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V. CMP INTERNATIONAL CONFERENCE ON MONITORING & PROCESS CONTROL OF ANAEROBIC DIGESTION PROCESSES

Dear anaerobic digestion enthusiasts,

the year is 2021, and this is the V. International Conference on Monitoring & Process Control of Anaerobic Digestion Processes (CMP). Five conferences in seven years is actually not a spectacular statistic to begin an editorial, nor is it a reason to fundamentally change a hitherto small but successful conference series. If the circumstances had not forced us to do so, we would not have done either. However, this year's conference is just different! Between the IV. CMP in 2019 and today, the Corona pandemic substantially affected our everyday life and work. Consequently, this is the first conference in this series organized as an online event.

Beside the Corona pandemic, there have also been changes in the head of the scientific committee that is now represented by Dr. Sören Weinrich and Dr. Jörg Kretzschmar, both working as group leaders at the DBFZ in Leipzig, Germany. Dr. Weinrich brings manifold experience in the field of modelling and simulation of the anaerobic digestion (AD) process to the board, whereas Dr. J. Kretzschmar is specialized in AD process monitoring and development of anaerobic bioprocesses in combination with microbial electrochemical technologies. With this combination of expertise, we hope to consolidate central topics of the conference that are modelling, simulation and monitoring of the AD process, but also give new impulses for development of sustainable and future-oriented AD concepts. In the past, this was excellently realized by Dr. Jan Liebetrau, Dr. Fabian Jacobi and Dr. Sabine Kleinsteuber, who still support this conference series as part of the scientific committee. We express our sincere thanks and acknowledgments for their commitment in establishing and developing this conference series over the past seven years and look forward to a successful cooperation.

However, even though we had to implement manifold modifications, the heart of the conference, remains the same. During the next days, you are cordially welcome to join talks as well as short presentations in the fields of process modelling and control, efficiency evaluation, process simulation and recent findings in microbiology of AD processes. Furthermore, we organized a session on methane emission and emission mitigation at biogas plants to properly address this issue, which severely affects the sustainability of biogas plants.

We therefore wish you an informative and interesting conference – even without personal discussions and socializing events – and we hope to welcome you again in 2023 in person, virtually or both!

Yours sincerely,

Dr. Sören Weinrich & Dr. Jörg Kretzschmar

CONTENT

SCIENTIFIC COMMITTEE

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Dr. Hinrich Uellendahl
Flensburg University of Applied Sciences, GER

Dr. Alastair James Ward
Aarhus University, DK

Prof. Christian Wolf
TH Köln, GER

PROGRAMME

1st DAY

15´ Welcome and introduction **Start: 10:00**
Jürgen Kretzschmar & Sören Weinrich (DBFZ), Jan Liebetrau (Rytech GmbH)

20´ Keynote: Opportunities and challenges in anaerobic process modelling
Sören Weinrich (DBFZ)

10’ Discussion

23.03.2021 SESSION A 10:45 – 12:00

Modelling & Control

Chair Fabian Jacobi,
Hessian State Laboratory (LHL)

15’ Flexible biogas production via a control system based on machine learning algorithms
Bernhard Huber, Professorship of Regenerative Energy Systems, Campus Straubing for Biotechnology and Sustainability, Technical University of Munich
5`Discussion

15’ Electricity-market-driven optimization of biogas plant operation – theory and application in full scale
Manuel Winkler, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
5`Discussion

15’ Robust state estimator for the anaerobic digestion process of the organic fraction of municipal solid waste (OFMSW)
Niloofar Raeyatdoost, TH Köln, Institute for Automation and Industrial IT, Angewandtes Zentrum für Umwelt gGmbH
5`Discussion

Lunch Break 12:00 – 13:00

SESSION B 13:00 – 14:30

BMP Tests | Efficiency Evaluation

Chair Jan Liebetrau,
Rytec AG

15’ Monitoring of anaerobic batch degradation in polyester bags
Alastair James Ward, Aarhus University, Department of Engineering, Denmark
5`Discussion

15’ Making BMP measurement more reproducible: results, recommendations, and resources from the IIS-BMP project
Sasha D. Hafner, Hafner Consulting
5`Discussion

15’ Comparison of different concepts for monitoring biological efficiency on agricultural biogas plants
Thorsten Mächtig, Universität Kiel, Institut Landwirtschaftliche Verfahrenstechnik
5`Discussion

15’ A novel gradient-based monitoring system for dark fermentation in plug-flow reactors
Marion Longis, Technische Universität Berlin, Bioprocess Engineering, Institute of Biotechnology
5`Discussion

2nd DAY

10´ Introduction **Start: 10:30**
Jürgen Kretzschmar (DBFZ)

24.03.2021 SESSION C 10:45 – 12:15

Simulation and Full scale

Chair Hinrich Uellendahl,
Flensburg University of Applied Sciences

15’ Use of simple observers and model predictive controllers at large-scale biogas plants
Jürgen Kube, Future Biogas
5`Discussion

15’ Prediction and real-time optimization in biogas production plants with circulating flow
Arne Nägel, Goethe-Zentrum für Wissenschaftliches Rechnen, Universität Frankfurt
5`Discussion

15’ Neural network modeling of Industrial-scale plug-flow biogas Plants
Imre István Antalfy, Zurich University of applied Sciences, MA ASCL
5`Discussion

15’ Calculation of a normalized energy baseline for biogas (upgrading) plants
Karlheinz Meier, BayWa r.e. Bioenergy GmbH
5`Discussion

Lunch Break 12:15 – 13:00

SESSION D 13:00 – 14:30

Microbiology

Chair Sabine Kleinsteuber,
Helmholtz Centre for Environmental Research – UFZ

15’ Adaptation of a microbial community to demand-oriented biological methanation
Hoda Khesali Aghtaei, Bioprocess Engineering, Max Planck Institute for Dynamics of Complex Technical Systems
5`Discussion

15’ Storing surplus electricity through biomethanation with microbial communities: How to cope with intermittency?
Washington Logrono, Helmholtz Centre for Environmental Research – UFZ
5`Discussion

15’ Effects of phenyl acids on different AD stages in thermophilic batch reactors
Eva Maria Prem, Department of Microbiology, Universität Innsbruck
5`Discussion

15’ Anna Karenina ecological principle in biogas research. Has ammonia stress a stochastic or deterministic effect on microbial community compositions?
Marcell Nikolausz, Helmholtz Centre for Environmental Research – UFZ
5`Discussion

30`discussion and enclosure

PROGRAMME

3rd DAY

10´ Introduction
Torsten Reinelt, Landesamt für Umweltschutz (LAU) Sachsen-Anhalt

Start: 10:00

The final results of the project EvEmBi will be presented in Session E »Methane emissions and possible mitigations from European biogas plants«

25.03.2021 SESSION E **10:10 – 12:15**

Methane emissions and possible mitigations from European biogas plants

Chair Torsten Reinelt,
Landesamt für Umweltschutz (LAU)
Sachsen-Anhalt

20´ Keynote: evaluation and reduction of Methane Emissions from different European biogas plant concepts – An Introduction of the EvEmBi project
Angela Vesenmaier & Martin Reiser, University of Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management
5`Discussion

15´ Evaluation of methane emissions from different European biogas plant concepts using harmonized methods including on-site and ground-based remote sensing approaches
Viktoria Wechselberger, University of Natural Resources and Life Sciences, Department of Water – Atmosphere – Environment, Institute of Waste Management
5`Discussion

15' Model to estimate methane emissions of different biogas plant concepts and national biogas plant stocks
Lukas Knoll, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
5`Discussion

15' Evaluation of methane emission reduction measures and cost-benefit-analysis
Jonas Dahl, RISE research Institutes of Sweden, Division Built Environment - Energy and resources
5`Discussion

25`Final discussion and enclosure

ABOUT THE PROJECT EvEmBi

Methane emissions from biogas plants have received growing attention over the past years due to the development of improved monitoring methods for evaluation. However, the dynamic and fugitive nature of methane emissions, changing operating conditions, and different as well as not standardized measurement approaches compromise the precise quantification of the overall emissions from biogas facilities. Within the EvEmBi project various European biogas plant concepts were evaluated and analysed in terms of their methane emission factors using harmonized methods.

As part of the EvEmBi project, this session will focus on the latest measurement results and mitigation strategies developed in the EvEmBi project. This include the presentation and discussion of the evaluation of methane emissions from biogas plants, a model for the estimation of methane emissions from biogas plants as well as a cost-benefit analysis of specific mitigation measures.

More information:

www.europeanbiogas.eu/project/evembi/
projekte.ffg.at/projekt/2863601

www.best-research.eu/de/kompetenzbereiche/alle_projekte/view/556

1st DAY

SESSION A MODELLING AND CONTROL
SESSION B BMP TESTS | EFFICIENCY EVALUATION

SESSION A

Modelling and Control

Chair Dr. Fabian Jacobi,
Hessian State Laboratory (LHL)

15' Flexible biogas production via a control system based on machine learning algorithms
Bernhard Huber, TUM Campus Straubing, TU München, Professur für Regenerative Energiesysteme

15' Electricity-market-driven optimization of biogas plant operation – theory and application in full scale
Manuel Winkler, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH

15' Robust state estimator for the anaerobic digestion process of the organic fraction of municipal solid waste (OFMSW)
Niloofar Raeyatdoost, TH Köln, Institute for Automation and Industrial IT, Angewandtes Zentrum für Umwelt gGmbH

SESSION B

BMP Tests | Efficiency Evaluation

Chair Dr. Jan Liebetrau, Rytec AG

15' Monitoring of anaerobic batch degradation in polyester bags
Dr. Alastair James Ward, Aarhus University, Department of Engineering, Denmark

15' Making BMP measurement more reproducible: results, recommendations, and resources from the IIS-BMP project
PhD Sasha D. Hafner, Hafner Consulting

15' Comparison of different concepts for monitoring biological efficiency on agricultural biogas plants
Thorsten Mächtig, Universität Kiel, Institut Landwirtschaftliche Verfahrenstechnik

15' A novel gradient-based monitoring system for dark fermentation in plug-flow reactors
Marion Longis, Technische Universität Berlin, Bioprocess Engineering, Institute of Biotechnology

Bernhard Huber, Prof. Dr.-Ing. Matthias Gaderer

Flexible biogas production via a control system based on machine learning algorithms

Session A
10:45 – 11 am
15' presentation

flexible biogas production, machine learning, NIR Sensor, Day-Ahead-Market, SVR

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Motivation

In the year 2000, the first EEG (Renewable Energy Sources Act) was introduced in Germany, which promoted the expansion of wind power, photovoltaic and biogas plants, among other things. The guaranteed feed-in tariffs for 20 years made these technologies financially attractive for many operators. This is also reflected in the increase in gross electricity generation in Germany since 2000. In the coming years, the first plants will fall out of the EEG and will have to assert themselves on the free electricity market, unless new political regulations for these plants are added. Already with the introduction of the EEG 2012, the flexibility premium for additionally installed CHP capacity was a first step in the direction of demand-oriented power generation from biogas plants. In an electricity market with a high proportion of volatile forms of generation such as wind power and photovoltaics, this can make an important contribution to the supply of balancing power and also to covering the residual load. The interval operation of biogas plants is mainly limited by the volume of the gas storage tank at constant biogas production [1]. In order to further increase flexibility without having to invest in additional gas storage capacity, it would be conceivable to change the biogas production from constant to demand-oriented by means of new feeding concepts. This is where the "FlexBioNeuro" project comes in.

Aim of the work

The main goal of the project is the demand-oriented production of biogas based on an intelligent control system. By feeding various substrates into the main fermenter the gas production is adjusted in a targeted manner. The control is based on a sensor-supported real-time measuring system. The data is taken in a scale of minutes.
The control system is designed to enable biogas plant operators to maximize revenues on the power exchange (e.g. EPEX Spot SE - European Power Exchange Spot SE) in the day-ahead market and possibly in the intra-day market while minimizing the use of substrate. On the day-ahead market, electricity is traded for the following day. Usually electricity is traded in blocks of hours. Bids for the following day can be placed until 12:00 noon. Trading on the intra-day market also begins the day before at 15:00 hrs with blocks of hours or quarters [2].
For example, a load profile is transferred to the control model, which is derived from participation in the day-ahead market for the following day. From this load profile, feeding quantities for the substrate (corn, liquid manure, dung) are calculated, taking into account the process limits of the biogas plant.

Target for the control model

1. specification of the required load profile (from day-ahead auction or intraday auction)
2. calculation of the feeding intervals and the mass flows for feeding in order to be able to run the desired load profile with as little material input as possible
3. design a feeding schedule recommendation for the operator of the plant

Key research topics and novelty

Control system based on machine learning:

The control model is designed to map the complex, biological processes of this plant concept on the basis of machine learning algorithms. For this purpose a data set of around 100 trials will be generated. The parameters to be recorded are listed below.

Input parameter
- load profile

the respective measured variables for hydrolysis reactor and fermenter
- acetic acid concentration
- dry matter content
- pH value
- temperature

and the data from the SPS of the biogas plant
- gas storage level
- electrical CHP power
- methane content in gas
- feeding intervals
- mass flows of feeding
- type of substrate/substrate mixture

a machine leairning algorithm is trained. This can then make predictions for the required mass flows of the feeding at a new given load profile.

Data generation via online measurements at a real plant:

In order to be able to specify boundary conditions for the control model, which are important for process stability in the hydrolysis reactor and in the fermenter, the following parameters are measured online in both vessels:
- pH value (pH electrode)
- dry matter content (NIR sensor)
- acetic acid concentration(NIR sensor)
- FOS/TAC
- temperature (pt 100)

Methods

Online measurements and data generation at the real plant is the first step. The measuring interval will be within minutes. After that the training data is analyzed and a machine learing algorithm (i.e. support vector regression and random forest regression) will be trained.

Results

The research project aims to provide practical solutions in the field of measurement and control technology. The concept will be transferable to other plants, but the creation of a certain amount of training data will be necessary for each plant. These solutions serve to make biogas production more flexible and thus improve the utilization of existing gas storage capacities.

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Manuel Winkler, Dr. Eric Mauky, Dr. Sören Weinrich

Session A
11:10 – 11:25 am
15' presentation

Electricity-market-driven optimization of biogas plant operation – theory and application in full scale

EPEX Spot market; model-predictive control; flexibilization; process modeling; mixed-integer optimization

20 years after the first Renewable Energies Act (EEG) came into force, many German biogas plant owners are facing an uncertain future. To ensure economic operation, most of them have opted for direct marketing of the generated electricity in order to keep receiving guaranteed feed-in tariffs for another 10 years. This involves trading hour blocks on the day-ahead market of the European Energy Exchange (EPEX). The combined heat and power units (CHP), which used to run continuously, are then required to run only part-time. This induces a fluctuating biogas demand over time, which in practice is most often only compensated with the existing gasholder.

However, to leverage a plants' full potential, manipulation of the substrate feeding amounts and times is required [1]. This has been proven both feasible and beneficial at lab [2] and full scale [3], while experiments were realized with one single fermenter, only simulating the gasholder and CHP. Nevertheless, flexible feeding strategies have not been adapted in industry due to increased requirements for process control, plant automation and staff training.

In the current work, the overall maximization of market revenue with an adapted feeding strategy, while exhausting the limits of the gasholder, has been incorporated into an iterative optimization procedure (Figure 1). Provided with suitable forecasts of the expected EPEX price development, it calculates optimal feeding regimes and best CHP operating times based on simplified linear models of the fermenter and gasholder.

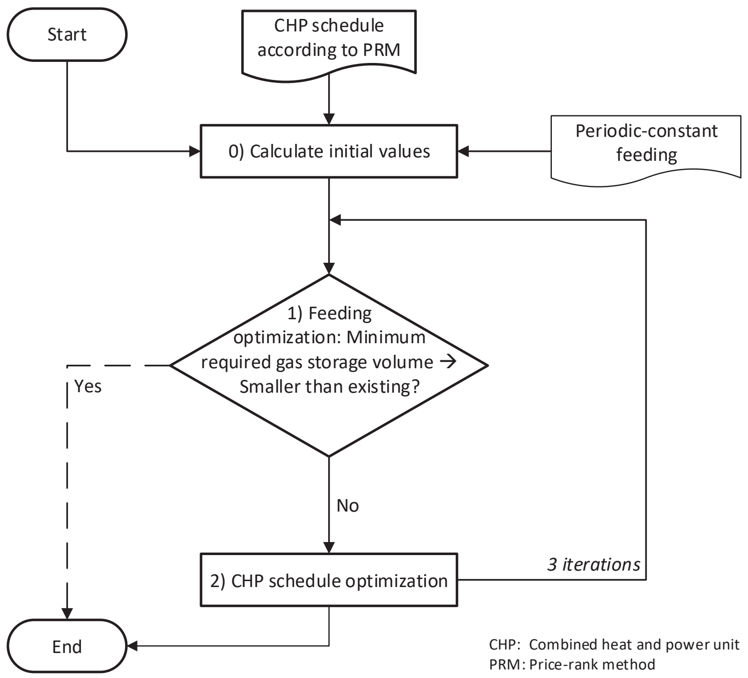

Figure 1: Schema of the iterative model-based optimization algorithm (simplified)

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Based on full-scale experiments at the research biogas plant of DBFZ, this algorithm has been implemented into a model-predictive control strategy in order to prove the effect of flexible feeding with a rather small gasholder (mean buffer time about 8.5 hours) and a power quotient of about 2.6. Real EPEX prices from the same day were used, with a linear regression-based extrapolation method to estimate future market development. Predictions, simulations and control variables were updated every 24 hours (except on weekends), while using the same overall substrate amount during one week as in constant feeding.

In general, the model overpredicted experimental properties. Biogas production was overestimated by 12.8 %, EPEX prices by 6.9 %, and total CHP operating hours by 3.4 %. Still, the overall dynamics of the process was accurately depicted. From an economic point of view, the obtained revenue reached 90 % of the theoretically possible income (e.g., if prices would have been known beforehand and no technical restrictions would have been in place). Taking these restrictions into account, even 95 % of the feasible revenue was accomplished.

Given that solely linear models were employed, the overall agreement between measurement and simulation was beyond expectations. Though the employed experimental setup cannot fully represent the wide variety of substrate combinations and plant concepts encountered in practice, results suggest that existing biogas plant may obtain direct marketing revenues close to optimal, even without major investments in additional gas storage capacity.

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Niloofar Raeyatdoost, Prof. Dr.-Ing. Michael Bongards, Prof. Dr. Christian Wolf

Session A
11:30 – 11:45 am
15' presentation

Robust state estimator for the anaerobic digestion process of the organic fraction of municipal solid waste (OFMSW)

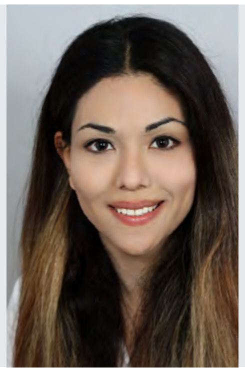
Unscented Kalman filter, H-infinity filter, anaerobic digestion, organic fraction of municipal solid waste, extended AM2 model

Anaerobic digestion (AD) plants with nonlinear dynamics require online monitoring and control for safe and optimal operation [1]. However, online measurement of all process states comes with limitations and high costs. State estimation techniques are able to provide the required information for control and monitoring purposes by online estimation of process state values.

