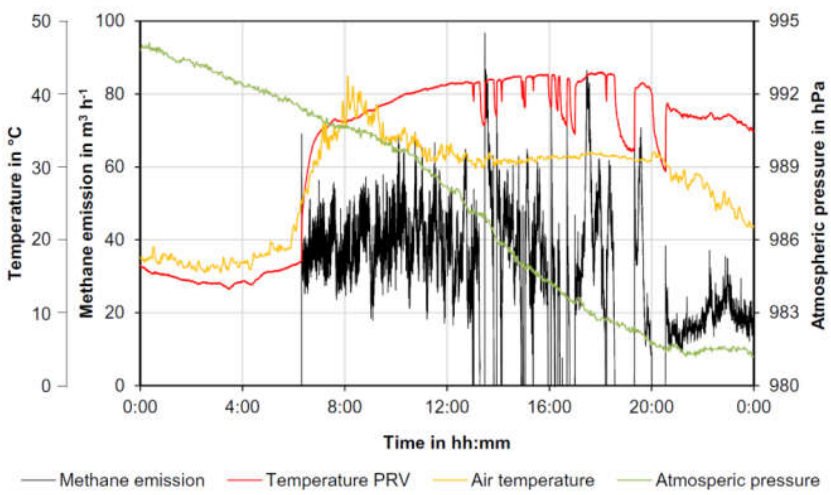
Pyranometer (global solar radiation)

Embedded in the PLS with database



Gas storage management

overpressure relief valve



adjusted according to Reinelt (2017)
Messtechnische Überwachung diffuser, betriebsbedingter und/oder zeitlich variabler Methanemissionen aus Biogasanlagen
Tagungsbeitrag FNR/KTBL-Kongress, Bayreuth, S. 237-249.

Causes of overpressure relief events

- Operation of gas holder in border area (between 80 and 100 %)
- insufficient integration of the conversion units in plant control
- lack of maintenance of the gas storage and conversion units
- Inappropriate feeding regimes
- No consideration of the weather conditions

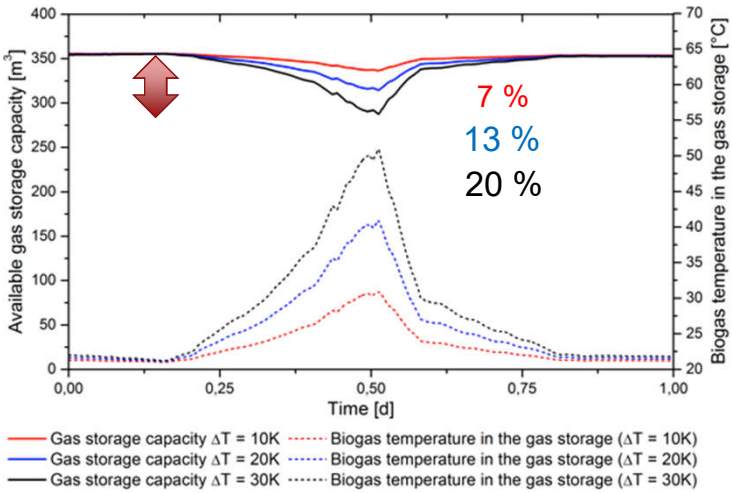
Gas storage management

Temperature influence in the gas storage

Intraday temperature difference [°C]:

5.1 ←→ 29.7 = 24.6 March
8.4 ←→ 33.5 = 25.1 April
8,7 ←→ 37,7 = 29,0 April
11.0 ←→ 34.2 = 23.2 May
16.8 ←→ 42.5 = 25.7 July
13,2 ←→ 40,8 = 27,6 August
23.6 ←→ 43,4 = 19.8 September

Up to 20 % difference in capacity



Based on Mauky et al. (2017)
Demand-driven biogas production in full-scale by model predictive feed control.
Conference Proceedings of the 25th European Biomass Conference and Exhibition (EUBCE), Stockholm, Sweden , S. 1845-1851

