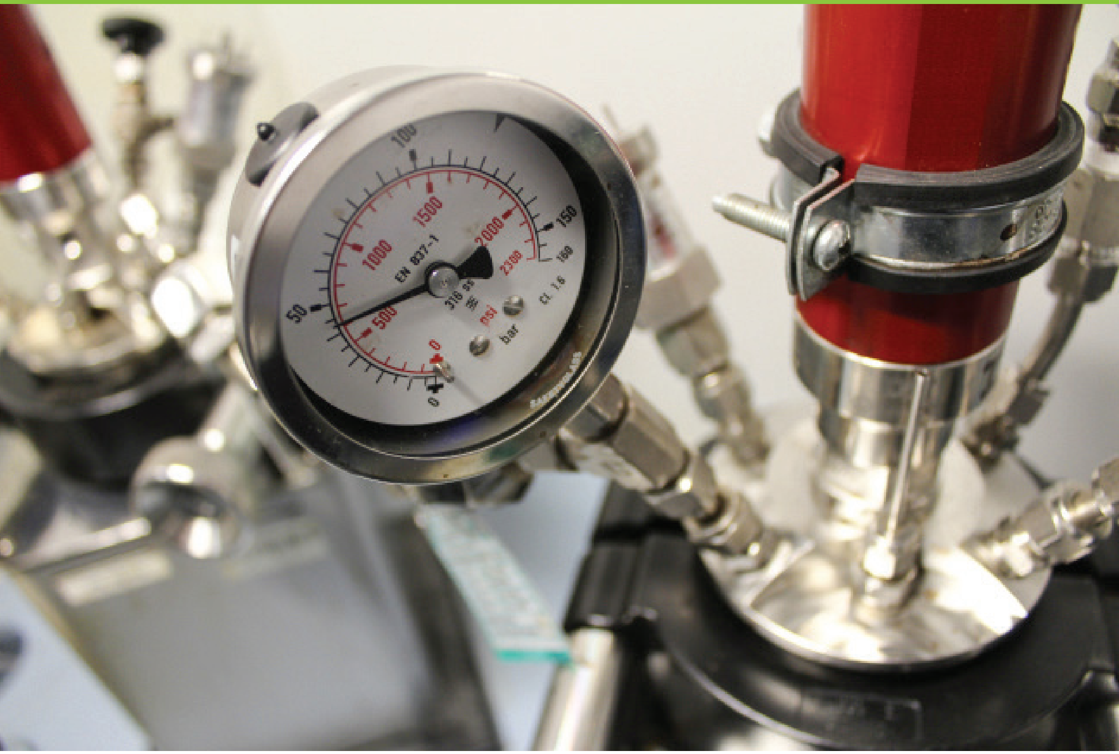
Deutsches Biomasseforschungszentrum

VI. CMP

International Conference on Monitoring and Control of Anaerobic Digestion Processes



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VI. CMP
22/23 March 2023 in Leipzig, Germany

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VI. CMP

International Conference on Monitoring and Control of Anaerobic Digestion Processes

22/23 March 2023 | Leipzig, DBFZ

Programme, 22 March 2023

REGISTRATION & OPENING

9:00 - 10:00	**REGISTRATION**
10:00 - 10:30	**Conference Opening** Dr. Jörg Kretzschmar (DBFZ) & Prof. Dr. Sören Weinrich (DBFZ / Münster University of Applied Sciences)

MICROBIOLOGY SESSION

10:30 - 11:00	**Impact of phenyl acid on the anaerobic digestion process** Dr. Andreas Otto Wagner (University of Innsbruck)
11:00 - 11:30	**Monitoring of Antibiotic Resistance Genes and Microbial Communities in mesophilic and thermophilic Anaerobic Digestion Systems** Zhe Cheng (Helmholtz Centre for Environmental Research – UFZ)
11:30 - 12:00	**Degradation of hardly degradable carbohydrates in a two-stage anaerobic digestion plant mainly takes place in the second fermenter** Prof. Dr. Dirk Benndorf (Anhalt University of Applied Sciences)
12:00 - 12:30	**Coupling synthesis gas fermentation and chain elongation for the production of green chemicals** Dr. Heike Sträuber (Helmholtz Centre for Environmental Research – UFZ)
12:30 - 13:30	**LUNCH**