For dynamic state estimation, a model of the AD plant is required. The Anaerobic Digestion Model No. 1 (ADM1), with a high number of parameters and states, is the most common model [2]. However, for state estimation and control purposes a simpler model with fewer states and parameters is required in order to shorten model building, calibration and computation times [3]. In this work, the extended version of the anaerobic digestion model number 2 (AM2) is used [4]. AM2 is a suitable model for control and state estimation applications, which includes 2 steps of acidogenesis and methanogenesis. For complex solid wastes such as the organic fraction of municipal solid waste (OFMSW), hydrolysis is the rate-limiting step [5]. Therefore, in this work the extended AM2 (E-AM2) including a hydrolysis step is considered as the model.

The overall goal is to propose a state estimation method that can handle the nonlinearity of AD plants and even performs in a robust manner in the presence of measurement and process noise. The unscented Kalman filter is a derivative-free state estimation method suitable for highly nonlinear systems [6]. The main issue with UKF is that it works well only in the case of Gaussian measurement and process noise. However, in practice most real systems are associated with uncertainties within the inputs and disturbances. The measurement and process noise characteristics are not always known and they can be non-Gaussian and time-variant. As a result, a conventional UKF might diverge under these circumstances. In [7], an H-infinity filter is used to guarantee a limit on the error caused by uncertainties and make the UKF method robust to non-Gaussian noise. Therefore, in this work the proposed H-infinity UKF (HUKF) method is applied to the AD process where the input substrate is OFMSW. The robustness of the developed estimator is evaluated for different noise scenarios. The development of the AD model and the state estimator has been done in Matlab.

In Fig 1, HUKF method is compared with UKF for 3 different scenarios. In scenario (a), measurement and process noise are unknown and Gaussian. In scenario (b), measurement and process noise are unknown and non-Gaussian. In scenario (c), uncertainty is defined within the model parameter k1 (the yield-coefficient for substrate degradation), where it is 10% higher than its actual value. In scenario (c), measurement and process noise are unknown and Gaussian. To compare the results, root-mean-squared error (RMSE) of all estimated states for each scenario is obtained. This model includes 10 state variables which are: X1: concentration of acidogenic bacteria, X2: concentration of methanogenic bacteria, S1: organic substrate concentration, S2: volatile fatty acids concentration, Z: total alkalinity, Xc: particulate composite, Xch: particulate component of carbohydrates, Xpr: particulate component of proteins, Xli: particulate component of lipids, C: total inorganic carbon concentration. For the estimation purpose, methane and carbon dioxide flow rates are used as the measurement variables to estimate all the 10 state variables. Results show that for all defined scenarios HUKF method outperforms UKF with better accuracy, while this improvement is less noticeable for scenario (a), where noise is Gaussian.



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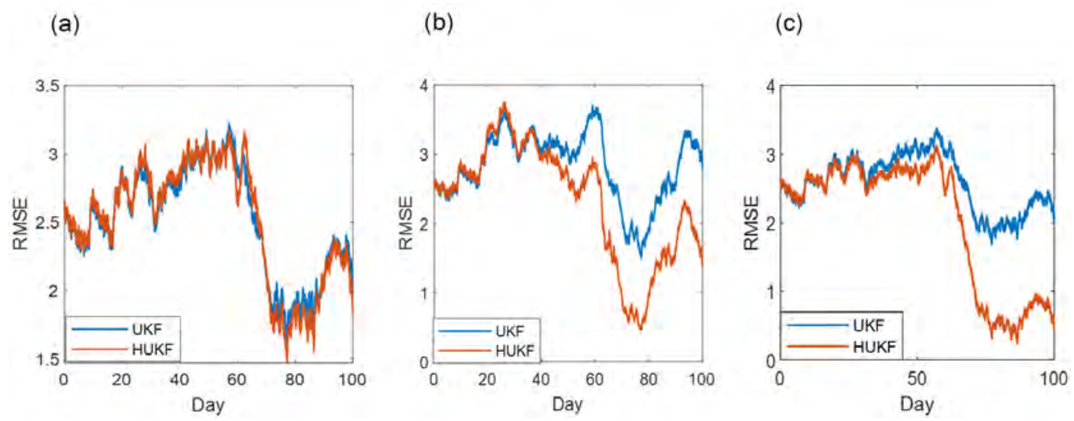

Figure 1: RMSE of the estimated state variables by UKF and HUKF methods, (a) in the presence of unknown Gaussian process and measurement noises, (b) in the presence of unknown non-Gaussian process and measurement noises, (c) in the presence of unknown Gaussian process and measurement noises with model uncertainties.

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Dr. Alastair James Ward, PhD Nicholas John Hutchings, Prof. Martin Riis Weisbjerg, Prof. Peter Lund

Session B
1:25 – 1:40 pm
15' presentation

Monitoring of anaerobic batch degradation in polyester bags

Batch digestion, polyester bags, degradation

The anaerobic batch digestion of freeze-dried and ground (1mm) substrates was investigated with substrates placed in polyester bags. Using bags to contain the substrate during digestion allowed for easy removal of the partially digested material, which could be washed to remove inoculum before analysis to investigate degradation over a period of 90 days. The biogas and methane production dynamics were compared to a traditional, non-bagged substrate method. Substrates were chosen to represent a variety of biogas production scenarios: manures from dairy cattle (CM) and fattening pigs (PM), agricultural by-products in the form of wheat straw (WS) and maize silage (MS) representing energy crops. Cellulose (CE) controls were set up to compare the gas production kinetics of a substrate with a known specific methane yield. By using batch bottles running in parallel with those used for gas measurement, bottles could be opened at time points corresponding to days when gas volume was measured (depending on gas production rates) and the bagged substrates were analysed. The aim was to follow the fate of carbon to volatile fatty acids and then to CO_2/CH_4, and the fate of nitrogen in organic matter to ammonia.

Methods

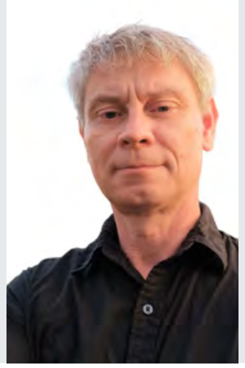
All bagged substrates were examined for total solids (TS) volatile solids (VS). All bagged substrates except CE were examined for total Kjeldahl nitrogen (TKN) and neutral detergent fibre (NDF). The bulk liquids (batch bottle contents after bags were removed) were tested for TS, VS, TKN, total ammonia nitrogen (TAN) and volatile fatty acids (VFA) at the same time points. Analytical methods for analyzing retrieved substrates followed standard methods.

Active anaerobic inoculum was sourced from a mesophilic anaerobic digester (temperature ca. 35°C) The batch assays were set up with inoculum to substrate ratios around 1.5:1 (based on VS) and incubated at 35°C. The bags used in the experiment were made of polyester (PES material 38/31 with 31 % open bag area and 38µm pore size).

Results

The cumulative specific biogas (SBY) and methane yields (SMY) were modelled by fitting first order curves to find the rate constant (k_{hyd}). The measured and modelled gas yield data are shown in Table 1, where the letter "B" in subscript following the substrate abbreviation means bagged substrate, whereas the letter "F" means free (i.e. not bagged) substrate.

It is clear from Table 1 that digesting the substrates in bags had a considerable effect on k_{hyd} values and, to a lesser extent, the final gas yields. The differences between bagged and free substrates were more significant during the earlier days of the assay. Based on the acquired data, it appears that the bag restricts access to the substrate, primarily against hydrolytic attack, as once solubilised, the material will pass through the bag pores more easily than the larger polymers. The study conducted by Negri et al. (2016) found no effect on biogas production when using nylon bags, although this was based on two separate experiments (with and without bags) using identical substrates but with inocula sourced from several operational digesters and it is unclear if the microbial communities remained identical in the two experiments.
The masses collected from the washed and dried bags were recorded to show mass loss over time. There was a high immediate mass loss of MS, PM and CM due to small particle sizes passing through the bag pores. After immediate mass losses, the substrates exhibited typical first order decay curves of mass loss over time.



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Substrate	Measured SMY (mL.gVS^{-1})	Methane k_{hyd} (d^{-1})	Modelled SMY (mL.gVS^{-1})	Methane model fit (R^2)	Measured SBY (mL.gVS^{-1})	Biogas k_{hyd} (d^{-1})	Modelled SBY (mL.gVS^{-1})	Biogas model fit (R^2)
MS_B	338	0.065	354	0.977	649	0.075	666	0.991
MS_F	325	0.114	324	0.994	688	0.139	673	0.997
WS_B	272	0.040	290	0.968	549	0.045	576	0.980
WS_F	287	0.059	294	0.984	589	0.064	594	0.993
PM_B	298	0.032	323	0.981	510	0.033	551	0.983
PM_F	317	0.051	330	0.981	516	0.053	531	0.993
CM_B	254	0.048	266	0.975	467	0.052	482	0.989
CM_F	254	0.059	259	0.987	472	0.070	471	0.996
CE_B	389	0.037	432	0.938	784	0.045	844	0.971
CE_F	348	0.065	366	0.979	776	0.086	799	0.991

Table I: Apparent hydrolysis rates (k_{hyd}), mean measured specific methane (SMY) and biogas yields (SBY) and mean modelled specific methane and biogas yields and the fit of the models.

There was a sharp decrease in TKN total masses retrieved from bags containing manures between days 0 and 5 which can partly be attributed to the high immediate mass losses of material for these substrates. MS_B showed a small decrease in TKN mass loss over time. For WS_B, however, the total TKN mass in the bags increased up to day 21, after which it decreased slowly.

The TAN measurements in the bulk liquid increased during the batch assay. This increase was particularly noticeable regarding the manures. The concentrations of TAN increased by ca. 0.2 g.kg^{-1}, which is similar to the increase in TKN. This was to be expected as the soluble N is likely to be that which is in the TAN form.
The total NDF mass of PM and CM changed less than that of MS and considerably less than WS. This would suggest that the fibre fractions in the manures are less degradable, which is logical considering they have both already passed through the digestion system of the animals and thus the easily-degradable material would be expected to have already been removed. However, one would expect MS to be more rapidly degradable than WS, yet WS had the greatest loss of total NDF mass because WS had considerably less immediate mass loss than the other substrates.

Conclusions

The use of polyester bags in anaerobic batch digestion of freeze-dried substrates was successful in that degradation rates and the N and NDF fluxes could be examined with less contamination by the assay inoculum material due to the washing of the bags after removal from the bottles. The small particle size following grinding of the dried substrates presented a problem of considerable immediate mass losses from the bags into the bulk liquid in the batch bottles. The use of bags had little effect on final gas production but a significant effect on the rate of gas production, which was assumed to be because the bag material offered some degree of obstruction to the degrading microorganisms. Future work should include a more frequent mixing regime to improve transfer across the bags. The bagged substrate method could also be used to test substrate degradation in a continuous process.

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Sasha D. Hafner, Sergi Astals, Hélène Fruteau de Laclos, Konrad Koch, Sören Weinrich, Christof Holliger

Session B
1:05 – 1:20 pm
15' presentation

Making BMP measurement more reproducible: results, recommendations, and resources from the IIS-BMP project

biochemical methane potential, biomethane potential, BMP test, round robin test, validation criteria

Introduction and aim

Inter-laboratory reproducibility of biomethane potential (BMP) is poor, with differences in BMP values for the same sample sometimes exceeding a factor of two. This contribution will summarize a large international project aimed at improving BMP measurement. The project is unique with respect to scale, in terms of geography (14 countries), BMP methods (5 types), and sources of error considered (including e.g., inoculum effects and calculations). A new »Standard BMP Methods« website (https://www.dbfz.de/en/BMP/) provides resources to improve BMP measurement, including open-access documents on BMP methods and links to new software tools.

Methods

The »International Inter-laboratory Study on BMP« (IIS-BMP) initiative started in June 2015 with an international workshop in Leysin, Switzerland, that included participants from 31 laboratories. The outcome was a new set of guidelines for BMP measurement [1].

The work continued with two inter-laboratory studies and one additional workshop in Freising, Germany, in 2018. In total, 37 laboratories measured the BMP of 5 substrates (cellulose, 3 animal feed ingredients, and wheat straw). Detailed raw data were collected. The resulting dataset, with > 400 BMP values, was used to quantify inter-laboratory reproducibility and refine validation criteria for BMP tests [2].

The current project focus is delivering guidance to prospective users. A new website shares citable open-access documents describing BMP methods in detail, along with other guidance and links. New tools for test planning and calculations have been added to the web application OBA [3].

Results and further information

Measurements of BMP showed precision similar to smaller studies, with relative standard deviation among laboratories (RSD_R) of 7 to 24 %, and relative range (RR) up to 130 %. Errors in data processing or entry were important, while substrate volatile solids (VS) measurement and inoculum origin did not clearly contribute to variability. There were negative biases in manual manometric and volumetric methods. However, much of the observed variability was not clearly related to any of these factors, and is probably related to particular practices that vary among laboratories.

BMP values for all substrates were correlated with the BMP of cellulose, reflecting systematic laboratory biases and supporting the use of a positive control for validation. New validation criteria were developed: (i) test duration at least 1 % net 3 d, (ii) relative standard deviation for cellulose BMP not higher than 6 %, and (iii) mean cellulose BMP between 340 and 395 $NmL_{CH4}\ g_{VS}^{-1}$. Exclusion of non-validated observations substantially improved reproducibility, with RSD_R < 8 % and RR < 25 % (Fig. 1). All methods delivered some validated values. But validation rates varied and 55 % of all observations were not validated; some laboratories need to improve their BMP methods.

PhD Sasha D. Hafner[1]*, Sergi Astals[2], Hélène Fruteau de Laclos[3], Konrad Koch[4], Dr. Sören Weinrich[5], Christof Holliger[6]

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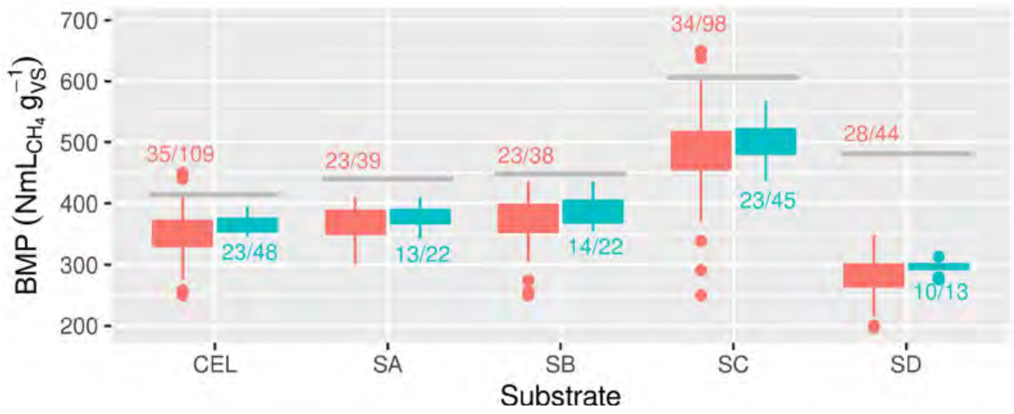

Figure 1: BMP of four substrates and a positive control (CEL = cellulose) measured in 37 laboratories showing the effect of validation criteria (red/left = all observations, blue/right = validated observations). Numeric values show number of laboratories/ observations. Gray lines show theoretical maximum.

All results and guidance from the project are available at https://www.dbfz.de/en/BMP/. Updated guidelines are compared to the originals [1] in a new commentary [4] and current requirements can be found in »document 100« [5], which is available in multiple languages. Feedback and contributions are welcome through https://www.dbfz.de/en/projects/bmp/contact.

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COMPARISON OF DIFFERENT METHODS FOR MONITORING BIOLOGICAL EFFICIENCY ON AGRICULTURAL BIOGAS PLANTS 27

Torsten Mächtig, Benedikt Hülsemann, Marcel Pohl

Comparison of different methods for monitoring biological efficiency on agricultural biogas plants

Session B
1:45 – 2:00 pm
15' presentation

efficiency, mass and energy balance, specific methane potential, steady state

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Anaerobic digestion is the central process step for agricultural biogas plants. The efficiency of this biological process plays an important role for economic and ecologic biogas production.

For efficiency evaluation, it is necessary to determine the mass flows as well as the anaerobically useable potential of the substrate for methane formation. Determination of the biological efficiency of agricultural biogas plants is typically done with a steady-state approach, as kinetic models are too complex to apply.

Different methods are described in literature for determination of the substrate's methane potential. A comparative study on the validity of the different methods was missing.

So, aim of this work was to compare the different methods for determination of the methane potential by assessment of the biological efficiency of agricultural biogas plants with a steady-state approach. Hereby, differences in methodology, validity and general problems with mass and energy balances at full-scale biogas plants were addressed.

For this study, 33 agricultural biogas plants were examined for their mass and energy balances, each in a period of 12 months. The system boundary included all gas-tight digesters. The fed-in substrate mass was measured by process equipment. The produced amount of biogas was recalculated from produced electricity from CHP-engines. Digestate mass was calculated from steady-state mass balance.

The mass and energy balances were checked for plausibility by calculating organic dry matter material balances und mass flow associated energy balances.

The specific methane potential of the substrates was determined using five different methods: literature values of specific methane potentials from KTBL (KTBL) [1], lab-scale biochemical methane potential test (BMP), calculation of fermentable organic dry matter (FOM) [2], energy of the fermentable organic dry matter (EFOM) [3] and anaerobically degradable energy (adE) [4]. BMP and adE were also used to determine the residual potential in the digestates. For each biogas plant, the yield and conversion efficiency were calculated based on all applicable methods.
The yield efficiency (YE) was calculated by dividing the produced amount of methane by the fed-in methane potential of the substrates. Besides, the conversion efficiency (CE) was calculated by relying the difference of fed-in substrate potential and the residual potential in the digestate to the fed-in potential of the substrate.

The results show, that only 55 % of the examined biogas plants give plausible result for mass and energy balances. Therefore, following analysis considers only biogas plants with plausible mass and energy balances.

The calculated conversion efficiencies based on adE from 72 – 93 % are throughout lower than those based on BMP with 85-99 %. CE based on FOM ranged from 91 – 126 % and on EFOM from 101 – 136 % - both indicating that the fermentable fractions of the substrates were underestimated by the fermentation coefficients, which are used to quantify the methane formation potential in both methods. The results for YE were similar. YE based on adE gave the lowest values from 69 to 89 %. YE based on KTBL-values ranged from 97 to 117 %, based on BMP from 94 to 138 %, based on FOM from 95 – 132 % and on EFOM from 86 – 132 %. All methods, except adE, were underestimating the methane potential of the substrates in full-scale digestion. However, compared to adE, these methods showed better correlation to the on-site specific methane yield. AdE was less sensitive, as it only reflects the material composition, but not the accessibility for degradation. KTBL-values as well as BMP-values seem to underestimate the potential due to differences between lab-scale, where the measurements are determined, and full-scale, where the value were applied. Like for CE, EFOM and FOM underestimate the methane potential by too low fermentation coefficients. Based on the findings, there is no clear recommendation which method should be used. A combination of adE and BMP could be useful to reflect both, the composition and accessibility of the substrate.

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A NOVEL GRADIENT-BASED MONITORING SYSTEM FOR DARK FERMENTATION IN PLUG-FLOW REACTORS 29

Marion Longis, Dr. Joana P. C. Pereira, Prof. Dr. Peter Neubauer, Dr. Stefan Junne

Session B
2:10 – 2:25 pm
15' presentation

A novel gradient-based monitoring system for dark fermentation in plug-flow reactors

process monitoring; dark fermentation; plug-flow reactor; electrooptical measurement

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Background/Motivation

The use of plug-flow reactors (PFRs) for the anaerobic digestion (AD) of biogenic residues offers the advantage of a flexible process, where the different phases of AD (i.e. hydrolysis, acidogenesis, and methanogenesis) can be segregated and evaluated along the retention time in the reactor. This is also useful when methanogenesis has to be suppressed in AD leading to the so-called dark fermentation (DF), in which hydrogen and short-chain carboxylic acids (SCCAs) are produced instead of the traditional biomethane [1].