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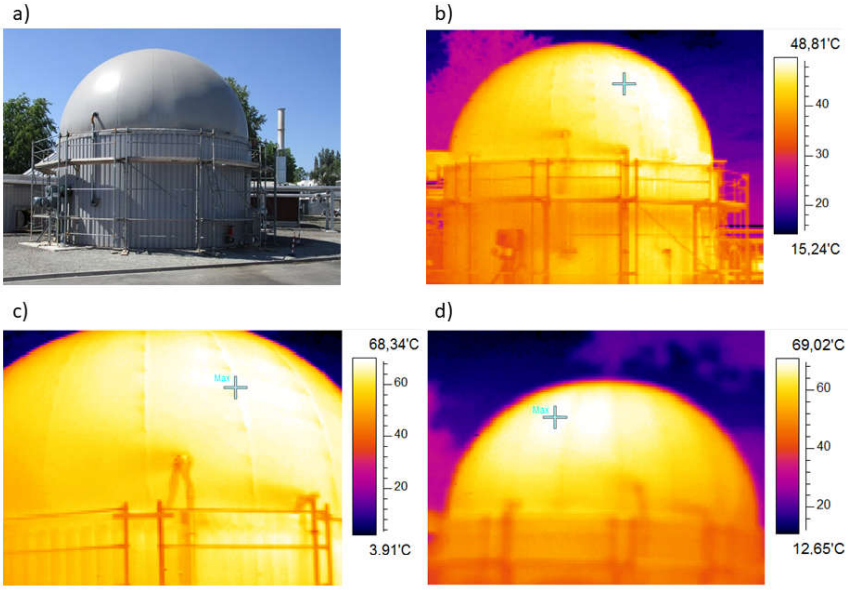
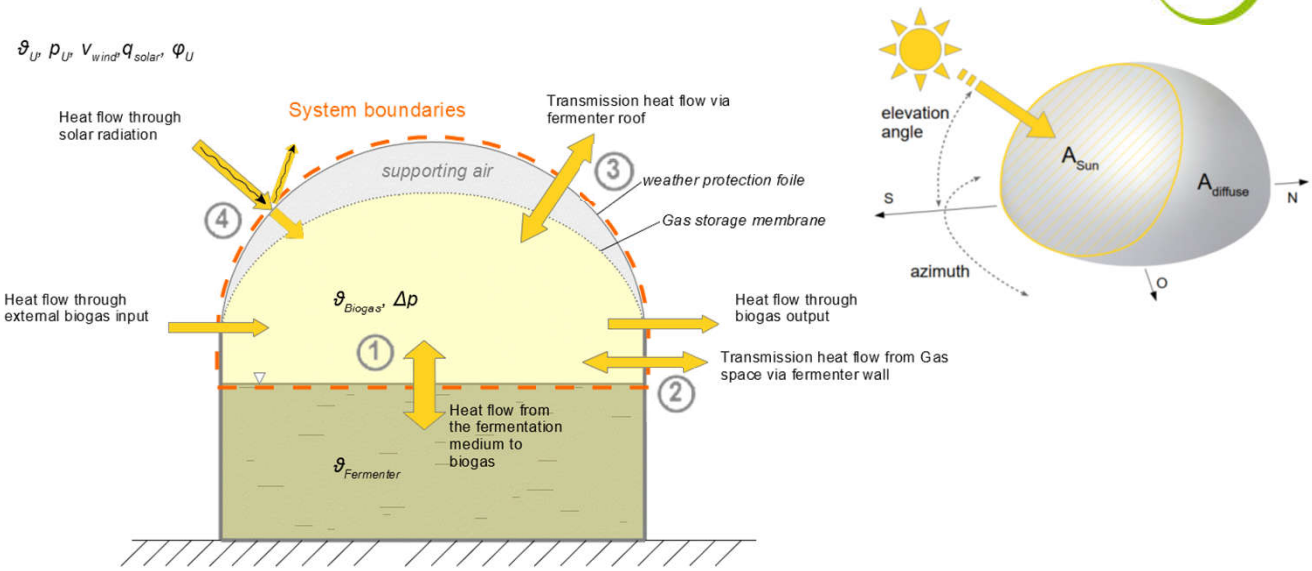
Influence of solar radiation on gas storage

a) total view with normal camera modus and
b, c, d): measured by Infrared camera; cross indicates the location of the respective maximal value