MONITORING & CONTROL SESSION

	Flexible biogas production through phase separation:
13:30 - 13:45	**1. Potential of dissolved hydrogen monitoring for improved process operation** Eike Janesch (TU Berlin)
13:45 - 14:00	**2. A novel method for a highly sensitive dissolved hydrogen measurement** Jens Zosel (KSI Meinsberg)
14:00 - 14:30	**A simple method of assessing viscosity of biological slurries** Dr. Alastair Ward (Aarhus University)

14:30 - 15:00	**Implementation of model estimation and discrete feedback control theories for flexible biogas production** Lingga Aksara Putra (Technical University of Munich)
15:00 - 15:30	**Extended and Unscented Kalman Filter Design for mass-based ADM1 Simplification** Simon Hellmann (DBFZ)
15:30 - 16:00	**COFFEE BREAK**

PILOT-SCALE & INDUSTRY SESSION

16:00 - 16:30	**Biogas upgrading in a pilot-scale trickle bed reactor** Carolina Feickert Fenske (Technical University of Munich)
16:30 - 17:00	**HyPerFerment II – Hydrogen from Biomass** Dr. Fabian Giebner (Fraunhofer Institute for Factory Operation and Automation IFF)
17:00 - 17:10	**Plants and Services for industrial water** Thomas H. Weißer (EnviroChemie GmbH)
17:10 - 17:20	**Correlation of Total Plant Energy Usage with used total substrate Mixture** Karlheinz Meier (Vorn Bioenergy GmbH)
17:20 - 17:30	**Biogas Batch Fermentation System** Dr. Joachim Ritter (Dr.-Ing. Ritter Apparatebau GmbH & Co. KG)
17:30 - 17:40	**Mobile Gas Leak Detection Solutions, Novel platform reduces risk, increases safety, and decreases waste** Robert Gast (ABB)
17:40 - 17:50	**Automated platforms for optimisation of biogasproduction** Mihaela Nistor (BPC Instruments AB)
17:50 - 18:00	**Closing of the first day** Dr. Jörg Kretzschmar (DBFZ) & Prof. Dr. Sören Weinrich (DBFZ / Münster University of Applied Sciences)
19:00 - 23:00	**CONFERENCE DINNER**

Programme, 23 March 2023

OPENING

08:45 - 09:00	**Opening second conference day** Dr. Jörg Kretzschmar (DBFZ) & Prof. Dr. Sören Weinrich (DBFZ / Münster University of Applied Sciences)

MODELLING SESSION

09:00 - 09:30	**Modelling of an acidogenic anaerobic fixed-bed reactor with a dynamic model descretized by Method of Lines** Dr. Pâmela T. Couto (University of São Paulo Brasil / NRAE French National Institute for Agriculture, Food and Environment)
09:30 - 10:00	**Optimization of an HRES Energy System with Biogas-Plant with flexible-demand driven biogas production** Dirk Kirchner (University of Leipzig)
10:00 - 10:30	**Smart process control of an anaerobic digester using Machine Learning algorithms** Hans Gelten (Saxion University of Applied Sciences)
10:30 - 11:00	**Model-based Prediction of Dynamic Methane Production at Laboratory-Scale with Machine Learning** Alberto Meola (DBFZ)
11:00 - 11:30	**COFFEE BREAK**

POSTER SESSION

11:30 - 12:30	**Microbial changes during OFMSW acid fermentation under different pH** Simón González-Martinez (National University of Mexico)
	Digesting organic waste with a new PFR reactor concept Dr.Simon Hageman (Saxion University of Applied Sciences)
	Regeneration of gas separation membranes Lars Jaspers (Saxion University of Applied Sciences)