Although the influence of phase segregation in PFRs on the performance of AD processes has been investigated before, the potential of on-line monitoring of the corresponding gradients for process control has not been fully explored. Typically, monitoring is restricted to the gas-phase, while also accounting for input parameters such as substrate addition, flow rates, and HRT. Using a gradient-based monitoring system along the residence time of the PFR, parameters such as pH, redox potential (ORP), conductivity, cell frequency-dependent anisotropic polarizability (FDAP), SCCAs concentration, sCOD, and FOS/TAC, can be monitored at the different phases of the process. The combined analysis of these parameters should allow for the identification of eventual correlations, contributing for improved process control, especially at dynamic feedstock load.

Aim of the work

This study presents a novel gradient-based monitoring approach to evaluate the performance of AD with renewables and biogenic residues (i.e. maize silage, lignocellulosic side products), in a PFR. By combining on-line monitoring of the liquid and gas phases, as well as off-line monitoring of the liquid-phase, it is investigated whether gradient monitoring in the PFR is advantageous to achieve an automated operation and increase process robustness.

Key research topics and novelty

The novel gradient-based monitoring system facilitates a spatial analysis of the gradient formation in the liquid phase, as well as rapid identification of process disturbances and performance optima. This should lead to increased process robustness and feedstock flexibility.

Methods

A lab-scale 12 L PFR module, was tailor-made of PVC and Teflon. Monitoring ports, located at the inlet, centre, and outlet of the vessel, were equipped with sampling ports and sensors for pH, redox potential, and conductivity (ARC sensor series, Hamilton Bonaduz AG). The frequency-dependent anisotropic polarizability (FDAP) of the washed cells was analysed at-line at 200, 400, 900 and 1200 kHz (EloTrace®), as a measure for cell viability [2]. SCCAs concentration, sCOD, and FOS/TAC were determined off-line using well-known methods. Off-gas analysis was performed on-line using a mass flow controller (BlueVCount) coupled to BCP-sensors (BlueSens GmbH, DE), for measurements of the total volume, and concentrations of CO_2, H_2 and CH_4. The combined analysis of these parameters provides information about gradient formation and monitoring performance under various process conditions.

Results

The results have shown that artificial acidification applied to the AD process has led to increased ORP and FOS/TAC values, as well as SCCAs accumulation, at the inlet and centre of the reactor. The conductivity values decreased accordingly, corresponding to a transition from an AD to a DF process state.

The results suggest that process disturbances caused by a low power input, the different feedstock loadings, and the process states have a great impact on the formation of gradients in the PFR. The gradients, identifiable from the variations of pH, ORP, and conductivity along the reactor, were well correlated to the concentrations of CO_2, H_2, and CH_4 in the gas phase. A strong correlation has been found between the concentrations of SCCAs and the ORP, as well as conductivity gradients at certain locations of the PFR. Also, a positive correlation has been observed at 200 kHz between FDAP and the yields of SSCAs at the inlet and centre of the PFR.

Overall, this work has shown that combining on-line monitoring of certain gradients in the liquid phase of a PFR and the gas phases, as well as at-line polarizability monitoring of the liquid-phase, allows for a more comprehensive process monitoring during the AD process, which should lead to increased process robustness and feedstock flexibility.

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2nd DAY

SESSION C SIMULATION AND FULL SCALE

SESSION D MICROBIOLOGY

SESSION C

Simulation and Full scale

Chair Prof. Dr. Hinrich Uellendahl,
Flensburg University of Applied Sciences

15' Use of simple observers and model predictive controllers at large-scale biogas plants
Dr.-Ing. Jürgen Kube, Future Biogas

15' Prediction and real-time optimization in biogas production plants with circulating flow
Dr. Arne Nägele, Goethe-Zentrum für Wissenschaftliches Rechnen, Universität Frankfurt

15' Neural network modeling of industrial-scale plug-flow biogas plants
Imre István Antalfy, Zurich University of applied Sciences, MA ASCL

15' Calculation of a normalized energy baseline for biogas (upgrading) plants
Karlheinz Meier, BayWa r.e. Bioenergy GmbH

SESSION D

Microbiology

Chair Dr. Sabine Kleinsteuber,
Helmholtz Centre for Environmental Research – UFZ)

15' Adaptation of a microbial community to demand-oriented biological methanation
Hoda Khesali Aghtaei, Bioprocess Engineering, Max Planck Institute for Dynamics of Complex Technical Systems

15' Storing surplus electricity through biomethanation with microbial communities: How to cope with intermittency?
Washington Logrono, Helmholtz Centre for Environmental Research – UFZ

15' Effects of phenyl acids on different AD stages in thermophilic batch reactors
Eva Maria Prem, Department of Microbiology, Universität Innsbruck

15' Anna Karenina ecological principle in biogas research. Has ammonia stress a stochastic or deterministic effect on microbial community compositions?
Dr. Marcell Nikolausz, Helmholtz Centre for Environmental Research – UFZ

Dr.-Ing. Jürgen Kube

Session C
10:45 – 11:00 am
15' presentation

Use of simple observers and model predictive controllers at large-scale biogas plants

anaerobic digestion, NIRS, unknown input observer, macerator

Recent research projects [1-3] have applied state observers and state controllers to biogas plants. The resulting models and controller structures are very sophisticated. The implementation of these structures in large scale AD-plants is not an easy task. For example, the state vector of a single digester in the ADM1-model comprises 24 dimensions [4]. Setting Eigenvalues or inverting matrixes in this scale requires dedicated software and cannot be achieved on PLC or SCADA-level of large-scale AD-plants.

This presentation gives two examples for the utilisation of simplified observers in the day-to-day operation of large-scale AD-plants.

Feed-control with NIRS using a model predictive controller

A near infrared spectrometer (NIRS) was installed on the infeed-auger of an AD-plant with a biogas production capacity of 1.100 Nm^3/h. It is used to monitor feedstock composition (crude fat, crude protein, NDF, ADF, starch, ash dry matter). The composition is used as a known disturbance in a feed-control loop. The control loop keeps the gas storage level constant at 80 % and adjusts the hourly feed. It comprises a closed loop PD-feedback controller and an open loop feed forward controller that uses an observer to predict the change of gas production and gas dome level. The controller was simulated to find optimal PID-parameters for both control loops and the PD-controller was the best solution. The controller was implemented successfully. A single-stage, two-fraction first order model was used to compute the gas production of the primary digester. The secondary digester and process water addition was not modelled to keep the model simple. The observer has three state variables: the concentration of the fast and slow-degrading substrate in the digester and the gas dome level. In future trials, the NIRS will be omitted and the feedstock composition will be given off-line by the operator.

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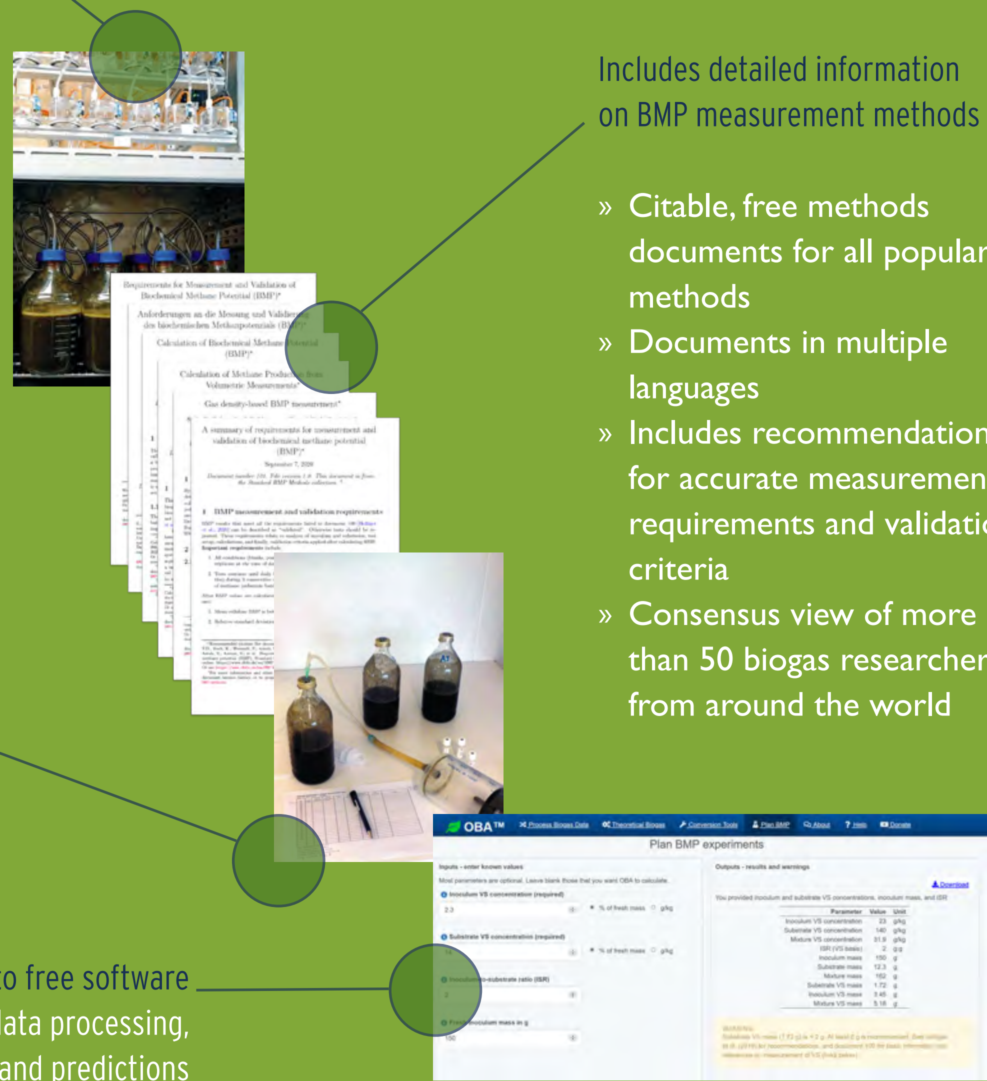

Dr. Arne Nägel, Babett Lemke, Falko Niebling, Tristan Scheidemann, Michael Tietze, Prof. Gabriel Wittum, Rebecca Wittum

Session C
11:10 – 11:25 am
15' presentation

Prediction and real-time optimization in biogas production plants with circulating flow

modelling and simulation, flexibility, control

Background/motivation

The complex biology of processes in biogas production plants (BPP) has been an active field of research for many years. Often an increase of both process efficiency and operational stability are primary concerns. Here modelling and simulation are attractive techniques, that can contribute in various settings. This includes, e.g, optimising feeding schedules for flexible production in existing plants, or assessing design decisions when plants are extended. Moreover, modelling provides am means for operational stability and prognosis options in complex trading scenarios for renewable resources with sector coupling [1].

Aim of the work

Develop a modelling tool serving as a guidance to BPP design and operation. Estimate the current state of the BPP based on a small subset of parameters. Adjust parameters, if required. Facilitate predictions for plant design, construction and operation.

Key research topics and novelty

In this work, we present a framework for the simulation of a BPP arranged in a network of coupled reactors and storage devices. The close interaction with optimization tools allows for parameter identification and control. This allows to control the operation in a semi-automated fashion.

Methodology

We consider a genuine biogas production plant that is operated under **circulating flow conditions**. The plant consists of a network of **coupled reactors** that connected by active and/or passive elements, e.g., overflow tubes or programmable controls. Mathematically, this is modelled and expressed as a graph.

In contrast to classic ADM1-type models, cf. [3,4] for an overview, the model features **full spatial resolution** of the reactors' interior [2]. This provides information on the heterogeneous composition of the circulating fluid. Depending on the physical dimensions of the reactors and the prescribed flow rates, this is important, e.g., for investigations on the impact of feeding or for the evaluation of sensor placement.

The long term goal of this work is to facilitate simulations on state-of-the-art workstations. In order to meet real-life run time requirements, **model reduction** techniques are employed. At the user's discretion, full resolution volume-type 3D reactors can be replaced by line-type 1D flow through reactors. In the simulation framework, both approaches coexist and are compared. This is important when evaluating different configurations, for instance plug-flow, batch or CSTR reactors.

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For treating data uncertainty, an **optimization** component is an essential: First, all sub-units, must be calibrated beforehand. This can be achieved, e.g., based on existing data and batch experiments. Second, it may be required to adjust the model on the flight. To that end, we extract short time series, and adjust parameters on the flight.

Results

We provide results for a genuine plant at GICON's test site in Cottbus. Model features are demonstrated and numerical experiments and real-world BPP data are intertwined. Predictions and hypothesis testing both w.r.t. design and operation mode, as well as the semi-automated control flow is demonstrated. Strategies for an application of the model for existing plants and the economic impact are discussed.

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Imre István Antalfy, Dr. Martin Schüle, Prof. Dr. Urs Baier, Dr. Hajo Nägele,
Adrian Schatz, Miriam Rabaçal

Session C
11:30 – 11:45 am
15' presentation

Neural network modeling of industrial-scale plug-flow biogas plants

solid-waste, industrial-scale, modelling, machine learning, data analysis

Biogas plants (BGP) are becoming increasingly important as alternative energy sources. Especially solid waste plants offer great potential in the form of yet unused input substrate. The theoretically additionally usable potential based on farmyard-manure, according to Thees et al., is just under 50 PJ primary energy. [1] The market in Europe and Switzerland has seen tremendous growth in the numbers of biogas plant and their installed capacity. [2] This development came with a strong increase in professionalism on the level of biogas plant operation. Nowadays, biogas plans are equipped with automated systems and data collection in order to control and guide the biological-technical process. While operating a biogas plant is already a challenge, new upcoming trends such as integration in the fluctuating renewable energy system and providing system services such as flexible biogas production will put another level of process understanding to the field. Such system services, like the integration into energy networks as a plannable power source, will be a chance to ensure the continuation of the growth of the biogas sector.

Hitachi Zosen Inova (HZI) is an engineering, procurement and construction contractor, with a strong share of system solutions for biological electricity from waste (EfW) recovery. Their BGP's are operated all around the globe, for example, in Switzerland and Sweden. The operational data of all their BGP's is collected in real-time with an in-house database solution. The database is used as a storage of raw, batch fed data, with basic built-in visualization.

Although plenty of data is logged, no regular data analysis takes place. Usually, the most important process parameters are only checked manually or semi-automatically after an operation-limiting incident occurs. Hence, much information is currently unused and cannot be implemented in mitigation or planning strategies by the biogas plant operator. In fact, the reactor processes are a black box to the operator, which may result in long reaction times and economic losses.

Recent research in process optimization for BGP's based on computational methods shows promising results. A study conducted on a wastewater treatment plant, using an artificial neural network (ANN) for the prediction of methane production, reached a normalized error under 10%. [3] A second study using ANN's successfully started a reactor and recovered it after its process destabilized. Loading rates of up to 12 kg COD m^3/d were reached with gas production of up to 3 m^3/m^3, yielding up to 70% of biogas. [4] Existing plants vary greatly in their efficiency, but often do not exceed 60% of methane. The group around Alejo et al. used support vector machines (SVM), ANN and an analytical model in comparison to predict the total ammonia nitrogen (TAN) in the effluent of poultry manure in AD. The relative average error in the TAN prediction in this study summed up at 43% for the analytical method, while the SVM reached 15.2%. [5] These results reveal the future promise of machine learning methods to predict and optimize biogas plants.

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The expected results will be a thorough data analysis, which signals are already available and defining needed upgrades to an existing plant. First steps to implement an unsupervised anomaly identification algorithm can mark the path to supervised anomaly prediction. In terms of modelling, the application of an ANN coupled with optimization methods like genetic algorithms should be able to predict biogas production effectively. As a follow-up to the project, the methods could be implemented to work with live data instead of batch data.

With an increasing amount of system services, it is necessary to operate the plants efficiently on a plant level and guided in a way to support the future energy system. A solid evaluation of the available data is key to the topic. This project aims to fill this gap between data analysis, plant/process modelling and the day-to-day operator.

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Karlheinz Meier

Calculation of a normalized energy baseline for biogas (upgrading) plants

Session C
11:50 – 12:05 am
15' presentation

energy baseline, energy consumption, biogas information system, digital solutions, biogas software

Background/motivation

Our Biogas data acquisition platform is capable of handling all production data (inputs leading to outputs) of biogas plants. This starts with the amount of substrate fed, the quality of substrate (in dry matter), includes measurements of gas quality within the digestation process along with required energy for plant components like stirrers. For the production side we measure kWh output for plants with a CHP, and biomethane flow if an upgrading unit is used to inject the upgraded gas into the gas grid.

Those figures differ from plant to plant due to their size and layout, as well as within the year. Energy consumption changes within the year due to outside temperatures, smaller plants need less energy due to less production output, and the qualities and amounts of substrates have a heavy impact onto production. Some substrates – like grass – lead to an increased energy consumption due to their handling needs (e.g. grass cutter) inside the production cycle. So currently the comparison between plants is not easily possible.

Aim of the work

Developing the following metrics:
Normalized amount of produced biogas (via measurements), compared with calculated amount based on amount, quality and type of substrate fed. A yearly production figure will enable the inner-year-comparison to account for seasonal factors like temperatures.
The normalized output then can be compared to the energy used for operating the plant.
For Plants of the same sizes and types we expect the energy for production to be same. Differences could be subject to further analysis.

Key research topics and novelty

Key research is developing the above metrics based on big data of a variety of plants. As all are no small-scale laboratory reactors but working production units, this approach is novel as the data has not been available for research before in the needed vast amount of at least 24 months of plant data. Taking less data would lead to insecurities whether differences repeat themselves as seasonal occurrences or are only a one-time event.

Methods

- In-depth analysis of some gigabytes of plant data from at least 5 upgrading plants and 3 CHP plants in Germany
- Usage of statistical methods

»Simple« statistical models for norming the baseline and figures from »Faustzahlen Biogas« are taken into account.

Further information

www.biorecs.de
The result is part of our product which is subject to the subsidiary »Pilotprogramm Einsparzähler« granted by BAFA.