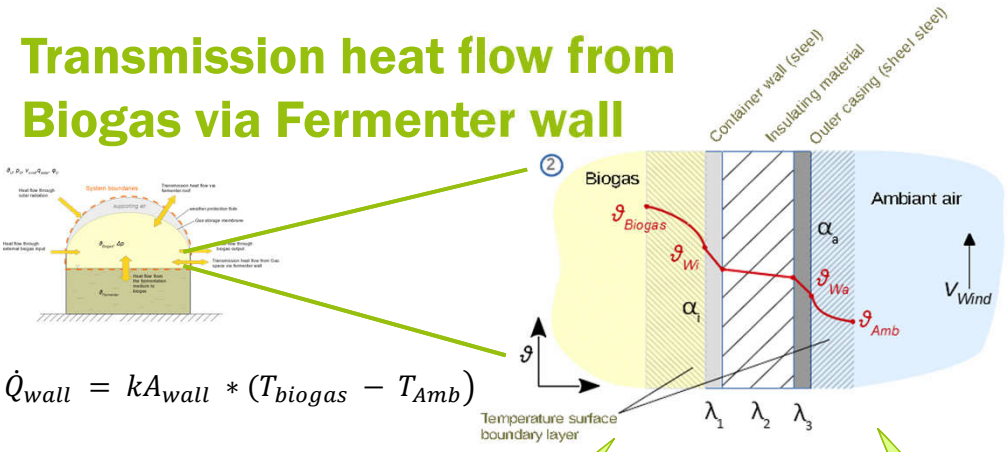


Source: Mauky/DBFZ

Heat Balance



Transmission heat flow from Biogas via Fermenter wall



calculation method beased on Springer VDI Heat Atlas (VDI Wärmeatlas)

$$\dot{Q}_{wall} = kA_{wall} * (T_{biogas} - T_{Amb})$$

free convection on vertical plane wall

- Characteristically length
- correction factor
- Prandtl-number
- Grashof-number
- Nusselt-number

thermal conductivity values of the material with surface area and thickness

forced convection

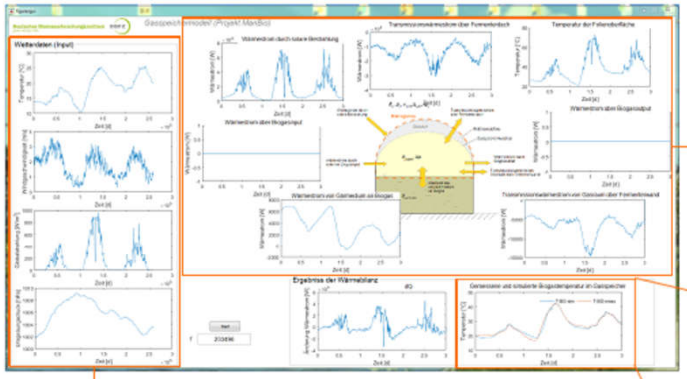
- Characteristically length
- Reynolds-number
- Prandtl-number
- Nusselt-number (laminar & turbulent)

heat transfer coefficient

heat transfer coefficient

$$\frac{1}{kA_{wall}} = \frac{1}{\alpha_{BG2wall} * A_{wallBG}} + \frac{s_{tank\ wall}}{\lambda_{tank\ wall} * A_{wallBG}} + \frac{s_{insulation}}{\lambda_{insulation} * A_{wallBG}} + \frac{s_{sheet\ metal}}{\lambda_{sheet\ metal} * A_{wallBG}} + \frac{1}{\alpha_{wall2amb} * A_{wallBG}}$$