	Disentangling the Influence Factors on Biogas Production from Pig Manure Jurek Häner (Münster University of Applied Sciences)
	tba Prof. Dr. Jakub Mazurkiewicz (Poznan University of Life Sciences)
	Development of a packed foam bed bioreactor for biological methanation Mohideen Abu Hanifa Sultan Mohideen (Otto von Guericke University Magdeburg)
	Methane production from fermented cacao waste husks Fabiany Morgado (National University of Mexico)
	Effects of phenyl acids on the active AD community at different pH conditions. Eva Maria Prem (University of Innsbruck)
	Biological Hydrogen Production for a Sustainable Energy Economy – Development and Application of Dark Fermentation for Hydrogen Production Juliana Rolf (Münster University of Applied Sciences)
	Modelling of anaerobic digestion process stability on the basis of chemical equilibria Nguyen Van Than (University of Wismar)
	Optimization pipeline tuning for ML-based anaerobic digestion predictive models Klara Maria Wolf (DBFZ)
	The glutamyl tail-length of the cofactor F420 in the methanogenic Archaea Methanosarcina thermophila and Methanoculleus thermophilus Mathias Wunderer (University of Innsbruck)
	A potential approach for the integration of biogas plants into cross-industrial systems Jonathan Heil, Nestor Patient Tchamba Sefekme (Fraunhofer UMSICHT)
12:30 - 13:30	**LUNCH**

Programme, 23 March 2023

BATCH SESSION

13:30 - 14:00	**Better BMP – Free resources for improving the quality of biochemical methane potential tests** Dr.-Ing. habil. Konrad Koch (Technical University of Munich)
14:00 - 14:30	**Towards improving the estimation of the kinetic parameter in BMP tests** Matthias Steindl (Bavarian State Research Center for Agriculture)
14:00 - 15:00	**Comparative Model-based Estimation of Biochemical Methane Potential and Degradation Kinetics in Batch and Continuous Operation at Two Scales** Manuel Winkler (DBFZ)
15:10 - 15:30	**Optimizing the energy recovery from agricultural-based digestates** Cristiane Romio (Aarhus University)
15:30 - 16:00	**Closing** Dr. Jörg Kretzschmar (DBFZ) / Prof. Dr. Sören Weinrich (DBFZ / Münster University of Applied Sciences)

Editorial

Dear anaerobic digestion enthusiasts and esteemed colleagues,

 

after several years with numerous online meetings and also an exclusively online VI. International Conference on Monitoring & Process Control of Anaerobic Digestion Processes (CMP) in 2021, we are more than happy to welcome you again in person to the VI. CMP in Leipzig. With both, a complete new organizing team and a new conference venue in the main building of the DBFZ, we hope to give our small but beautiful conference series an appropriate restart.

Beside the organizational changes, we tried to follow the footsteps of the conference and prepared a program that covers core topics of the CMP, but added a few highlights to make it a memorable event. Consequently, there will be established sessions on microbiology, modelling, monitoring and control of anaerobic processes. As usual, we included a session on critical evaluation of anaerobic batch tests. New highlights come from the pilot-scale and industry session at the first day. Here we give companies the chance to present their latest developments and share their insights from the real world of anaerobic digestion in ten-minute-presentations. Some of the companies are conference sponsors to whom we would like to express our severe thanks for the continuing support of the conference. Furthermore, there will be a poster session with short spotlight presentations to give every active participant of the conference the opportunity to present their work to the audience. We hope you will enjoy the programme and we wish you lively discussions with colleagues and old friends during the conference dinner and all conference breaks.

Our severe thank goes to the organizing team and all members of the scientific committee who have made a significant contribution to the success of this conference. We wish you an exciting conference and hope that you will take new impressions from anaerobic digestion research and development home with you!

Yours sincerely,

Jörg Kretzschmar and Sören Weinrich

MICROBIOLOGY SESSION

22 March 2023 | 10:30

Dr. Andreas Otto Wagner
University of Innsbruck

Impact of phenyl acid on the anaerobic digestion process

The progressively improved exploitation of the chemically bound energy in substrates designated for anaerobic digestion (AD) increased both, biogas yields and the risk of undesired by-product formation due to improved substrate disintegration, which can cause severe disturbances during the cascade-like working anaerobic degradation process. Thus, restricted biogas performance and (tremendous) financial problems may result. Phenyl acids (PAs) like phenylacetate, -propionate and/or -butyrate (PAA, PPA, PBA) are suspected of having negative effects on AD processes. These aromatic acids can emerge from substrates rich in protein or ligno-cellulose content reflecting microbial degradation products or intermediates. In lab-scale investigations it could be shown, that concentrations of up to several grams of phenyl acids can result as product of dramatic overload with phenyl acid precursor substrates.