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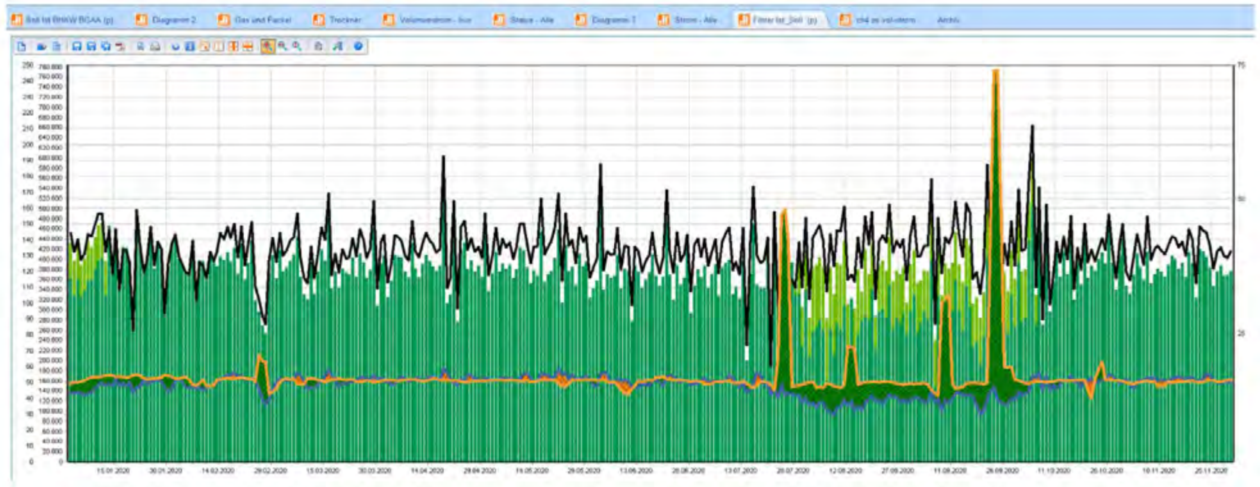


Figure 1: Current Screenshot of live working »Metric a«, showing estimated Gas Output and real gas output for Jan-Nov 2020 in Plant Pliening. Orange = Output too small, Green = Output beyond estimation

Hoda Khesali Aghtaei, Dr. Dirk Benndorf, Prof. Udo Reichl

Session D
1:00 – 1:15 pm
15' presentation

Adaptation of a microbial community to demand-oriented biological methanation

biological methanation, intermittency of renewables energies, power to methane, metaproteomics analysis

Power to methane is increasingly discussed in the last decade as a crucial process to store the surplus of renewable electricity while moving forward on mitigation of the climate change. The conversion of green H_2 with biogenic CO_2 from biogas production can upgrade biogas to pure biomethane. Furthermore, it could buffer the inherent oscillations of this renewable electricity resource by converting the surplus of power to CH_4 and allowing its storage in the gas network.

While discontinuous H_2 feeding may damage chemical methanation catalysts, biological methanation handled by methanogenic archaea was reported to be less sensitive to H_2 starvation [1]. Nevertheless, changes in process parameters could result in variations in microbial communities and subsequent process disturbances. Metaproteomics of microbial communities, reveals alterations in microbial communities on taxonomic and functional level [2].

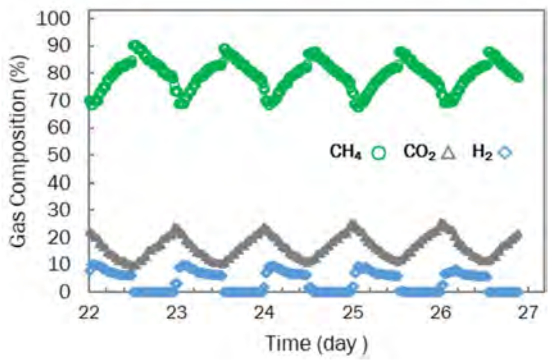


Figure 1: Headspace gas composition of a biological methanation fermentation during H_2 gas oscillation).

In this study, a biological methanation fermenter (CSTR) running for more than a year (T = 40 °C, Pmax = 1.08 bar, 800 rpm, working volume 400 ml, biogas as source of CO_2) was exposed to repeated H_2 fluctuations (12 h H_2 feeding, 12 h stopped; in the following named "partial loading pattern"). Sampling was done before (pattern 1) and during the partially loading pattern experiment (pattern 2). The effect on headspace gas composition was followed by online gas chromatography (Fig.1). A high-resolution metaproteomics approach was applied for sample preparation. 25 µg protein were separated by SDS-PAGE (Fig.2).

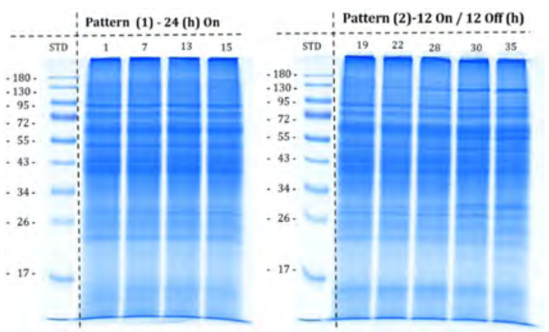
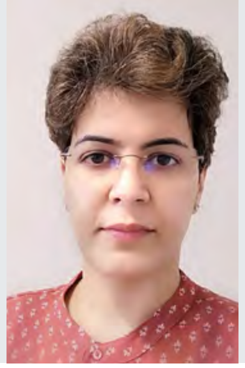


Figure 2: SDS–PAGE of a 25 µg protein extract from samples of two H2 loading patterns. Pattern 1 presents the samples of 24 h H2 feeding; pattern 2 presents the samples of the 12 h H2 feeding / 12 h stopped regime. Considering the first day of pattern 1 as 0 day, the numbers on the top of each lane corresponds to date of sampling (day).

Obtained lanes were cut to 10 pieces, submitted to tryptic digestion and prepared for LC-MS/MS measurements [2]. Shortly after H_2 shut down, the highest methane level was observed, while the amount of H_2 and CO_2 were at their minimum (Fig.1). In the following, non-converted CO_2 enriched in the headspace gas. Starting full-load H_2 feeding resulted in increasing amounts of H_2 in the headspace, a decrease in the level of non-converted CO_2 while methane levels increased again. Although a repeated pattern of headspace gas composition could be seen for the partial H_2 loading pattern, the SDS-PAGE gel in Fig.2 showed appearance and fade of some bands during the partially loading H_2 pattern. These variations in



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protein level could be probably the results of community variations in time due to the oscillation of H_2. Furthermore, metaproteomic analysis of the microbial communities of the partial loading H_2 pattern revealed a high share of detected metaproteins (about 45 %) with the full load pattern (Fig.3).

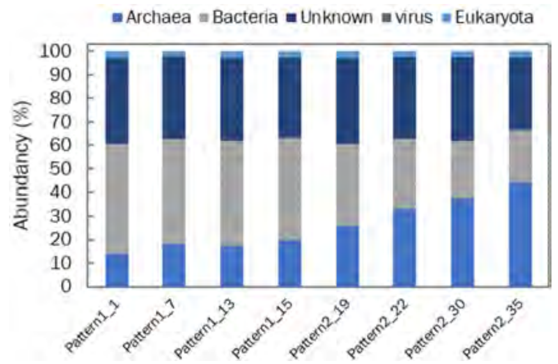

Figure 1: Composition microbial samples for the two H_2 loading patterns. The numbers beside each pattern corresponds to date of sampling (day).

With continued operation of discontinuous feeding of H_2, the community shifted towards a higher abundancy of archaea. Overall, with a 31% increase, the abundancy of archaea reached 45 % at the end of experiments (Fig.3). Taxonomical investigations at the order level displayed the strongest increase in abundancy for Methanosarcinales (26-fold), Methanobacteriales (2.6-fold) and Methanococales (2.2-fold). Methanobacteriales and Methanococales are classified as hydrogenotrophic methanogens, whereas Methanosarcinales can obtain their energy from a wide range of substrates such as acetate, methyl-compounds and also H_2 and CO_2. In contrast, the abundance of all bacterial species was reduced. As no increase in homoacetogenic bacteria and no strong decrease in pH value were detected, the drastic and continuous increase in the Methanosarcinales community cannot explained by an increase in volatile fatty acids such as acetic acid and propionate as reported earlier for the H_2 starvation and the initial H_2 feeding phase [3]. Possibly, the discontinuous feeding of H_2 favoured the growth of Methanosarcinales with a lower affinity for H_2 rather than strictly hydrogenotrophic methanogenic archaea [4] due to transiently increased H_2 concentration in the recovery phases.

Taken together, the stability of the process and the ability of the microbial community to adapt to a discontinuous feeding regime confirm the robustness of biological methanation processes. Furthermore, it seems that discontinuous feeding strategies could be used to enrich methanogenic archaea during establishment of a microbial community.

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Wachington Logrono, Dr. Marcell Nikolausz, Dr. Denny Popp, Prof. Dr. Hauke Harms, Dr. Sabine Kleinsteuber

Storing surplus electricity through biomethanation with microbial communities: How to cope with intermittency?

Session D
1:25 – 1:40 pm
15' presentation

power to gas, functional resilience, Methanobacterium, renewable energy, anaerobic digestion

Storing surplus electricity from renewable energies, i.e. wind power and photovoltaics, is a great challenge. The power-to-gas (P2G) technology allows the storage of electricity in the form of H_2 or CH_4 as chemical energy carriers [1]. H_2 can be produced via water electrolysis but injection into the gas grid is limited to certain percentages. Alternatively, H_2 can be converted to CH_4, which can be readily injected into the gas grid and utilized by existing technologies and infrastructure. Methanation of H_2 can be done by chemical conversion of H_2/CO_2 to CH_4 using the Sabatier reaction or by biochemical conversion employing the CO_2 reductive pathway of hydrogenotrophic methanogens (Eq. 1). P2G can additionally be coupled to the well-established anaerobic digestion technology and used for biogas upgrading.

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \qquad \text{Eq. 1}$$

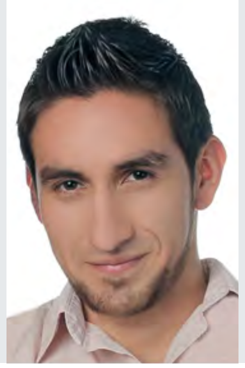
The biological conversion of the reactant gases outside a conventional biogas reactor is also called ex situ biomethanation [2]. Considering the utilization of only surplus electricity and the intermittency feature of renewable energy, it can be expected that microbial communities performing biomethanation need to endure periods of starvation. Here, we investigated the response of two microbial communities performing ex situ biomethanation of H_2/CO_2 under simulated flexible operation conditions. The aim of this study was to investigate the effect of starvation events on the hydrogen consumption and methane production rates, to test if complex microbiota are functionally resilient to starvation periods and follow the microbial community dynamics.

Methods

We used sludge from a plug flow reactor digesting maize silage and manure (PF) and crushed sludge from a paper industry wastewater treatment plant (WW) to assess the effect of the inoculum source on the flexibility of the process. Bioreactors were assembled in quadruplicates and fed with H_2/CO_2 (4:1) in fed-batch mode. For all reactors, the experiment comprised five consecutive phases: after 56 days of regular fed-batch cycles every 24 h (phase 1), one fed-batch cycle without shaking lasted 7 days (phase 2), followed by single fed-batch cycles (24 h each) after starvation periods of 7 days (phase 3), 14 days (phase 4), and 21 days (phase 5). Gas and liquid phase were analysed by gas and liquid chromatography. Microbial community composition was analysed by amplicon sequencing of 16S rRNA and mcrA genes for bacteria and methanogens, respectively.

Results and Discussion

Long-term stable production of CH_4 was observed with both inocula. The highest concentration of CH_4 was 97 %, which corresponds to grid quality. The gas consumption (H_2 and CO_2) and production (CH_4) rates of WW were higher than those of PF. Omitting shaking dramatically reduced the gas conversion rates as expected due to gas mass transfer limitations. In terms of pH, WW showed a rather stable behaviour whereas PF was more variable across experimental phases [3]. Both WW and PF inocula demonstrated the feasibility of flexible biomethanation with complex microbiota. H_2 consumption efficiency was ~100 % for both inocula. Compared to the rates during regular fed-batch operation, the CH_4 production rates were significantly lower after the first starvation period of 7 days or an extended starvation of 21 days but not after the second starvation of 14 days (Table 1). This indicates that microbial communities were functionally resilient after repeated starvation even lasting for 14 d but extending the starvation period even further to 21 days proved to be detrimental, thus indicating the limits of resilience [3]. Most importantly, acetate did not accumulate in the medium, which is a relevant aspect for practical application. WW was the most effective inoculum under regular feeding as well as after starvation events [3].



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Inoculum	**Regular fed-batch**	**No shaking**	**7 d**	**14 d**	**21 d**
PF	6.42 ± 0.05	0.34 ± 0.02	5.21 ± 0.14	6.39 ± 0.07	5.35 ± 0.10
WW	6.73 ± 0.09	0.50 ± 0.01	6.34 ± 0.29	6.65 ± 0.15	5.83 ± 0.11

Table 1: CH_4 productivity after different starvation periods (mmol L^{-1} h^{-1}; mean ± SD, n=4)

The WW inoculum was more diverse than PF. Feeding H_2/CO_2 significantly reduced the diversity of the methanogenic communities in both setups. After H_2/CO_2 feeding, Methanobacterium dominated the methanogenic communities with >92 % and >75 % relative abundance for WW and PF, respectively. Our results indicate that origin and type of inoculum, community structure and dominant methanogens are important for process performance. Complex microbiota are functionally resilient to starvation but flexible biomethanation has its limits. Future research will target the development of a biogas upgrading concept in wastewater treatment facilities using flexible ex situ biomethanation.

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Eva Maria Prem, Alessa Schwarzenberger, Rudolf Markt, Dr. Andreas Otto Wagner

Effects of phenyl acids on different AD stages in thermophilic batch reactors

Session D
11:10 – 11:25 am
15' presentation

Anaerobic digestion, phenyl acids, acetogenesis, methanogenesis

The increasing energy demand and the concurrent efforts to reduce greenhouse gas emissions from fossil fuel combustion are ever-present challenges to humankind. To increase the contribution of organic wastes for biogas production, several chemical, physical, and (micro)biological pre-treatment procedures were established over the last decades [1]. One drawback of using (pre-treated) organic wastes is the release of aromatic compounds like phenyl acids, which can cause severe disturbances within the microbial community and thus low biogas yields. The effects of aromatic compounds on the overall biogas process are still not thoroughly understood. Hence, a closer look on microbial groups specific to a degradation phase (hydrolysis, acidogenesis, acetogenesis, or methanogenesis) is pending to better understand the overall dynamics and the "weak" points within a methanogenic community when exposed to phenyl acids.

For this purpose, thermophilic communities were exposed to phenyl acids and fed with a substrate specific to a certain degradation phase or methanogenic (acetate, formate, methanol) pathway in batch reactors for 28 days. Biochemical (gas production, VFA and phenyl acids concentrations) as well as molecular biological parameters (qPCR) were assessed. For each substrate, controls without phenyl acid addition were included but otherwise treated equally.

Reactors fed with butyrate, propionate, or acetate were especially susceptible to phenyl acid exposure. Consequently, compared with the respective controls, the cumulative methane yields were significantly ($p<0.05$) lower in those samples after 28 days (up to 93% lower methane yields in propionate fed reactors when exposed to phenyl acetate (PAA), phenyl propionate (PPA), or phenyl butyrate (PBA). The VFA concentrations as well as qPCR results further show that acetoclastic methanogens were directly and syntrophic VFA oxidisers were directly / indirectly affected by phenyl acid exposure. These first results are the basis for further investigations on the effects of phenyl acids on pure and (syntrophic) co-cultures as well as on organisational characteristics and dynamics within a methanogenic community.

Further information

https://www.uibk.ac.at/microbiology

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Bogdan Rusu, Washington Logroño, Dr. Ulisses Nunes da Rocha, Nafi'u Abdulkadir, Dr. Marcell Nikolausz

Anna Karenina ecological principle in biogas research. Has ammonia stress a stochastic or deterministic effect on microbial community compositions?

Session D
2:10 – 2:25 pm
15' presentation

Anna Karenina ecological principle, stochastic, anaerobic digestion, VFA accumulation, process control

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Process monitoring and control is a very important issue in case of biogas plants utilizing substrates of fluctuating quality including feedstock with potential inhibitory effects. As an example, anaerobic digestion of protein or urea-rich feedstock is often associated with ammonia inhibition, which affects the microbial community structures. Appearance of certain indicator species is considered to be used as a warning signal of process failure. However, according to the Anna Karenina ecological principle (AKP) certain stressors have stochastic rather than deterministic effects on microbial community compositions. The theory got its name from Leo Tolstoy's opening line of his famous novel that »all happy families are all alike; each unhappy family is unhappy in its own way« [1].

The AKP was found to be valid in systems ranging from surface of corals exposed to high temperatures, to the lungs of patients suffering from HIV/AIDS [2]. However, AKP has not been investigated in any engineered reactor system. In a previous study of our group, the effect of AKP was considered in ammonia inhibited biogas reactors co-digesting chicken manure and maize silage but the low number of replicates hampered us to draw a clear conclusion [3]. If this principle is valid in biogas systems, process monitoring should focus more on disappearance of indicator species of stable operation or to deviation from a stable community structure.

The aim of this study was the investigation of the validity of AKP in biogas reactors experiencing ammonia inhibition. To achieve this aim a higher number of well-reproducible parallel small-scale biogas reactors (7 controls, 7 treatment reactors) was necessary. An automatic methane potential test system (BPC Instruments, Sweden) was modified to allow semi-continuous feeding mode of suspensions of solid substrates and to enable a real-time monitoring of methane production from a large number of reactors. The high number of biological replicates allowed us to produce a statistically relevant data set to test an ecological theory. Such hypothesis testing experiment in an engineered system is novel because AD reactors are typically operated in less replicates (two or maximum three) for process engineering research. Higher number of replicates has been used only in batch experiments, which are not suitable to address AKP.

Dried distiller's grains with solubles (DDGS) was chosen as a complex substrate with stable composition to avoid the effect of fluctuating feedstock quality. DGGS was ground to fine particles and fed as a suspension. Trace element solution was regularly supplemented to provide ideal conditions for the adaptation and control phase. The reactors were inoculated with sludge from a pilot-scale system co-digesting a mixture of DDGS and straw. After an adaptation phase of three hydraulic retention times (HRT=21 days) ammonia inhibition was introduced by urea addition in the treatment reactors. The methane production was the major indicator of process inhibition but volatile fatty acids accumulation was also monitored by ester-GC measurements. In addition, pH and total ammonia nitrogen concentrations were measured. The community structures of bacteria and methanogenic archaea were monitored by T-RFLP and amplicon sequencing analysis (Illumina MiSeq platform) of the 16S rRNA and *mcrA* genes, respectively.

Methane production was very similar in all reactors during the adaptation period. After urea addition a fast accumulation of free ammonia was observed, leading to a strong inhibition of gas production in treatment reactors. After 21 days of urea addition the feeding (for all the reactors) was stopped to avoid complete process failure but the reactors were further monitored. The process inhibition was associated with the accumulation of mainly acetate and propionate, which were consumed slowly after substrate feeding and urea addition were stopped.

There was a change in community structure compared to the inoculum samples during the adaptation phase but the samples from all reactors clustered together showing high similarity to each other. Already after the second HRT the community structures had been stabilized, and in the control reactors, they remained stable until the end of the whole experiment. Introducing ammonia as a stressor resulted in quick changes of the community structures of both bacteria and methanogenic archaea. Along with the separation of the inhibited reactors from the controls, a dispersion of the samples was observed indicating that inhibited ('unhappy') reactors varied more in composition than stable ('happy') reactors. The validity of AKP in anaerobic digestion was proved for the first time by a detailed statistical analysis of the data for both methanogens and bacteria. The main implication of these results is that process control should focus on the stable communities instead of searching for indicator species of an inhibited state, which is mainly driven by stochastic effects.