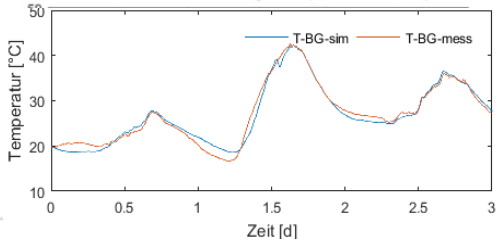
GUI and Results



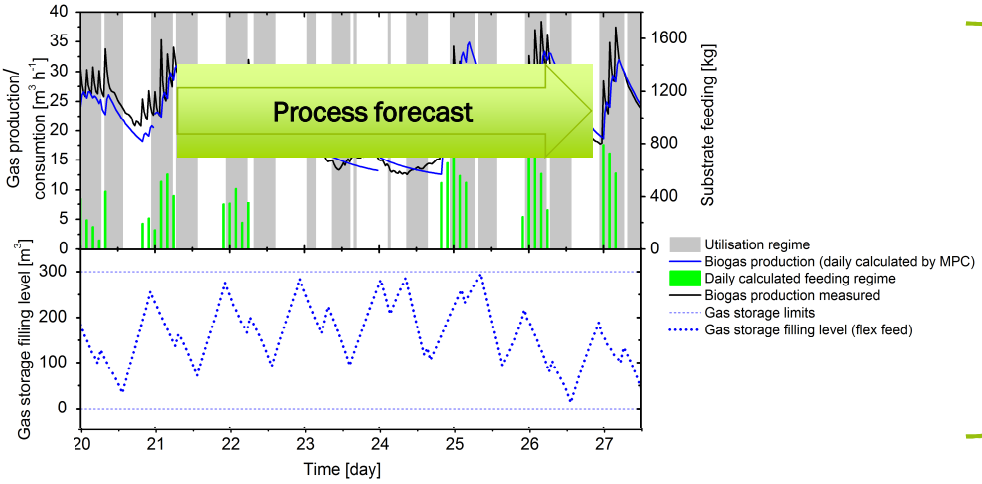
Calculated heat flows and temperatures

Weather data

Results



Feed control with weather forecasts

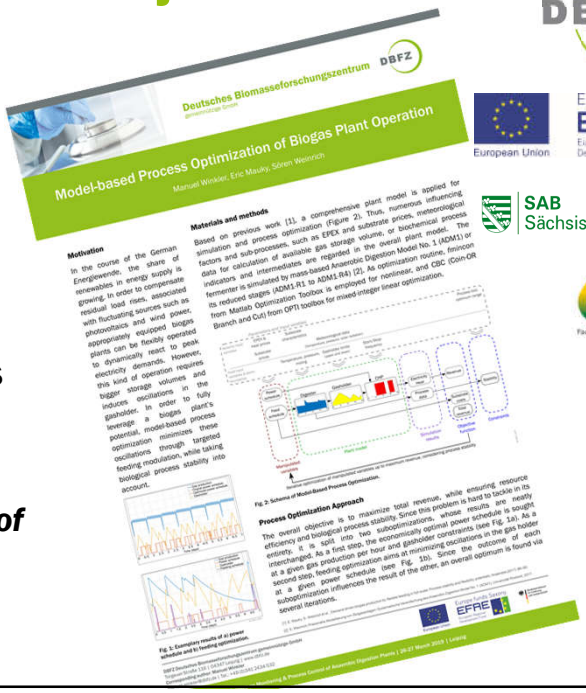


Based on Mauky et al. (2016), Model Predictive Control for Demand Driven Biogas Production in Full Scale, Chem. Eng. Technol., 39, No. 4, 652–664

Holistic plant control in the Projects *Gazelle* and *OptiFlex*

- Integration of influencing factors and sub-processes (e.g. Disintegration, Gas storing, conversation, mixing) in a overall plant model and control concepts

See Poster Nr. 11:
Model-based Process Optimization of Biogas Plant Operation


Deutsches Biomasseforschungszentrum

Model-based Process Optimization of Biogas Plant Operation

Manuel Winker, Eric Mauky, Sören Weinrich

Motivation

In the course of the German Energiewende, the share of renewables in energy supply is growing. In order to compensate residual load risen, associated with fluctuating sources such as photovoltaics and wind power, appropriately equipped biogas plants can be flexibly operated to dynamically react to peak electricity demands. However, this kind of operation requires bigger storage volumes and induces oscillations in the gasholder. In order to fully leverage a biogas plant's potential, model-based process optimization minimizes these oscillations through targeted feeding modulation, while taking biological process stability into account.

Materials and methods

Based on previous work [1], a comprehensive plant model is applied for simulation and process optimization (Figure 2). Thus, numerous influencing factors and sub-processes, such as EPEX and substrate prices, meteorological data for calculation of available gas storage volume, or biochemical process indicators and intermediates are regarded in the overall plant model. The fermenter is simulated by mass-based Anaerobic Digestion Model No. 1 (ADM1) or its reduced stages (ADM1-R1 to ADM1-R4) [2]. As optimization routine, fmincon from Matlab Optimization Toolbox is employed for nonlinear, and CBC (Coin-OR Branch and Cut) from OPTI toolbox for mixed-integer linear optimization.

Fig. 2: Schema of Model-Based Process Optimization.

Process Optimization Approach

The overall objective is to maximize total revenue, while ensuring resource efficiency and biological process stability. Since this problem is hard to tackle in its entirety, it is split into two suboptimizations, whose results are nearly interchanged. As a first step, the economically optimal power schedule is sought at a given gas production per hour and gasholder constraints (see Fig. 1a). As a second step, feeding optimization aims at minimizing oscillations in the gas holder at a given power schedule (see Fig. 1b). Since the outcome of each suboptimization influences the result of the other, an overall optimum is found via several iterations.

Fig. 3: Exemplary results of a power schedule and its feeding optimization.

[1] Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Straße 116 | 04347 Leipzig, Germany, Manuel Winker, Telephone: +49 (0341) 2434-550, E-Mail: Manuel.Winker@dbfz.de

[2] Weinrich, S.; Mauky, E.; Nelles, M.: Process Control of Anaerobic Digestion Plants | 06-07 March 2018 | Leipzig

Europe funds Saxony. EFRE European Regional Development Fund

European Union

SAB Sächsische AufbauBank

FNR Fachagentur Nachwachsende Rohstoffe e.V.

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Take Home Message

- Gas management is important, especially for advanced flexible operation
- The thermodynamic processes could be reproduced well

Current & future work

- Sensitivity analysis
- Investigations in different seasonal periods
- Including the Methods in overall plant observation and optimization

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Smart Bioenergy – Innovations for a sustainable future

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