Regarding the (negative) impact of phenyl acids on biogas production and methane yields the picture is not clear yet. Semi-continuous AD experiments applying increasing phenyl acid concentrations showed a decrease in biogas production finally resulting in a total breakdown of methane production and process failure as a result of acidification of the reactors, whereas control reactors which were not fed with any phenyl acids, showed a stable biogas and methane production.

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However, elevated phenyl acid concentrations not necessarily lead to process imbalance but may also pose an additional pool of carbon if a biogas reactor's microbial community is capable of attacking and – at least partially – degrading these molecules.

In the lab it was also possible to maintain microbial biogas production activity in mixed cultures fed with phenyl acids only. Which organisms exactly drive this degradation cascade from PAs to methane is still to be elucidated; however, investigations using methanogenic pure cultures showed an impact of (especially high concentrations of) phenyl acids on growth and methane production ability of these methanoarchaea but at the same time a high adaptation potential of these cultures.

22 March 2023 | 11:00

Zhe Cheng
Helmholtz Centre for Environmental Research GmbH – UFZ

Monitoring of Antibiotic Resistance Genes and Microbial Communities in mesophilic and thermophilic Anaerobic Digestion Systems

Introduction: Animal husbandry is a crucial sector using antibiotics. Livestock manure is a common substrate for large-scale anerobic digestion (AD) systems. Depending on the medical treatment of the animals the manure is often contaminated with antibiotics and antibiotic resistant genes (ARGs). It was pointed out that AD systems can be potential reservoirs for multi-resistant bacteria considering the continuous load of antibiotics and various resistant bacteria from livestock manure. However, the survival of resistant bacteria from livestock could be reduced in a well-managed AD process.

Methodology: Samples from different stages of six biogas plants in Germany or Denmark were collected. Six selected ARGs (sul1, sul2, tetA, tetM, tetX, qnrD) were quantified by real-time PCR. The relative abundance of each ARG was also quantified in comparison to 16S rRNA gene concentration. In addition, the bacterial communities and methanogenic archaea communities were investigated by amplicon sequencing of 16S rRNA and mcrA genes, respectively.

Results: Among the six quantified ARGs, tetM was the most abundant one in all the stages of mesophilic biogas plants. The gene qnrD was abundant in one thermophilic biogas plant. From pig slurry or pre-tank, to main fermenter, secondary fermenter, post digester, digestate storage, it was observed that the ARG concentration was

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reduced and the relative abundance of ARGs was also reduced. However, ARGs were not completely eliminated from the biogas systems. The bacterial community or methanogenic archaea community of mesophilic biogas plants differed from that of thermophilic biogas plants. In mesophilic biogas plants, Methanobacterium, Methanobrevibacter, Methanoculleus and Methanothrix were the predominant methanogens. In thermophilic biogas plants, Methanobacterium, Methanoculleus, Methanosarcina and Methanothermobacter were the predominant methanogens. The bacterial community of pig slurry/ pre-tank was different from that of the other stages of biogas plants. In pig slurry or pre-tank, Actinobacteria, Bacilli, Bacteroidia, Clostridia, Spirochaetia and Synergistia were the most abundant bacteria. In the other stages, except for what were mentioned, Cloacimonadia and Limnochordia became predominant in mesophilic biogas plants while Dethiobacteria, Limnochordia, Thermacetogenia and Thermovenabulia became predominant in thermophilic biogas plants.

Conclusions: Biogas plants are probably not a hotspot for the spread of antibiotics and ARGs, but ARGs are not eliminated through biogas plants. The bacteria communities and methanogens differ based on whether the biogas plant is mesophilic or thermophilic.