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3rd DAY

SESSION E
EVALUATION OF METHANE EMISSIONS:
FINAL RESULTS OF THE PROJECT EVEMBI (ERANET)

SESSION E:

Methane emissions and possible mitigations from European biogas plants

Chair Torsten Reinelt, Landesamt für Umweltschutz (LAU) Sachsen-Anhalt

20' Evaluation and reduction of methane emissions from different European biogas plant concepts – an introduction of the EvEmBi project
Angela Vesenmaier, Martin Reiser, University of Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management

15' Evaluation of methane emissions from different European biogas plant concepts using harmonized methods including on-site and ground-based remote sensing approaches
Viktoria Wechselberger, University of Natural Resources and Life Sciences, Department of Water – Atmosphere – Environment, Institute of Waste Management

15' Model to estimate methane emissions of different biogas plant concepts and national biogas plant stocks
Lukas Knoll, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH

15' Evaluation of methane emission reduction measures and cost-benefit-analysis
Jonas Dahl, RISE research Institutes of Sweden, Division Built Environment - Energy and resources

Project EvEmBi

The **EvEmBi project** aims to evaluate different biogas plant concepts (e.g., agricultural biogas, bio-waste or wastewater treatment plants) used in Europe with respect to their methane emission factors (EF). Based on collected emission data, a quantification system for representative EFs for the biogas sector will be developed for the first time, enabling the derivation of representative EFs for the greenhouse gas (GHG) inventories. After emission quantification and identification of the major sources, emission reduction strategies will be developed, implemented, and reviewed for particular biogas plants. This results in the elaboration of a general European position paper as well as national position papers on GHG emissions and mitigation strategies. Additionally, a general European voluntary system as well as specific national voluntary systems for emission mitigation in the biogas sectors will be developed in cooperation with the involved national biogas associations. The gained knowledge will be disseminated to the European biogas community in training workshops elaborated within the project.

»» **www.europeanbiogas.eu/project/evembi/**

Angela Vesenmaier, PhD Tina Clauβ, Viktoria Wechselberger, Dr. Jonas Dahl, Dr. Charlotte Scheutz,
Dr. Deborah Schafy, Dr. Martin Reiser, Prof.Dr.-Ing. Martin Kranert, Dr. Peter Kornatz, Dr. Anders Fredenslund

Evaluation and reduction of methane emissions from different european biogas plant concepts – An introduction of the EvEmBi Project

biogas plants, methane emissions, emission mitigation, EvEmBi

Session E
10:10 – 10:30 am
20' presentation

Methane is a strong greenhouse gas (GHG) and therefore unintended methane emissions from biogas production will reduce the positive environmental benefits of this process. Thus, methane emissions from biogas plants have received growing attention over the past few years due to the development of improved and more extensive monitoring methods for evaluating overall methane losses. However, the dynamic and fugitive nature of methane emissions, changing operating conditions, and different as well as not standardised measurement approaches compromise the precise quantification of the overall emissions from full-scale biogas facilities. The mitigation of methane emissions is essential for climate protection, safety issues and economic reasons.

The EvEmBi research project (funded within 11th ERA-NET Bioenergy Joint Call/ 1st add. Call of BESTF3) aims to evaluate different biogas plant concepts (e.g., agricultural biogas, bio-waste or wastewater treatment plants) used in Europe with respect to their methane emission factors (EF). Overall and single source methane emissions are measured in each country with a harmonised measurement approach of the countries participating in the project (Austria, Denmark, Germany, Sweden, and Switzerland). Based on the collected emission data, a quantification system for representative EFs is developed. The Emission Quantification Model (EQM) enables the derivation of representative EFs for the greenhouse gas inventories within the biogas sector for the first time.

After emission quantification and identification of the major sources, emission reduction strategies will be developed, implemented, and reviewed for individual biogas plants. These active emission mitigation strategies are evaluated in terms of costs and benefits. The three major project modules are outlined in more detail in follow up abstracts (Keyword EvEmBi).

Besides the active mitigation of emissions at individual plants, the project intends to mitigate emissions via secondary mitigation measures. A general European position paper as well as national position papers on GHG emissions and mitigation strategies at biogas plants are elaborated. Operator workshops addressing the mitigation of methane emissions at biogas plants are organized. Furthermore Voluntary monitoring systems for the operators within the participating countries (if not already existing) are launched.

Voluntary monitoring systems have already been initiated in Sweden, Denmark and Switzerland. The Swedish system, which was introduced in 2007, is considered the pioneer. The participating plants have their total methane emissions regularly quantified. This gives a better credibility in terms of the carbon footprint and an understanding of possible emission sources at the plant. This has led to an overall reduction in methane emissions from Swedish biogas plants. The system in Denmark was launched in 2016 and is to some extend based on the Swedish system. Due to a low number of participants, the Danish Energy Agency in 2019 initiated a programme where Danish biogas plants can apply for economic support for measurements and guidance on mitigation actions. By June 2020, the number of participants has increased considerably. The Swiss voluntary system considers only individual emission sources, but these can be sufficiently representative in terms of total emissions.

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The EvEmBi project will contribute to an improved estimation of national GHG inventories. The evolving low emission plant concepts will lead to a direct mitigation of emissions and increase of efficiency in the plant inventory.

Acknowledgement

The project "EvEmBi"- Evaluation and reduction of methane emissions from different European biogas plant concepts was funded within 11th ERA-NET Bioenergy Joint Call/ 1st add. Call of BESTF3 and nationally by the Federal Ministry of Food and Agriculture Germany via Agency for Renewable Resources e. V. (FNR), the Austrian Research Promotion Agency (FFG), the Swedish Energy Agency, the Swiss Federal Office of Energy, and the Technical University of Denmark.

The project partners involve DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, University of Stuttgart, Fachverband Biogas e.V., University of Natural Resources and Applied Life Sciences Vienna, BEST Bioenergy and Sustainable Technologies GmbH, Abwasser und Abfalltechnik GmbH, Kompost & Biogas Verband Österreich, Ökostrom Schweiz, Bern University of Applied Sciences, Oester Messtechnik GmbH, Research Institutes of Sweden, Avfall Sverige, Svenskt Vatten, and Technical University of Denmark.

Viktoria Wechselberger, Katharina Meixner, PhD Tina Clauß, Lukas Knoll, Torsten Reinelt, Angela Vesenmaier, Dr. Marcel Bühler, Johan Yngvesson, Prof.-Dr. Charlotte Scheutz, Dr. Anders Fredenslund, Prof. Dr. Marion Huber-Humer, Dr. Marlies Hrad

Evaluation of methane emissions from different european biogas plant concepts using harmonized methods including on-site and ground-based remote sensing approaches

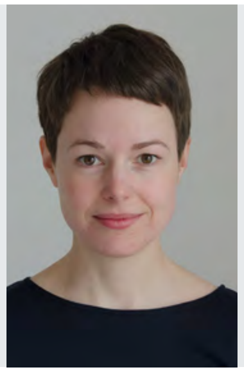
Session E
10:45 – 11:00 am
15' presentation

anaerobic digestion, methane emissions, ground-based remote sensing, EvEmBi

With regard to greenhouse gas emissions, the production of biogas may be beneficial in various ways. As flexible renewable energy carrier, biogas can substitute fossil fuels and balance renewable energy supply in a mix with wind and solar power [1]. Furthermore, mineral fertilizers can be substituted by the production of digestate and methane emissions from manure management can be reduced by anaerobic digestion [2], [3]. However, benefits are reduced if methane is emitted during plant operation, which can occur depending on the used technology and mode of operation. Methane emissions can emerge, for example, as a result of biogas utilization (methane slip), not-gastight covered digestate storage, leakages and the activation of safety valves [4], [5], [6], [7], [8] [9], [10], [11]. Although the number of studies investigating methane losses from biogas plants has increased during the last decade, reliable data on the magnitude of these emissions is still scarce. The dynamic and fugitive nature of methane emissions, changing operating conditions, and different as well as not standardized measurement approaches compromise the precise quantification of the overall emissions from full-scale biogas plants. However, reliable and verifiable emission data from biogas or biomethane facilities are required in order to optimize and improve the plant-specific process efficiency as well as future technology developments. In addition, precise and comprehensive measurement data from full-scale anaerobic digestion facilities are needed for more accurate emission factors (EFs) estimates, which are required for annual reporting according to the Intergovernmental Panel on Climate Change (IPCC) guidelines [12].

Within the project »EvEmBi – Evaluation and reduction of methane emission from different European biogas plant concepts« (2018-2021, funded within the 11th ERA-NET bioenergy call), 36 biogas plants in four European countries were investigated with regard to their methane emissions. For that, different measurement approaches, based on a guideline developed in the previous project »MetHarmo – European harmonization of methods to quantify methane emissions from biogas plants« (funded within the 9th ERA-NET bioenergy call) [13], were applied. While emissions from single sources were determined on-site, i.e. by static/dynamic flux chamber techniques or measurements in the off-gas duct of a biogas utilization unit, overall plant emissions were quantified by two ground-based remote sensing methodologies. For the inverse dispersion modelling method (IDMM), an open-path technology (Open-Path Tunable-Diode-Laser-Spectroscopy) was used together with meteorological data (ultra-sonic anemometer) and inverse dispersion modelling (Backward Lagrangian Model). The tracer gas dispersion method (TDM), by contrast, is based on a continuous and controlled on-site release of a tracer gas and simultaneous concentration measurements of methane and the tracer gas downwind of the plant. For that, a mobile analytical platform equipped with a high-precision gas analyzer was used.
In this presentation, an overview of the measurement results, revealing methane EFs of whole biogas plants as well as of the main and most common emission sources, is given. Total emissions of the investigated plants ranged from 0.4 % to 4.0 %, related to the methane produced. As the main contributors, gas utilization units and non-gastight covered digestate storage tanks were identified. However, the collected data indicate that the kind of implemented technology can be a key factor when it comes to the magnitude of methane emissions from gas utilization units, with EF ranging from 0.04 to 3.9 % of utilized methane. In addition, OTNOC (other than normal operating conditions)-events, such as leakages at major biogas bearing components, can have a non-negligible effect on emissions with values up to 1.1 % methane loss.

Acknowledgement



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The project »EvEmBi«- Evaluation and reduction of methane emissions from different European biogas plant concepts was funded within 11th ERA-NET Bioenergy Joint Call/ 1st add. Call of BESTF3 and nationally by the Federal Ministry of Food and Agriculture Germany via Agency for Renewable Resources e.V. (FNR), the Austrian Research Promotion Agency (FFG), the Swedish Energy Agency, the Swiss Federal Office of Energy, and the Technical University of Denmark. The project partners involve DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, University of Stuttgart, Fachverband Biogas e.V., University of Natural Resources and Applied Life Sciences Vienna, BEST Bioenergy and Sustainable Technologies GmbH, Abwasser und Abfalltechnik GmbH, Kompost & Biogas Verband Österreich, Ökostrom Schweiz, Bern University of Applied Sciences, Oester Messtechnik GmbH, Research Institutes of Sweden, Avfall Sverige, Svenskt Vatten, Technical University of Denmark, and European Biogas Association.

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PhD Tina Clauβ, Lukas Knoll, Dr. Peter Kornatz, Viktoria Wechselberger, Angela Vesenmaier, Dr. Jonas Dahl

Model to estimate methane emissions of different biogas plant concepts and national biogas plant stocks

Session E
11:10 – 11:25 am
15' presentation

anaerobic digestion, methane emissions, national biogas plant stock, Monte-Carlo-simulation, EvEmBi

By using biogas as a renewable energy source, fossil fuels can be replaced, which protects climate. One advantage over other renewable energy sources, e.g. wind and solar energy, is the possibility of storage and flexible use. Anyhow, the major component in biogas, methane, is a very strong greenhouse gas (GHG). Therefore, it is very important to keep the emission during biogas production low. Only in this way, the biogas technology is competitive compared to other technologies. The GHG emissions of biogas production depend largely on the type of the plant, e.g. the used feedstocks, the methane emissions and the usage of heat.

The work presented refers to the methane emissions of biogas plants, which is an important component for the greenhouse gas balance of the particular plant. The methane emissions largely depend on the used biogas plant concepts, including the used technologies on the plants and the existing emission sources. In Europe, very different biogas plant concepts exist. Which types of plants and emission sources are present in the individual countries also depend strongly on the respective laws or the national situation.

To evaluate the different plant concepts in terms of GHG emissions, and also to evaluate the ecological impact of using biogas for replacing fossil fuels, it is important to quantify the methane emissions of different technologies and also of the whole national biogas plant stock. This knowledge can also be used to reach methane mitigation in the biogas sector, e.g. by further development of technologies which are particularly climate-friendly.

During the EvEmBi research project (funded within 11th ERA-NET Bioenergy Joint Call/ 1st add. Call of BESTF3), the methane emissions of single emission sources and overall plant emission were determined at different biogas plant concepts in four countries. The measurement results obtained are used together with data from earlier projects, data of third parties and information of existing technologies in the particular biogas plant stock (e.g. from surveys) to develop a model for the estimation of methane emissions from different plant concepts, and also for the national biogas plant stock. A similar model was already used to estimate emissions in the gas distribution grid [1]. The model uses the data to calculate probability density functions describing the probability of the amount of emitted methane in terms of produced methane for the different emission sources using a certain technology occurring at biogas plants. In the subsequent Monte-Carlo simulation, these calculated density functions are used to simulate the distribution of methane emissions for a certain biogas plant type as a combination of different technologies existing on biogas plants of this type, or for the whole biogas plant stock. For the whole biogas plant stocks, the additional information of produced methane from plants with this certain technology has to be used.

During the presentation, the final status of the model developed in EvEmBi project will be presented. The model includes the emissions from different emissions sources, e.g. open digestate storage tanks, CHP exhaust pipes, exhaust from biogas upgrading and methane diffusion through foil roofs. Furthermore, calculations will be presented which simulated the emissions of the plants where the methane emissions were determined within the EvEmBi project. From that, the emission situation of the single plant can be evaluated.

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The project "EvEmBi"- Evaluation and reduction of methane emissions from different European biogas plant concepts was funded within 11th ERA-NET Bioenergy Joint Call/ 1st add. Call of BESTF3 and nationally by the Federal Ministry of Food and Agriculture Germany via Agency for Renewable Resources e.V. (FNR), the Austrian Research Promotion Agency (FFG), the Swedish Energy Agency, the Swiss Federal Office of Energy, and the Technical University of Denmark.
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Evaluation of methane emission reduction measures and cost-benefit-analysis

Session E
11:30 – 11:45 am
15' presentation

anaerobic digestion, methane emissions, mitigation measures, EvEmBi

Biogas is an important part of the future fossil free and sustainable society. Both as a potential by-product from necessary waste treatment (water and solid organics) as well as a fossil free fuel that can be used for transport, power and heat production. However, methane is also a greenhouse gas and thus any emissions during production should be kept as low level as possible. Not only for environmental reasons but also for economical productivity and safe working environment at these plants.

Within the current project "EvEmBi - Evaluation and reduction of methane emission from different European biogas plant concepts" (2018 – 2021, funded within the 11th ERA-NET bioenergy call), biogas plants in the four European countries Germany, Austria, Switzerland and Sweden are investigated with regard to their methane emissions.

Methane emissions are identified and quantified using on- and off-site measurement approaches based on the guideline developed in previous project »MetHarmo – European harmonization of methods to quantify methane emissions from biogas plants« [1]. Based on these measurement results and identified sources of emissions, different reduction strategies are investigated and for chosen cases implemented and quantified by methane emission measurements prior and after the implementation of the measures taken.

The source of methane emissions varies between plants and how they are equipped and operated. Common sources are e.g. leakage from joints and pressure valves but the large volumes are often from slip in exhaust pipes from gas engines, open storage tanks for digestate and from upgrading units. Some of these sources of emissions can be mitigated by sealing, changing, adding or upgrading equipment, but also improving efficiency and productivity of the process by organizational measures at the plants in that sources of leakage are regularly discovered is also important for an overall mitigation improvement. E.g. by educating personal and implementing more thorough self-controls as well as cooperating with measurement experts has also been seen to have an important effect.

In this presentation and paper, an overview of general mitigation measures, as well as cost-benefit-analysis of chosen cases where equipment or changes of operation at the plants have been undertaken or upgraded will be presented.

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Final measurements are still ongoing during autumn 2020 but as an example a reduction of a methane emissions from 1,4 kg/h to 0,02 kg/h (98,5 %) could be achieved by covering an open digestate tank. The cost-benefit for the investment of such investment is set in relation to the total value of the losses such loss of income on either sold gas or produced power as well as cost of emission allowance.

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SHORT PRESENTATIONS

VARIOUS CONFERENCE TOPICS

SHORT PRESENTATIONS

Various conference topics

5' Optimization analysis of biological power-to-methane with Matlab/Simulink
Robert Bauer, Technische Hochschule Deggendorf, HAW Landshut

5' Designing synthetic microbiomes with metabolic modeling techniques to enhance biogas production
Amarante Colpo Rodrigo, Helmholtz Centre for Environmental Research – UFZ

5' Sand and gravel deposited in the fermentation chamber during the anaerobic digestion of chicken manure
Jan Cebula, Instytut Maszyn Przepływowych PAN

5' Implementation of a simple mass-based kinetic model for dynamic simulation of methane production rates
Félix Delory, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH

5' Inhibition of electroactive bacteria may hinder the combination of microbial electrochemical technologies with anaerobic digestion
Daniel Ngoumelah Dzofou, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH

5' Simulating biogas production in agricultural biogas plants based on a first-order reaction model
Johan Grope, Universität Rostock

5' Inter-laboratory reproducibility in batch anaerobic digestion kinetics
Sasha D. Hafner, Hafner Consulting

5' The use of biomagnetism for biogas production of sugar beet pulps
Matheus Pessoa, Technische Universität Berlin

5' Model-based analysis to increase the efficiency of a biogas plant
Ingolf Seick, Magdeburg-Stendal University of Applied Sciences

5' Assessment and mitigation of methane emissions from agricultural biogas plants in southern Germany
Angela Vesenmaier and Martin Reiser, University of Stuttgart

5' Potential of F420 tail length for the characterization of acetoclastic and hydrogenotrophic methanogens – a preliminary study
Andreas Otto Wagner, Universität Innsbruck

5' Biological hydrogen production for a sustainable energy economy - Development and application of dark fermentation for hydrogen production
Sören Kamphus, Fachhochschule Münster

Robert Bauer, Prof. Dr. Raimund Brotsack

SHORT PRESENTATION
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Optimization analysis of biological power-to-methane with Matlab/Simulink

Power-to-Gas (PtG), biological methanation, simulation

Motivation

Sustainable energy supply today and in the future remains an intricate issue that calls for concerted political, technical and scientific efforts. One pressing aspect is the storage of renewable energy another question is the distribution of storable renewable energy forms as well as the question how future transportation will be powered or the question how to support the energy transition in the heat sector. A promising solution for those challenges is chemical energy storage, namely methanation. Surplus renewable energy and CO_2 are hereby transformed into renewable natural gas (RNG), which in turn can be fed into the natural gas grid reducing the load on electrical grids. However, chemical processes require strict conditions and, due to the destructive influence of pollutants on catalysts, can only be carried out when using unpolluted gases. Therefore, biological methanation offers advantages because it takes place under moderate conditions and biology can handle such contaminants. Currently biological methanation is still in the research and development stage and needs further investigation to identify optimization potential to drive the scale-up process.

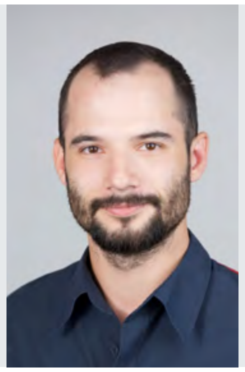
Methods

With the aim of increasing the efficiency of Power-to-Gas plants with biological methanation, the complete and systematic coupling of a PtG model system with a suitable simulation software (Matlab/Simulink) is demonstrated. Based on literature and experimental data, suitable mathematical models for reaction kinetics as well as for the process engineering of methanation are developed. Based on this, the hydrogen transport into the liquid phase of the reactor is modelled and the implementation of a biological reaction system is described. In addition to the simulation of different basic conditions for the exact representation of the functionality, the simulation model is validated holistically on experimental and literature data. The simulation quality will be compared with previously used simulation methods.

Results

The results show that the developed simulation model exceeds common methods with respect to accuracy. A sensitivity analysis of the most important parameters is carried out for a detailed investigation of critical factors influencing the final result. Finally, simulations of process variants consistently show the optimization potential of biological methanation, which leads to proposals for effectively implementable measures.

With the groundwork provided by this study industrial plants of adjusted size can be built and optimized for a demand driven manner at sites of surplus renewable energy, reducing the load of the electric grid. Further work building on the experience collected at the TZE can also establish whether and how the influence of contaminated gases, e.g. Pyrolysis gas, affect the biological methanation and consider how these gases can be converted into methane in the best possible way. A prospected outcome is a centralized, industrial sized plant fine-tuned with the help of the developed Matlab/Simulink based tool to maximize efficiency. This approach will contribute to



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sustainable energy supply in form of RNG, stored and distributed in the existing natural gas grid for applications in the transport- as well as in the decentralized heat and power sector while simultaneously utilizing the energy potentials of organic waste material and residuals after their transformation in hydrogen-containing syngas.

>>> Short presentation

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Rodrigo A. Colpo, Dr. Bernard Henrissat, Prof. Dr. James McDonald, Florian Centler

SHORT PRESENTATION
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Designing synthetic microbiomes with metabolic modeling techniques to enhance biogas production

synthetic microbiomes, microbial communities, constraint-based modeling, metabolic modeling

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Motivation

Waste biomass is a source of methane which is formed by the microbial driven process of anaerobic digestion. This process is deliberately facilitated in biogas plants, but also occurs spontaneously in landfill sites. Microbiomes of anaerobic digestion plants are typically originating from animal guts via inoculation with animal manure or slurry. While these microbial communities are already well characterized, microbiomes of landfill sites still lack a more complete understanding, especially as they inhabit a more diverse and heterogeneous environment than the gut microbiomes.

Aim of the work

The SYNBIOGAS project aims at using insights gained during the characterization and analysis of landfill microbiomes, to reach higher digestion rates in industrial digestion plants by using bioaugmentation strategies.

Methods

To design synthetic microbiomes with enhanced methane production rates, we will use metagenomic, metatranscriptome and metabolomics data from bioreactors inoculated with landfill material, and isolated microorganisms from landfill sites. We will screen for novel enzymes, create community-wide metabolic networks, reconstruct genome-scale metabolic network models, and perform dynamic community simulations. For synthetic community simulations, the microbial community composition and feedstock composition will be systematically varied to screen for optimal communities as candidates for experimental bioaugmentation tests. Bioinformatics pipelines that will be used include CobraPy [1], CarveMe [2], and µbialSim [3].

Expected results

Potential modeling results may include (i) suggestion and validation of new species or consortia to be injected into anaerobic digestion plants or landfill sites to improve biogas production; (ii) identification of critical metabolic conversion steps; (iii) identification of species whose activity must be limited to improve biogas production. The communities designed in silico will be validated in laboratory tests and tested by industrial partners for their practical application feasibility.

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››› Short presentation

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Jan Cebula, Izabela Konkol, Adam Cenian

SHORT PRESENTATION
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Sand and gravel deposited in the fermentation chamber during the anaerobic digestion of chicken manure

sand, gravel, chicken manure, adsorption, anaerobic digestion

The potential production of biogas from chicken manure is closely related to manure composition. One constituent of chicken manure is sand and gravel which is added to chicken feed. During methane fermentation of chicken manure, sand and gravel are deposited at the bottom of the fermentation chamber, which can reach a thickness of 2 meters after many years of accumulation (Fig. 1a). Failure to remove the sand and gravel results in a reduction of the active volume of the fermentation chamber, increase of mixing resistance, which in turn causes stirrer damage (Fig. 1b). Smaller, light, fine mineral particles of the sludge are removed from the fermentation chamber during digestate discharge. Heavy sand and gravel particles sink to the bottom. Sand and gravel deposited in the fermentation chamber act also as adsorbents. After a sufficiently long time, mineral compounds crystalize on the surface of the sand and gravel. This paper presents the effects of sorption, including compounds containing calcium, magnesium, phosphorus, potassium, sodium, carbon, sulphur and nitrogen. Sand in chicken manure, freshly added into the fermentation chamber, is slow to sorb these elements, and it takes several years before significant deposits on their surface is observed. The chemical composition of these mineral layers on sand particles was examined using the SEM-EDS system. The observations were made in two biogas plants. Samples were taken in triplicate, several days after the initiation of digestion and again after 10 years of digestion. Tables 1 and 2 shows the results of the measurements. Sand particles sampled several years after initiation of fermentation are characterized by a several-fold increase in the content of sorbed elements. The quantity and structure of the deposited compounds are influenced by composition of the feed used, feed additives and the type of biomass added to the fermenter. It must be pointed out that on the surface of the sand, biogenic elements such as nitrogen, potassium and phosphorus, all constituents of fertilizers, are adsorbed. They should therefore be incorporated into the biofertilizer and returned to the soil.

Figure 1: a) Sand and gravel removed from digester and b) damaged stirrer

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Element [%]	Sand after few days digestion					
	Biogas plant P			Biogas plant B		
Magnesium	0,79	0,64	0,67	0,59	0,80	0,55
Phosphorus	0,37	0,51	0,57	0,64	0,55	0,62
Calcium	22,43	23,58	24,22	16,22	14,18	14,44
Potassium	0,54	0,92	1,22	0,74	0,82	0,88
Sodium	0,43	0,86	0,60	0,34	0,48	0,54
Carbon	10,14	8,98	8,79	3,37	3,69	1,90
Sulphur	0,46	0,15	0,14	0,11	0,15	0,24
Nitrogen	0,38	0,32	0,30	0,36	0,34	0,42

Table 1: Content of elements on sand after few days digestion

Element [%]	Sand after few years digestion					
	Biogas plant P			Biogas plant B		
Magnesium	6,43	1,67	1,36	1,40	0,72	0,57
Phosphorus	5,24	3,10	4,20	2,17	1,17	0,86
Calcium	13,34	15,74	16,46	20,14	18,64	16,80
Potassium	0,76	1,81	0,92	1,12	1,18	2,12
Sodium	2,13	1,14	1,25	1,86	1,71	1,98
Carbon	7,25	4,85	4,55	3,82	4,93	4,29
Sulphur	0,71	1,19	1,26	0,49	1,42	0,44
Nitrogen	2,34	1,44	1,34	1,48	1,22	0,98

Table 2: Content of elements on sand after few years digestion

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IMPLEMENTATION OF A SIMPLE MASS-BASED KINETIC MODEL FOR DYNAMIC SIMULATION OF METHANE PRODUCTION RATES 67

Félix Delory, Dr. Sören Weinrich

SHORT PRESENTATION
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Implementation of a simple mass-based kinetic model for dynamic simulation of methane production rates

anaerobic digestion, biogas technology, process model, first-order kinetic, parameter estimation

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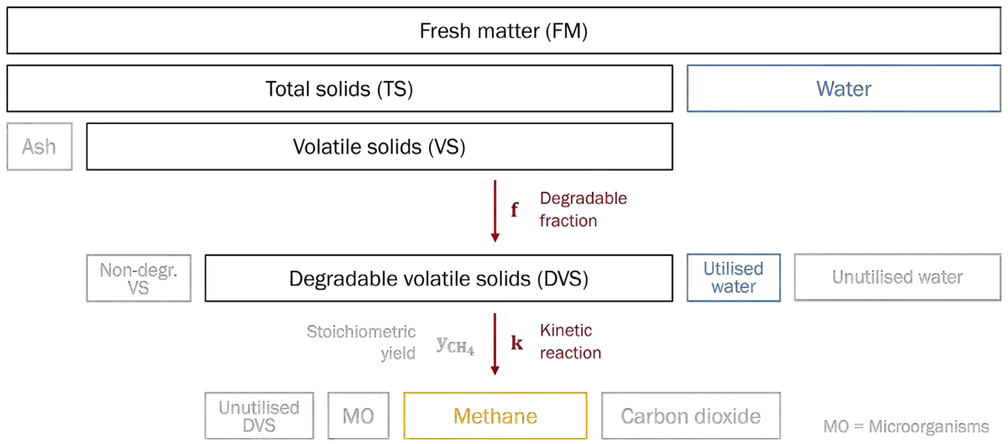
Modelling of anaerobic digestion has been realized multiple times with models ranging in complexity, type and application [1, 2]. Despite the existing knowledge and many years of experience in mathematical modelling and process monitoring, model-based state observers or control procedures are rarely applied on industrial biogas plants. Established models – such as the Anaerobic Digestion Model No. 1 (ADM1) [3] – include numerous components and unknown parameters, and cannot yet be utilised as a reliable basis for process automation in practise. Furthermore, numerical procedures required for solving ordinary differential equations (ODE) and parameter estimation as well as measurements for substrate characterisation (model input) are often not available in regular plant operation.
During anaerobic degradation of particulate materials, hydrolysis often limits the overall reaction rate. Thus, first-order reaction kinetics can be applied as an empirical expression to describe substrate degradation and methane production [3, 4]. Corresponding models based on first-order kinetics are typically used for kinetic assessment of discontinuous biomethane potential (BMP) tests [5]. However, these models are seldom applied for process simulation of continuous processes.
In the current investigation, we propose a simple mass-based kinetic model for dynamic and robust simulation of methane production rates during semi-continuous operation.

Methods

Substrate properties for process monitoring and evaluation are typically characterized by measurement of total solids (TS) and volatile solids (VS), as illustrated in Figure 1. To account for non-degradable organic substances (such as lignin), Weißbach [6] originally proposed an additional parameter to describe the share of degradable volatile solids (DVS). The share of DVS in total VS of the employed substrates is described by an unknown fraction parameter (*f*). During semi-continuous operation, the mass of DVS entering and leaving the reactor is balanced at each feeding time. Based on a stoichiometric yield coefficient Y_{ch4} = 420 L kg^{-1} DVS and first-order kinetics (*k* in d^{-1}), DVS is converted to methane [6]. Assuming discontinuous process behaviour between individual feeds, this model can be solved analytically (without numerical ODE solvers).

Figure 1: Conversion of degradable volatile solids to methane, as implemented in the simplified kinetic model.



The model is implemented in the software environment Matlab (The Mathworks, USA). The interior-point algorithm (`fmincon` function in Matlab) is applied for numerical estimation of unknown model parameters (f and k), while minimizing mean squared error (MSE) between simulation results and measurements of methane production rates. For constraint optimization lower and/or upper bounds for each model parameter are defined ($0 < f \leq 1$ and $0 < k$).
For model validation, mesophilic anaerobic digestion of wheat straw and cattle manure was conducted in two laboratory semi-continuous stirred tank reactors. After initial start up, both reactors (duplicates) were operated with constant organic loading rate (VS-based) until steady state conditions were attained. Substrate characteristics (such as TS and VS) were determined according to standard methods. Established parameters for process monitoring (such as pH, NH_4-N or total VFA concentrations) were measured weekly to ensure stable and uninhibited process conditions.

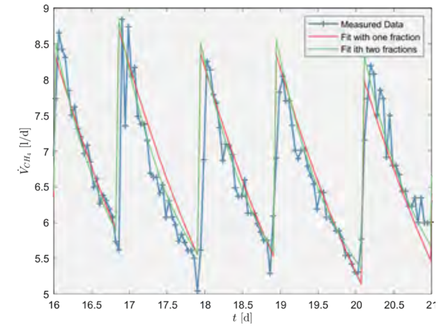


Figure 2: Simulation results during steady state conditions of semi-continuous laboratory experiments.

Results and discussion

As shown in Figure 2, the implemented model structure can sufficiently describe methane production rates of semi-continuous laboratory experiments. In addition to a single fraction of DVS, an extended model implementation considering two DVS fractions with different first-order kinetics was applied. Thus, this combination of multiple DVS fractions allows for more accurate depiction of experimental results. Individual model parameter estimates can be used to calculate the BMP or assess kinetic properties of the applied substrate mixture.

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Daniel Ngoumelah Dzofou, Prof. Dr. Falk Harnisch, Dr. Jörg Kretzschmar

SHORT PRESENTATION
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Inhibition of electroactive bacteria may hinder the combination of microbial electrochemical technologies with anaerobic digestion

Microbial electrochemical technology, anaerobic digestion process, resistance, methanogens, alternative electron acceptors

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Combination of microbial electrochemical technologies (MET) and anaerobic digestion (AD) have been examined in recent years to, e.g., i) remove monovalent ions as ammonium from AD[1], ii) remove COD from AD effluent also known as effluent polishing [2], iii) upgrade biogas [3] or iv) monitor AD using microbial electrochemical sensors [4]. All these applications bear quite some advantages for improving the efficiency and environmental impact of AD but research is still at laboratory level. One limiting factor for combining microbial electrochemical systems with AD is the observed loss of electrochemical activity of *Geobacter* spp. dominated biofilms at graphite electrodes [4]. It was found that biofilms disappear from the electrode when adding AD effluents or incorporating them in AD processes. The cause of this inhibition is unclear so far but several hypothesis exist. Inhibition can be induced, e.g. by toxic compounds (e.g. high $N\text{-}NH_4^+$), alternative dissolved electron acceptors (sulfate, nitrate or humic substances [5]) or even methanogens itself. The latter is probably connected to direct interspecies electron transfer (DIET) where methanogens accept electrons directly from electroactive bacteria [6].

Therefore, the goal of this study was to investigate optimal conditions for *Geobacter* spp. dominated biofilms to survive for a long time-period in AD processes. To answer this question, several experiments with increasing concentration of AD effluent (10–100 %) and inhibition of methanogens using 2-BES were performed. The experimental setup consisted of 250 mL threeneck round bottom flasks that were used as single-chamber microbial electrolysis cell by integrating a graphite anode (surface area 7.1 cm^2), a graphite cathode (surface area 10.2 cm^2) and an Ag/AgCl sat. KCl reference electrode as described elsewhere [7].

Experiments using different AD effluent concentrations showed negative effects on the performance and the resistance of pre-grown mature biofilms from 50 % AD effluent (v/v) onwards. Contrary, the use of 2-BES stabilized biofilm performance for over 4 weeks at 50 % AD. Therefore, we hypothesize that methanogens may have a direct influence on the performance of *Geobacter* spp. dominated biofilms [8]. However, this hypothesis still needs to be proven using different kinds of AD effluents as well as molecular biological analysis of the biofilms and the planktonic phase.

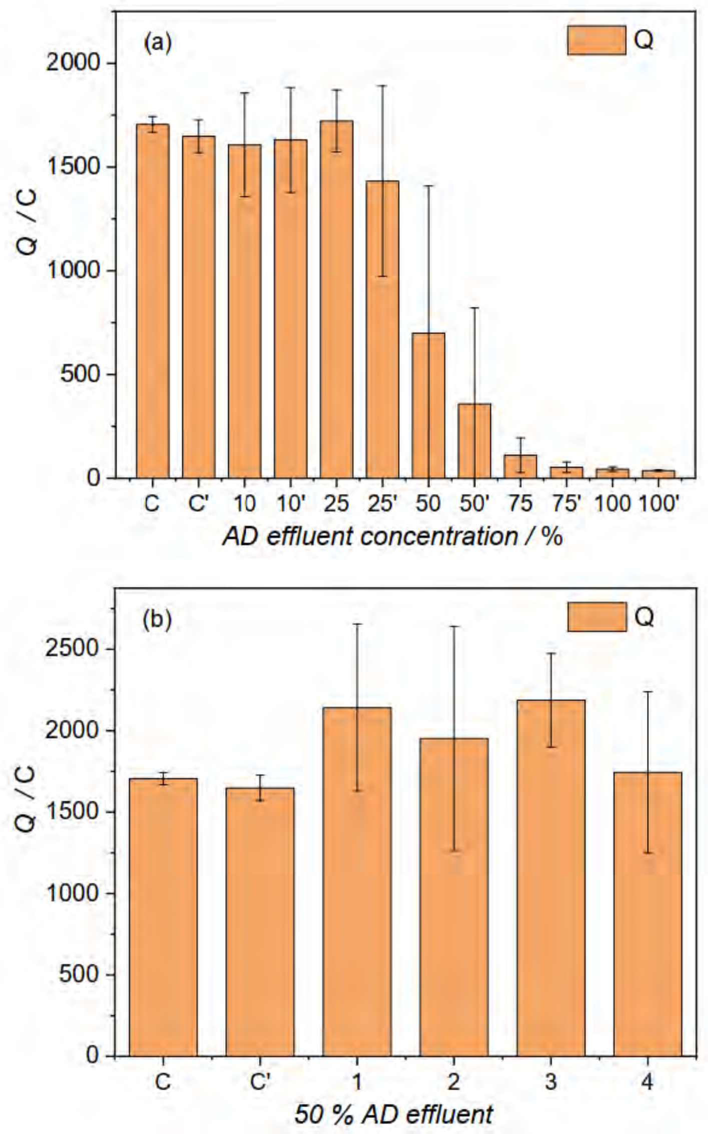

Figure 1: Transferred amount of charge of Geobacter spp. dominated biofilms during (a) biofilm inhibition by stepwise increase of AD effluent concentration, and (b) successful stabilisation of biofilms during application of 50 % AD effluent using 2-BES to inhibit methanogens, C: AD effluent free control (acetate as only carbon source), ': second batch (one batch = one week), numbers at the X-axis in b) indicate successive batch cycles with 50% AD effluent, n=3, error bars indicate CI.

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SHORT PRESENTATION
»» CMP WEBSITE

Simulating biogas production in agricultural biogas plants based on a first-order reaction model

biogas technology, kinetic modelling, full-scale application, Matlab, Excel

Motivation

Simulating biogas production on agricultural biogas plants offers various possibilities for efficiency evaluation, process optimization and demand-oriented operation. A major challenge is the definition of suitable model structure, which requires only a limited number of available process data, but still guarantees precise and reliable simulation results. For practical application, a simplified process model based on first-order reaction kinetics is characterised by the following substrate-specific parameters [1]:

- stoichiometric biogas or biomethane potential
- different substrate fractions of degradable volatile solids (VS)
- first-order kinetic parameters of individual substrate fractions of degradable VS

For semi-continuous plant operation, biogas production can be described by a system of ordinary differential equations (ODE). The analytical solution of the specific ODE during discontinuous (batch) operation results in an exponential progression of gas production rates, which is typically applied for kinetic description of biomethane potential (BMP) tests [2].

Aim of the work

The aim of the work is to evaluate two different implementations of a simple first-order reaction model for simulating daily biogas production during semi-continuous operation of full-scale biogas plant.

Methods

The different model structures differ in the specific description of the individual plant concept as illustrated in Table 1. While model A describes the biogas plant as a single unit (based on simplified assumptions of HRT distribution), Model B includes mass balances of each individual digester. Both models are implemented as analytical solutions of a discontinuous first-order reaction model in Excel (Microsoft, USA). Thus, the biogas production resulting from every single feeding is described by an exponential function.