22 March 2023 | 11:30

Prof. Dr. Dirk Benndorf
Anhalt University of Applied Sciences

Degradation of hardly degradable carbohydrates in a two-stage anaerobic digestion plant mainly takes place in the second fermenter

Productivity and biogas yield of anaerobic digesters depend on the degradation performance of their microbiomes. Spatial separation of the anaerobic digestion process into a separate open hydrolysis fermenter and a main fermenter providing optimized conditions (i.e., pH values) for microorganisms was often discussed as an option to improve the hydrolysis of complex substrates and overall process performance. However, the impact of separating hydrolysis and main fermentation on the composition, structure and functions of microbiomes wase not sufficiently understood, so far. Therefore, the process performance of a stable two-stage agricultural anaerobic digester was investigated over a period of one year, and the corresponding microbiome data acquired by metagenome-centric metaproteomics.

Technical and chemical parameters indicated a stable operating biogas process within the main fermenter but varying conditions within the hydrolysis fermenter. Accordingly, the microbiome in the hydrolysis fermenter showed more variation compared to the main fermenter. Comparative metagenome and metaproteome data analysis of abundant metagenome-assembled genomes showed that species prefer a specific substrate, although they encode the metabolic potential to break down different carbohydrates but do not exploit this at all. Further, metaproteomics

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also revealed the preferred hydrolysis of oligomeric carbohydrates and primary fermentation in the hydrolysis fermenter. In contrast degradation of complex carbohydrate (e.g. cellulose), secondary fermentation, and methanogenesis occurred in the main fermenter. Remaining methanogenic activity in the hydrolysis fermenter due to recirculation of residuals indicated the risk of methane loss in open hydrolysis. Comparative metagenomics and metaproteomics analyses showed that different species focus on specific substrates instead exploiting their full potential of metabolic pathways.

Two-stage anaerobic digesters are rarely implemented in Germany since technical and chemical parameters of a separated hydrolysis has not been shown as a clear advantage. Our microbiome analyses suggest that the rate limiting degradation of complex carbohydrates occurs mostly in the main fermenter making the use of two-stage anaerobic digesters less attractive.

22 March 2023 | 10:00

Dr. Heike Sträuber
Helmholtz Centre for Environmental Research GmbH – UFZ

Coupling synthesis gas fermentation and chain elongation for the production of green chemicals

One of the key technologies in future biorefineries will be anaerobic fermentation including microbial chain elongation, a process that can be used to convert complex organic matter such as agro-industrial waste and residues into a range of useful green biochemicals. These commodities can be integrated into different markets after converting them to, for instance, lubricants, detergents, additives for food and feed or cosmetics. Microbial chain elongation involves the controlled conversion of short-chain carboxylates (SCC) into medium-chain carboxylates (MCC) using specialized microbial consortia. Electron donors such as lactate or ethanol, provided together with the substrate or produced during anaerobic fermentation, are necessary to fuel the chain elongation. Instead of these organic electron donors, syngas (H2, CO, CO2) can be used to expand the substrate base, as dry biomass can thus be integrated into the technology through gasification. The combination of syngas fermentation and anaerobic fermentation of biomass can lead to the more efficient use of waste streams and a higher yield of valuable products.
There are several ways how syngas fermentation and anaerobic fermentation of organic substrates can be coupled. One approach is to feed syngas directly into the anaerobic fermentation process, for which mixotrophic bacterial communities are needed. In our study, we operated a mixotrophic gas recirculation reactor with H2/CO2 or H2/CO/CO2 and a mix of acetate and lactate simulating an organic substrate. We found that the bacterial communities efficiently utilized both syngas and organic substrates to produce SCC and

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MCC. The biggest challenge was the misrouting of the gaseous compounds to methanogenesis. By inhibiting methanogens with ethylene and CO, the microbial community shifted to a community dominated by Clostridium sensu stricto 12, Eubacterium and Colidextribacter. The relative abundance of species related to the mixotroph Clostridium luticellarii JA3 correlated positively with the formation of caproate and iso-butyrate and the consumption of H2 and CO. In experiments with corn silage as organic substrate in presence of syngas at different CO ratios, 9 kPa CO inhibited chain elongation, however, the presence of formate alleviated this inhibition. This effect was explained by the replenishment of reducing equivalents provided by formate reductase, which kept the chain elongation running. Higher CO partial pressures led to an increase in the overall carboxylate yield and turned the anaerobic fermentation from a carbon-emitting into a carbon-fixing process. However, chain-elongating genera were displaced by lactic acid bacteria such as Lactobacillus, Weissella and Enterococcus, and mainly SCC (acetate and propionate) were formed.
Overall, the anaerobic fermentation of biomass coupled with syngas fermentation represents a promising approach for the production of green chemicals from diverse feedstocks. The selection of mixotrophic bacterial communities that can efficiently utilize both organic and inorganic carbon sources will be crucial for the success of this technology in biorefineries, which can help reduce our reliance on fossil resources and move forward to a circular economy.