	Model A	Model B
Mass balance	entire plant only	each digester
HRT distribution[a]	entire plant only	each digester
Different digesters sizes	not considered	considered
Digesters in parallel	not considered	considered
Recirculation of digestate	not considered	considered

Table 1: Description of individual model characteristics of the implemented first-order reaction models

a) The hydraulic retention time (HRT) distribution has been calculated for a system of complete stirred tank reactors (CSTR) in a row, based on [3]. The calculation is only valid for CSTR in a row, each of the same size

Model A and B are evaluated by comparing the relative accuracy of the simulation results with the simulation results of the semi-continuous ODE model implemented in Matlab/Simulink (Mathworks, USA). The accuracy is rated by a) the coefficient of determination (R2) and b) the absolute value regarding the simulated amounts of daily biogas production. For absolute comparison, the simulation results based on real plant data of several month have been compared. The real plant data includes daily substrate specific feeding amounts for a large-scale agricultural biogas plant with two digesters in parallel and three additional post-digesters in a row.

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For evaluating the influence of individual plant configurations, simulation results for a variation of the following plant characteristics have been compared:

- average HRT
- variation of daily feeding rate
- number of digesters in a row
- recirculation of digestate

Results

As the investigation of Model B is still ongoing the following results are limited to the comparison of Model A implemented in Excel with the model description of ODE in Matlab/Simulink.

Process simulations based on real plant data show similar results between Model A and the semi-continuous Matlab/Simulink implementation, with R2 = 0.99 and a relative difference between the average simulated daily biogas production of 2.4 %. These results are related to the following plant parameters:

- average retention times of 97 days
- fluctuating daily feeding rate of minimum (- 25 %) and maximum (+ 100 %) compared to the average amount
- 5 digesters: 2 digesters in parallel, 3 post-digesters in a row, no recirculation

The following table shows the influence of an increasing average HRT, an increasing variation of the daily feeding rate and an increasing number of digesters on R2 and the difference of the average daily biogas amount of the Excel Model A in comparison to the simulation results of the semi-continuous model implemented in Matlab/Simulink.

with increasing:	average HRT	variation of daily feeding rate	number of digesters
R^2	increasing	decreasing	decreasing
difference of average daily biogas amount	decreasing	increasing	no influence

Table II: Influence of plant design parameters regarding the simulation results of the Excel Model in comparison to the model description of ODE in Matlab/Simulink

The results of further investigation with regard to Model B will be presented at the conference.

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SHORT PRESENTATION
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Inter-laboratory reproducibility in batch anaerobic digestion kinetics

anaerobic digestion; biochemical methane potential (BMP); hydrolysis; first-order model; parameter estimation

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Introduction

There is a general consensus that kinetic information derived from laboratory batch trials does not exactly reflect full-scale behaviour. Still, kinetic results from batch biochemical methane potential (BMP) tests are commonly used to compare substrates or assess pre-treatment effects [1] and even to estimate conversion rates for full-scale systems [2]. In this work, we assessed inter-laboratory reproducibility in first-order rate constants *k* for anaerobic conversion of four substrates measured in BMP tests in 37 laboratories. The aim of this work was to assess the quality of kinetic information extracted from BMP tests.

Methods

A first-order model was applied to 968 methane production curves from BMP tests carried out in a large inter-laboratory study [3]. Finely ground substrates varied in composition and degradability: microcrystalline cellulose (CEL, positive control), three mixed animal feed ingredients (SA, SB, SC), and wheat straw (SD). BMP tests were carried out in two periods (study S1 and S2). Inoculum-to-substrate ratio was 2:1, except for SD (1:1), and SC in S1 only (4:1).

First-order rate constant *k* and ultimate BMP were extracted by fitting a model to measurements made after excluding a possible lag phase, defined as the period prior to the maximum average rate. Least-squares estimates of the two model parameters were determined for each SMP curve (bottle) using the Levenberg-Marquardt algorithm. The response variable was average rate of CH_4 production in each interval. All calculations were carried out using the biogas package in R (v1.26) [4] (https://CRAN.R-project.org/package=biogas), with function fitFOM(), which relies on nls.lm() [5].

Results and discussion

Repeatability in *k* was high: median relative standard deviation among replicates was 5-11%. However, inter-laboratory reproducibility was low and substrate-dependent (Fig. 1). Relative standard deviation among laboratories was 41 to 140%. Range of *k* was above 10-fold for most substrates. The lowest relative variability was for SD, the slowest-degrading substrate. Normalization to CEL rate only slightly improved variability, except for SD, where it increased.

Differences between substrates varied among laboratories. Nearly half of laboratory-specific *t*-tests (56/118) comparing CEL and SC had $p < 0.01$ but those with SC $k >$ CEL k (24) were nearly as common as those with the opposite result (32) (lowest p value was $< 1 \cdot 10^{-7}$, and ratio in mean *k* was 0.13× to 4.1×). However, a large difference in mean *k* coupled with a low *p* value may still be meaningful, as shown by a similar comparison between SD and CEL, with median *k* values that differed by about 4-fold. Here, all tests with $p < 0.01$ had lower *k* for SD.

Application of current BMP validation criteria [6] did not clearly improve reproducibility, but *k* was higher for BMP-validated results for at least some substrates (+22%, $p = 0.004$). Some extreme *k* values were eliminated, but reproducibility clearly improved only for SD (Fig. 1).

There were no consistent differences in variability among different measurement methods. All three popular methods (AMPTS II, other volumetric, manometric) were variable for some combinations, and showed similar results for SD. In contrast, there were differences in *k* magnitude: AMPTS II *k* estimates were higher than other (typically manual) volumetric methods (30-50% higher, $p < 0.01$). Mechanical mixing and a high measurement frequency for AMPTS II may have played a role.

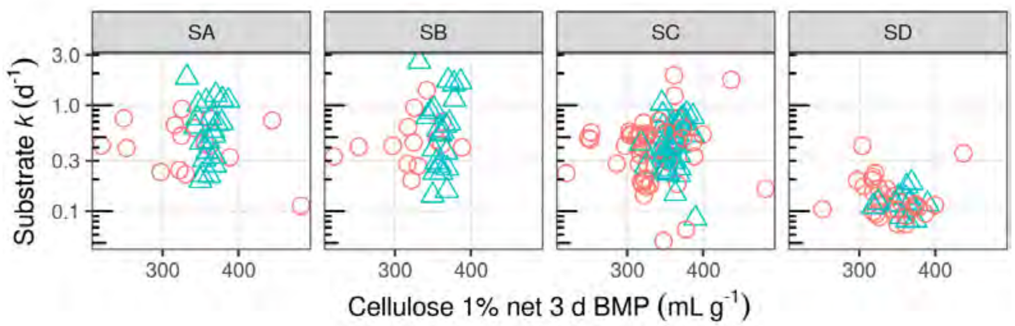

Figure 1: Mean least-squares estimates of first-order rate constant k (n = 3) versus positive control microcrystalline cellulose BMP measured in the same test. Validated points (blue triangles) meet all validation criteria [6], while others (red circles) fail one or more (typically cellulose BMP).

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Matheus Pessoa, Prof. M.A. Motta Sobrinho, Prof. Dr.-Ing. Matthias Kraume

SHORT PRESENTATION
»» CMP WEBSITE

The use of biomagnetism for biogas production of sugar beet pulps

Sugar beep pulp, enzymatic pretreatment, magnetic fields, sonication, biogas

Background/motivation

The development of the proposed process arises from the different possible applications of magnetic fields to increase the potential of anaerobic digestion. As most strategies tend to focus in a continuous application on the fermentation broth, here the use of a magnetic field in combination with enzymatic pretreatment, aiming at an increase in enzymatic activity and substrate digestibility, is proposed as a substrate pretreatment. The influence of sonication is also investigated.

Aim of the work

Apply the concept of biomagnetism, i.e., the effect of magnetic field in biological systems, to biogas production of sugar beet pulp (SBP).

Key research topics and novelty

The novelty of this research lies in the development of parameters for increasing the specific energy gain of the biogas production from SBP pulp by applying a magnetic field to an enzyme-substrate mixture.

Methods

Batch experiments with a 10% total solids (TS) fermentation broth in a 11,2 L bioreactor were carried out for 21 days. Anaerobic sewage sludge was used as an inoculum in the proportion of 1:2 g of VS_{SBP} /VS_{Sludge}.
Pretreatments were performed with 220 gTS of SBP, except for sonication.
Enzymatic pretreatment (E): Pectinase from Aspergillus niger (Sigma Aldrich) was used for the pretreatment, which consisted of mixing the enzyme solution (enzyme powder + ultra-pure water) with the grinded SBP (0,3 $U/g_{Substrate}$). After 10 min of mixing with a magnetic stirrer, the sample was incubated at 50 °C for 48 h. The incubator has a rotational frequency of 20 Hz.
Magnetic pretreatment (MF): A solenoid made with cooper wire 0.2 mm (100 turns over 10 cm) was place in a Plexiglas tube (120 mm). A current of 0.2 amps induced a magnetic field of 0.2 mT. The solenoid was connected to a Heizinger LNG 16-30 power supply that delivers DC current. He magnetic field pretreatment was 4 h. A Digital Gauss/Tesla Meter CYHT20 from Chen Yang Technologies GmbH & CO. KG was used to measure the magnetic field.
Sonication (US): An ultrasound generator from Bandelin (20 kHz) was used with a specific energy of 2100 kJ/kg TS. The generator was operated with 100 % of its capacity (70 W) for 2 min (50 % pulsed cycle). The sonicated sample was placed in an ice-water bath to decrease the effects of increasing temperature and pressure during sonication.
Gas quality was measured with a modular stationary gas analyzer MaMos system from Madur® calibrated with CH_4-CO_2 mixtures purchased from Linde AG. For statistical analysis, a multi-comparison method, the Tukey- Kramer method after one-way ANOVA was used to test the null hypothesis, that there is no significant difference between the pre- treatments and the control batch, in the pretreatments mean values with a significance level $\alpha = 0.05$. Soluble COD (sCOD), VFA and pH were also monitored.

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Results

Biogas/methane:

Biogas increased by 26 ± 4.4% for the combination of three pretreatments (US-E-MF) in comparison to the control. Data analysis indicates that the combination of pretreatments E–MF, US–E and US–E–MF presented statistical differences in comparison with the control, which was not the case for E and MF when applied alone. Analyzing all experiments involving enzymes, i.e., comparing the enzymatic pretreatment to its combination with MF, US and both together, E–MF and US–E–MF presented statistical difference. US–E did not present statistical differences.

The methane production also increased in comparison to the control batch. Methane production from the combination of three pretreatments (US–E–MF) was 79 ± 3.2% (244.6 N L/kgVS) greater than the control batch, followed by E–MF (62 ± 5.08%) (221.7 N L/kgVS). The control batch yielded 136 N L/kgVS; the enzymatic pretreatment (E) yielded 171.1 N L/kgVS; MF (180.7 N L/kgVS); and US-E (210.1 N L/kgVS). Data analysis for methane production followed a similar tendency compared to the biogas production. Statistical analysis of all pretreatments indicates that the combination of pretreatments E–MF, US–E and US–E–MF presented significant differences in comparison to the control batch while MF and E did not. The analysis of pretreatments involving enzymes, i.e., comparing the enzymatic pretreatment (E) to its combinations (E-MF, US-E, US-E-MF), did not present significant differences, i.e., there is no significant difference between E and its variations (E-MF, US-E, US-E-MF).

Specific energy gain:

The energy balance of the batch experiments compares the energy from the methane content produced by the pretreatment subtracted from the energy consumed to perform the same pretreatment. The energy net indicates that the magnetization of the enzyme-substrate mixture (E-MF) exhibit the greatest balance. The energy consumed to perform the E–MF pretreatment accounted for 0.15% of the energy produced for the same pretreatment, while its variation with sonication (US–E–MF) accounted for 27.53%. The magnetic field pretreatment (MF) accounted for 0.19% of its energy production and the sonication pretreatment followed by enzymatic pretreatment (US-E) accounted for 31.89% of its energy production.

The application of sonication before E-MF increased biogas and methane production. However, sonication demands a higher energy input than the magnetic field facility, resulting in a lower specific energy gain. The rated power of the solenoid used in this work (0.08 W) is considerably lower than the rated power used in by Litti et al. [1] (1.3 kW) that reached a similar increase in biogas production as in the present work.

The innovative aproach of this process is the base of a patent application from TU Berlin.

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Ingolf Seick, Prof. Dr.-Ing. Jürgen Wiese

SHORT PRESENTATION
»» CMP WEBSITE

Model-based analysis to increase the efficiency of a biogas plant

Biogas plant, Substrate efficiency, Dynamic simulation

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The **background** to the work presented is a current R&D project »ThermoFlex-WAVE« (FKZ: 03KB142) for the further development and testing of the »ThermoFlex process« [1]. The ThermoFlex process enables biogas plants to become more flexible with a high degree of heat utilisation without additional heat storage tanks. The investment costs can thus be significantly reduced compared to conventional heat storage systems. The process is based on a thermophilic secondary digester with controlled temperature variations for heat storage. Within the framework of the current R&D project, a biogas plant is to serve as an example plant for the large-scale testing of the ThermoFlex process.

It is an agricultural biogas plant in the state of Saxony-Anhalt in Germany. The feed mixture consists of the following substrates (with mass proportions in %): cattle manure (55-60 %), maize silage (25-30 %), grass silage (5-10 %), solid cattle manure (2-3 %), dry chicken manure (2-3 %) and residual feed (approx. 2 %). The plant was built in 2009 with a combined heat and power plant (CHP) with an electrical output of 370 kW and was later extended by a further CHP to a total of 740 kW. Because the fermentation volume was not increased accordingly, this results in an above-average load. The fermenter and secondary digester each have working volumes of 2,200 m³. In addition, there is a tank designed as a hydrolysis stage (150 m³ working volume), which is equipped with heating and gas collection and is currently used as a pre-fermenter. An open mixing tank with an average filling volume of 100 m³ is used for mashing the above-mentioned substrates with recirculated material from the secondary digester. The digestate is transferred to a currently not yet covered digestate storage tank (max. 5,900 m³ filling volume).

In the fermenter, the loading rate with organic dry mass (VS) averages almost 6 kg VS/(m³d). Added to this is the relatively high nitrogen content of the above-mentioned substrate mixture as well as the fact that suboptimal silage batches are preferably fed to the biogas plant, while silages of better quality are used for the farm's cattle feed. This situation results in a below-average methane yield from the feed mixture compared to reference values [2], a relatively low degradation of dry matter and a temporarily noticeably stressed process biology. The relatively high dry mass contents in the fermentation tanks require a recirculation from the secondary digester of approx. 3-4 times the amount of substrate input, via the mixing and the hydrolysis tank, back into the fermenter. This results in an average hydraulic retention time in the fermenter as well as in the secondary digester of only approx. 5-7 days each. These short hydraulic retention times can have an unfavourable effect on the process biology under different milieu conditions as planned in the ThermoFlex process (mesophilic fermenter and thermophilic secondary digester).

In this context, the **aim** is to increase the substrate efficiency and reduce the load on the system before implementing the ThermoFlex process.

The **novelty** of the presented work already results from the degree of innovation of the ThermoFlex process described above and furthermore with the methodical implementation of the model-based analysis and the concrete results achieved for the example plant (see below).

The **methods** chosen for these studies are divided into the following main steps:

- First, on the basis of the available plant data (operating log, laboratory data), an analysis and evaluation of the actual condition - in particular of the substrate efficiency - of the plant was performed in comparison with reference values.
- Based on these data and analyses, a dynamic simulation model of the biogas plant was created and matched with daily values over an operating year. A modification of the »Anaerobic Digestion Model (ADM1)« [3], which is implemented as »ADM1da« in the simulation programme Simba#Biogas [4], is used as the model basis.
- On the basis of the model adjustment, various measures for the optimisation of plant operation were investigated and evaluated with regard to the potential for increasing substrate efficiency.

The main results are summarised below:

For an exemplary year of operation, a deficit of the methane yield related to the organic dry matter fed into the biogas plant to the calculated value according to guide values [2] of 4 % was determined. This deficit seems to be relatively small. However, it must be taken into account that 2-stage biogas plants (with fermenter and secondary digester) often achieve significantly better methane yields than those given in the reference values. Against this background, a potential for improving the methane yield on the example plant of approx. 10-15 % is quite realistic.
The model adjustment carried out provided a good approximation of the simulation results to the curves of essential operating variables, such as the methane production of the plant and the contents of dry matter, organic acids and ammonium nitrogen in the fermenter. The adjustment thus allows the qualitative and quantitative evaluation of different operating variations.
The comparison of variants is done by simulation at constant substrate quantities and qualities. The effect of measures for the following aspects is analysed:

- Changes of the internal sludge flows,
- Moderate increase in fermentation temperatures,
- Avoidance of part-load operation of the CHP,
- Covering of the digestate storage tank.

Based on the modelled boundary conditions, there is a potential increase in substrate efficiency of up to 10 %. Thereby, a substantial part of up to 5 % would only be achieved by covering the existing digestate storage tank. Added to this is the potential for improvement through substrate variations, which has not yet been taken into account in this phase. The investigations will be continued in the further course of the project.

The poster will focus on the adjustment of the dynamic simulation model as well as the model-based analysis of the optimisation potential and evaluation of corresponding measures to increase the substrate efficiency of the biogas plant.

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SHORT PRESENTATION
>>> CMP WEBSITE

Assessment and mitigation of methane emissions from agricultural biogas plants in southern Germany

biogas, fugitive methane emissions, emission mitigation, inverse dispersion modelling, single source quantification

In Germany, renewable energy sources are cultivated in agriculture in order to utilize them together with animal residues in biogas plants. The resulting methane is collected and used in further process steps. In addition to the collected sources (exhaust gas stream from gas utilization or air ventilation of double membrane domes), there are various fugitive methane sources at a biogas plant from which methane can escape into the atmosphere.

For the quantification of the total methane emissions, an innovative method is used which includes "open-path" concentration measurements and micrometeorological dispersion modelling. By recalculating the gas distribution, the emission rate of an area source can be determined from the gas concentration measured downwind of the plant reduced by the background concentration measured upwind, taking wind conditions into account. Additionally, a leak detection survey and single source quantifications were performed to identify major methane emission sources.

The methane emissions of two biogas plants were evaluated with regard to different categories by representative emission factors. This resulted in mitigation strategies, which were implemented and checked in follow-up measurements. The greatest reduction achievements were found with regard to the coverage of digestate and the regular checking of leakages.

The combination of an optical remote measurement method and inverse dispersion modelling provides a simple and generally available method for monitoring emissions from biogas plants. The method contributes to the estimation of the climate impact and does not affect the ongoing treatment processes. The identification of single source emissions improves the elaboration of operational recommendations for mitigation measures. The reduction of methane emissions from biogas plants brings ecological and economic advantages whose potential cannot be neglected.

Acknowledgement

The results are part of the research project EvEmBi - Evaluation and reduction of methane emissions from different European biogas plant concepts; funded by: Federal Ministry of Food and Agriculture (Lead partner: Fachagentur Nachwachsende Rohstoffe e.V. (FNR)) as part of the ERA-NET Bioenergy funding programme.

>>> Short presentation

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SHORT PRESENTATION
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Potential of F420 tail length for the characterisation of acetoclastic and hydrogenotrophic methanogens – a preliminary study

Methanogenesis, F420, biogas, methane

Cofactors are indispensable in many enzymatically catalysed processes. During biogas production, the co-enzyme F420 (»co-factor F420« or »F420«) is involved in the methane generation process and inevitable for CH4 production. This remarkable co-factor is found in methanogenic Archaea [1] but also in aerobic Prokaryotes [2] and is equipped with a polyglutamic tail that varies in length. Aim of the present study was the evaluation of co-factor F420 glutamyl tail length in two methanogenic pure cultures. It represents a preliminary investigation as part of a project finally aiming on the differentiation of acetoclastic and hydrogenotrophic methanogenesis via analysis of F420 polyglutamyl tail length and its distribution during AD process.

In the presented investigation, pure cultures of *Methanosarcina thermophila* (acetoclastic methanogen) and *Methanoculleus thermophilus* (hydrogenotrophic methanogen) were cultivated under optimum growth conditions. Cultures of *M. thermophila* were adapted to different energy sources including acetate, methanol, and acetate/methanol, whereas *M. thermophilus* was grown on H_2/CO_2. Subsequently, after transfer into fresh medium samples were collected in the lag-, exponential-, and stationary growth phase. Methane production was evaluated, DNA extracted and F420 gathered after cell disruption via solid phase extraction (SPE). Finally, F420 was analysed quantitatively and qualitatively via HPLC analysis.

F420 expression could be verified in the two investigated organisms and differences regarding both, total F420 quantity and F420 tail length were found. Additionally, the growth phase impacted F420 tail length expression, however, *M. thermophila* tended to produce F420 with longer F420 glutamyl tails length than *M. thermophilus*. Moreover, the substrates fed to *M. thermophila* cultures had an impact on F420 tail length expression profiles.

Conclusions: Different F420 tail length expression profiles were observed for hydrogenotrophic and acetoclastic methanogenic pure cultures, respectively. In future, the F420 tail length might be a valuable, additional monitoring parameter during biogas production. Prior to application; however, more pure culture investigations as well as in situ assessment are required to evaluate this promising approach.

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BIOLOGICALHYDROGENPRODUCTIONFORASUSTAINABLEENERGYECONOMY-DEVELOPMENTANDAPPLICATIONOFDARKFERMENTATIONFORHYDROGENPRODUCTION 81

Sören Kamphus, Tobias Weide, Juliana Rolf, Dr.-Ing. Elmar Brügging

SHORT PRESENTATION
»» CMP WEBSITE

Biological hydrogen production for a sustainable energy economy - Development and application of dark fermentation for hydrogen production

dark fermentation, biohydrogen, wastewater

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Using innovative biohydrogen technology (dark fermentation), hydrogen is produced regeneratively as part of the HyTech research project (FKZ: 03EI5419A, BMWI). For this purpose, the process (2-stage) is operated on a semi-industrial scale and a comprehensive test program creates the data basis for a scale-up. The project started in August 2020 and will run for three years. The planning of the test facilities has been completed and in the next few months the test facilities will be set up and put into operation.

In the project, innovative reactor designs are being tested that increase the overall efficiency of the process through microorganism retention [1]. In addition, biogenic residual and wastewater streams are used for hydrogen production. Dark fermentation produces mainly hydrogen (H_2), carbon dioxide (CO_2) and volatile organic acids (VFA) from biomass by means of anaerobic fermentation. The process can ensure future security of supply in the field of hydrogen production and is independent of fluctuating renewable energies. In addition, previously unused biomass potentials, such as heavily polluted wastewater and residual material streams from the food and textile industries, can be made usable [2].

Finally, in addition to production, the utilization paths of the produced biological hydrogen are considered. Although existing utilization paths for hydrogen are known, they have not yet been implemented across the board. In addition, biologically produced hydrogen does not meet the quality requirements for the use in fuel cells, for example. Since the produced gas mixture is contaminated by e.g. hydrogen sulfide or ammonia, previous hydrogen utilization paths can only be used after gas purification. Within the framework of the project, a study will be conducted on the utilization possibilities and the after-treatment costs. Finally, the entire process will be evaluated ecologically and economically.

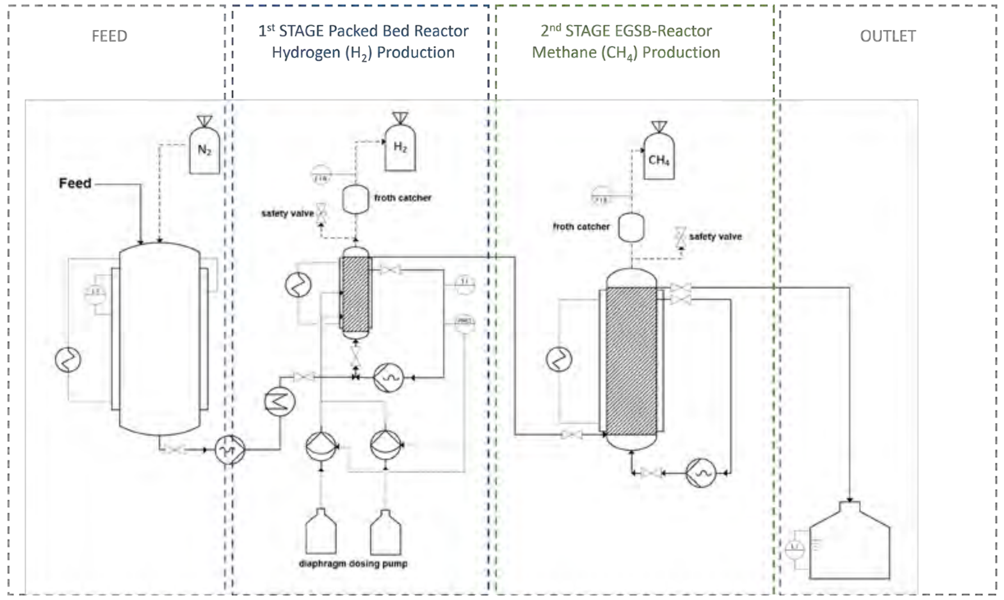

Figure 1: P&I flowsheet of one of the two planned test plants (shown here: packed bed reactor as the first stage, also planned is a separate plant with a CSTR with a biomass retention system)

Further information

Weide, T.; Peitzmeir, J.; Wetter, C.; Wichern, M.; Brügging, E. (2020): Comparison of thermophilic and hyperthermophilic dark fermentation with subsequent mesophilic methanogenesis in expanded granular sludge bed reactors. In: International journal of hydrogen energy. Doi:10.1016/j.ijhydene.2020.11.156.

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- Service

Quality has always been the focus of Awite. Since the company was founded in 2000, we have been manufacturing gas analysis systems of the highest quality according to individual requirements. More than 3300 of our gas analysis systems are installed worldwide.
The requirements of your processes take centre stage. Through our commitment and continous further development, we can offer tailor-made and high-quality gas analysis systems with and without measurements technology all the way through to the laboratory facility.

Service — seamless support
In order for you to enjoy your Awite gas analysis system for many years, we or our trained partners are happy to support you on site, by telephone, remote maintenance or email. We recommend an annual routine check of the systems combined with a calibration of the sensors. We are happy to provide all spare parts at economical conditions. Uninterrupted, safe operation of the Awite systems is important for the operation of your plant.

Desulphurisation — Never too much O_2 in the system.
The microbiological AwiDESULF desulphurisation system with fuzzy logic gives you full control over hydrogen sulphide. Sounds complicated? It is quite simple: just switch it on. The gas analysis system measures the oxygen content and the hydrogen sulphide concentration and uses this data to regulate the air supply or to add pure oxygen. Your advantages? Easy to operate, low operating costs, high process reliability.

Lab facilities
Individual, flexible, expandable. With the AwiLAB product family, we can support any kind of your research within the field of biogas. The AwiLAB Digester is a modular all-in facility in mid-scale for your laboratory. From the insulated stainless-steel digester to the control and the AwiFLEX Gasanalysis module, this high-quality product is perfect for longer-term projects.

PORTFOLIO
- more than 100 gas analysis systems installed in laboratories worldwide
- Equipped with AwiFLEX, AwiLAB Gasanalysis and AwiLAB Digester
- 6 projects in cooperation with DBFZ

ACTIVE IN FOLLOWING COUNTRIES
www.awite.de/en/unternehmen/vertriebspartner/

FURTHER INFORMATION
www.youtube.com/channel/UCI5WJ7H4lizylw7bndgP5Og?view_as=subscriber

BayWa r.e. Bioenergy GmbH

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Through the BayWa Group, our expertise and experience working with the agricultural community stretches back over decades. We have helped design, develop, construct, commission and successfully run bioenergy plants across Germany and into wider Europe.

Adding value at every stage, we provide the full bandwidth of services, ranging from full-service plant management contracts over feedstock management to bookable on-spot expertise for solving biological or technical problems.

KEY MESSAGE
Turning bioenergy into a success

FOCUS TOPICS
- Planning and technical consultancy
- Project development
- Turnkey construction
- Feedstock management
- Digital solutions for biogas operations

PORTFOLIO
References in the field of monitoring & process control of anaerobic digestion processes
- Repowering project Pliening; retracing Germany's first biomethane plant into success
- Monitoring the entire biogas portfolio with one manufacturer independent system

ACTIVE IN FOLLOWING COUNTRIES
- Europe

FURTHER INFORMATION
https://www.baywa-re.de/en/bioenergy/

NAME OF THE COMPANY
BPC Instruments AB
(former: Bioprocess Control Sweden AB)

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BPC Instruments AB

BPC Instruments AB (former Bioprocess Control AB) is a Swedish-based technology company that develops and sells automated, analytical instruments that allow for more efficient, reliable and higher quality research and analysis in a wide range of industries. The result is significant reductions in time and labour and more efficient use of manpower resources.

KEY MESSAGE

Smart Instruments for Smart People

FOCUS TOPICS

BPC Instruments AB markets solutions for a range of applications including biogas production, animal nutrition, bioplastics and biodegradability, bioethanol production, wastewater treatment and biohydrogen production.

PORTFOLIO

- Automatic Methane Potential Test System (AMPTS II)
- BioReactor Simulator (BRS)
- Gas Endeavour (GE)
- BPC Go

BPC Instruments products have been widely used by both academic and commercial actors who have benefited from significant improvement in data quality and labour savings. A selection of scientific articles, in which our smart analytical instrument was used, is listed at our website.
https://bioprocesscontrol.com/scientificreferences/

ACTIVE IN FOLLOWING COUNTRIES

Based on our recent statistics, BPC Instruments AB has over a thousand customers from nearly 500 organizations in 70 countries, covering both academic research institutes and industrial players in biogas sector. Currently, there are about 800 scientific publications based on data generated by our smart instruments and more are added each month.

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BlueSens – Gas Sensor GmbH

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Bluesens Gas Sensor GmbH

BlueSens Gas Sensor GmbH – we are the experts for gas analysis. Thousands of projects and processes worldwide that serve sustainability are equipped with BlueSens sensors. Besides food, feed and pharma, the fields of application range from the optimization of biogas and bio-H_2 production, to tasks in the areas of wastewater and waste treatment or the control of algae processes. BlueSens gas measurement technology is there wherever competence and quality are required. Founded in 2001, BlueSens is the market leader when it comes to gas measurement technology for the bioprocess industry. No matter if sensors for single gases (CH_4, O_2, CO_2, H_2, EtOH), like the well-known »blue mushrooms« or sensors that can measure two gases at the same time (BlueVary e.g. CO_2/CH_4; BlueInOne CO_2/O_2). Especially for the biogas sector, we also offer modular analysis sets (Yieldmaster), whose high-quality components are individually assembled at the customer's site depending on the task at hand.

KEY MESSAGE

BlueSens – Quality Gas Measurement Technology

PORTFOLIO

- https://www.bluesens.com/products/gas-analyzers

ACTIVE IN FOLLOWING COUNTRIES

- worldwide

FURTHER INFORMATION

Follow us on:

- Linkedin,
- Twitter,
- Facebook,
- Youtube

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Boreal Europe BV

Boreal Europe BV specializes in measuring gases with laser technology. The measurements are fast, accurate and can be used in process, emission or background measurements. Target gases are CH_4, CO_2, CO, NH_3, N_2O, HCl and many others.

It is possible to measure gases at different locations and in different ways, combination of process, ambient emission is possible with one analyser system.

KEY MESSAGE

Precise measurements, sure decisions.

FOCUS TOPICS

- Development, production and sales of laser-based gas sensing instruments in the NIR and beyond. Mainly based on tuneable diode laser spectroscopy

PORTFOLIO

- BOKU Vienna
- DFBZ Leipzig

ACTIVE IN FOLLOWING COUNTRIES

- Europe
- Middle -East

NAME OF THE COMPANY
Institute for Biogas,
Waste Management and Energy

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Institute for Biogas, Waste Management and Energy

The Institute of Biogas, Waste Management and Energy is established as a contribution to finding a more sustainable way of living and to aid climate protection. With scientific analyses, expert advice, appraisal reports and knowledge transfer based on many years' experience we do:

- Concepts for a feasible future for existing biogas plants – also after phase out of feed in tariffs
- Consulting for industrial and political decision-makers
- Independent expert evaluations
- Development and evaluation of in-depth technical and economic concepts
- Cooperative analysis for identifying and resolving weak points in plant operations
- Concept and execution of seminars, conferences and expert presentations
- Coordination and execution of scientific work in national & international research projects
- Greenhouse gas emission calculations

KEY MESSAGE

We do our work based on the conviction that biogas technology will play an important role in the future and help to protect the livelihood of future generations.

FOCUS TOPICS

- Biomethane – Technology & Use
- System Integration
- Biogas Process Biology
- Knowledge Transfer
- Biogas Weak Point Analysis…

PORTFOLIO

- Process modelling application in large scale
- Process monitoring and biological process control

ACTIVE IN FOLLOWING COUNTRIES

- Germany
- Scandinavia
- Brazil
- China
- Luxembourg

FURTHER INFORMATION

- https://www.ibbaworkshop.eu/communicating-biogas-second-edition/
- https://www.kraftstoffvergleich.de/

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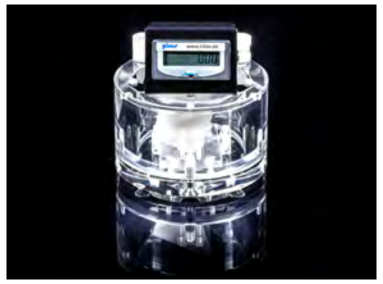

Dr.-Ing. Ritter Apparatebau GmbH

RITTER Engineering has been successful in the manufacture of measuring instruments as well as in the field of thermoplastic engineering for 70 years. In addition to innovative modular Multi-Gas Sensors and Biogas Batch Fermentation Systems, RITTER manufactures Gas Meters made out of various superior thermoplastics and high grade stainless steel, which are used world-wide in research & development laboratories as well as in industry. These meters can be used for volumetric measurement of even highly aggressive gases with laboratory precision.

Products for Biogas R&D:

- Biogas Batch Fermentation System
- MilliGascounter
- PMMA Fermentation Bottle
- CO_2 absorption bottle
- Gas analysis with NDIR / NDUV gas sensors
- Drum-type gas meters

KEY MESSAGE

Precision matters - Made in Germany

FOCUS TOPICS

- Volumetric measurements of biogas, medium and highly aggressive gases
- Biogas batch fermentation systems
- Gas analysis with NDIR / NDUV gas sensors

PORTFOLIO

- R & D labs
- Universities
- Service labs and pilot plant manufacturers for biogas

ACTIVE IN FOLLOWING COUNTRIES

- Word-wide, see https://www.ritter.de/en/worldwide

FURTHER INFORMATION

- Products: https://www.ritter.de/en/products

NAME OF THE COMPANY
Rytec GmbH
Engineering für Abfalltechnologie + Energiekonzepte

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Rytec GmbH

Rytec offers a unique combination of innovative engineering, market know-how and experience in planning, construction and operation of plants. We develop your ideas to process engineering plants in the energy and waste sector up to commissioning or we adapt existing plants to new requirements.
Our extensive experience in plant engineering for biogas production, biological and thermal waste treatment, energy technology, and waste and landfill technology is transferred into customer-specific solutions. With innovations and future-oriented business models in the circular economy and energy industry, we support the development of new business opportunities and improve revenue for our customers.
In addition to the planning and construction of plants, we also offer the operation of landfills, CHP plants, fermentation plants, biomass power plants and wastewater treatment plants.

Rytec's employees are committed to developing solutions that meet the customer's requirements technically, ecologically and economically in long-term operation and have a high level of functionality. We look forward to your exciting projects - which we are happy to lead to success with you for a sustainable future.

Rytec is mainly active in Germany and France. There is a close exchange and cooperative projects with Rytec GmbH in Switzerland.

FOCUS TOPICS

Within the waste treatment and energy sector we offer:

- Engineering
- Plant construction
- Service and operation
- Consulting

ACTIVE IN FOLLOWING COUNTRIES

- Germany
- France
- Switzerland

UMWELTLEISTUNGEN
Umwelt- und Ingenieurtechnik GmbH Dresden

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UMWELT- UND INGENIEURTECHNIK GMBH DRESDEN

UIT GmbH Dresden is a Germany-based technology company which develop and sells bio gas test plants, bioreactor systems, pilot plants for bio gas applications and technology scale plants. Our services range from the planning and design of complex plants to their finished turnkey construction. We offer standard lab plants and realize also customer specific technical solutions.

KEY MESSAGE

Technology pro Environment

FOCUS TOPICS

- Laboratory bioreactor test plants
- Pilot bioreactor test plants
- Technology scale plants
- Automatization of bioreactors and pilot plants
- Pump systems – feeding and discharge
- Gas quality analysing / pH-control

PORTFOLIO

- Universities and university of applied sciences
- National research institutes
- Bio gas company's and technology developer
- Biotec research company's
- Producer of nutrients; enzymes; supplements

ACTIVE IN FOLLOWING COUNTRIES

- Germany, Europe
- Africa
- America
- Australia
- Asia

FURTHER INFORMATION

https://youtu.be/3kGTE0IFB2s

FURTHER INFORMATION

Organizing institutions

DBFZ Deutsches Biomasse-forschungszentrum gGmbH

The work of the DBFZ is centered on politically relevant issues, such as how the limited availability of biomass resources can contribute in the most efficient and sustainable manner to existing, as well as future energy system. The DBFZ monitors and evaluates the most promising fields of application for bioenergy in theory and practice, supported through various collaborative research projects, carried at both national and international level, with partners and stakeholders ranging from industry, academia and various scientific research associations. The project orientated research provides scientifically-based results to support informed decision making governmental and non-governmental organizations, and adjacent industrial sectors in the energy, agriculture and forestry, while also identifying areas for further research. The scientists of the DBFZ are represented as experts in bioenergy research due to their excellent technical expertise and their presence in numerous national and international committees.

Helmholtz Centre for Environmental Research

As an international competence centre for the environmental sciences, the Helmholtz Centre for Environmental Research (UFZ) investigates the complex interactions between mankind and nature under the influence of global change. In close cooperation with decision-makers and stakeholders, scientists at the UFZ develop system solutions to improve the management of complex environmental systems and to tackle environmental issues. The Helmholtz Centre for Environmental Research - UFZ was established in 1991 and has more than 1,100 employees in Leipzig, Halle/S. and Magdeburg.

LHL - The Hessen State Laboratory

We are point of contact for Hessian consumers at our locations in Gießen, Kassel, Bad Hersfeld, Frankfurt and Wiesbaden. Our scientific staff carries out tests and analyses, gives expert opinions as well as provides advisory services for you on-site. We cooperate closely with state veterinary and consumer protection offices and thus monitor consumables from along the food production chain… from field to plate.

Autum 2021

Next Status Conference

Biomass energy use

Since 2009, the participants of the programme and research network Bioenergy meet regularly at the status conference. As of 2012, this network meeting has been opened up to a broader public.

CALL FOR PAPERS UNTIL END OF APRIL 2021.
www.energetische-biomassenutzung.de/veranstaltungen/statuskonferenzen

CMP

Biomass energy use

www.bioenergie-events.de/cmp