MONITORING & CONTROL SESSION

22 March 2023 | 13:30

Eike Janesch
TU Berlin

Flexible biogas production through phase separation: potential of dissolved hydrogen monitoring for improved process operation

Energy from biogas has the potential to balance seasonally fluctuating production of wind and solar energy to a certain amount if the process mode can be made more flexible. Therefore, process modifications to increase the controllability of the biogas synthesis and the flexibilization of the substrate use have to be found. In the „ProPhaSep" project, a two-stage anaerobic digestion reactor system on a laboratory scale was combined with a thin sludge recirculation. This allows to maintain environmental conditions for the acid-producing bacteria of the first hydrolytic/acidogenic stage and for the methanogenic archaea of the second methanogenic stage.

In this setup, 10 g/L and more of short-chain carboxylic acids are accumulated in the supernatant in the acidogenic fermenter, which are subsequently transformed into biogas (300 mL/g_{COD}) with a methane share of up to 60 %. As feedstock, a mixture of maize silage and straw manure (50/50 m/m) was continuously fed.
Hydrogen plays a key role in biogas production, since hydrogenotrophic methane production requires hydrogen transfer between the hydrogen-producing bacteria and the hydrogen-consuming archaea. In case of a two-stage system, the exchange of hydrogen has to happen via the head-space and, to a minor extent, the dissolved hydrogen in the liquid phase. In addition, externally generated hydrogen can be fed

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to the digestion process in order to boost methane production.

Since the cell suspension of archaea can primarily consume the dissolved hydrogen, its concentration and distribution in the culture broth is of particular importance. With regard to power-to-gas and carbon capture concepts, in which green hydrogen is fed into the methanogenic stage together with carbon dioxide for methane production, the dissolved gas measurement is becoming increasingly important. Therefore, a novel sensor for the quantification of dissolved hydrogen in the liquid phase was applied in both process stages. The system consists of a membrane-free extraction chamber and a metal oxide sensor for hydrogen detection.

The measuring device was successfully integrated and tested in the two-stage anaerobic digestion process under fluctuating feedstock load and power input. The sensor shows a fast and precise response to the dynamic changes of the process operation. Currently, the boundaries of flexibility with respect to methane production by the external addition of hydrogen to the methanogenic stage are explored as well as the role of dissolved hydrogen for improved process monitoring and control.

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22 March 2023 | 13:45

Dr. Jens Zosel
KSI Meinsberg

Flexible biogas production through phase separation: a novel method for a highly sensitive dissolved hydrogen measurement

Hydrogen is a cofactor in many microbial transformation processes and therefore important to achieve a high product yield. In stable multistep biogas fermentation processes, this low solubility dissolved gas occurs usually at partial pressures below 10 Pa. Thus, the provision of cells with sufficient hydrogen is crucial. Often, a trade-off has to be established between the power input and the availability of dissolved hydrogen for a cell.

The measurement of dissolved hydrogen in biogas fermentation media is complex, because it is conducted at side conditions, which disturb stability and precision of the measured value. These concern biofilm formation on sensitive surfaces as well as hydrogen consumption on surfaces in the fermenter headspace with access to traces of oxygen. It could be shown in the past that unreliable measurements caused by these issues can be avoided successfully by enabling a membrane-free extraction of dissolved hydrogen into a clean chamber before its detection. This chamber is rinsed with a constantly flowing carrier gas, which is analyzed subsequently concerning its hydrogen concentration. Initially an automated chromatographic system was used for this task, which is highly sensitive and selective but requires a high installation effort and relatively high investment costs.

This contribution describes a new approach for the measurement of dissolved hydrogen in biogas culture broth by using semiconducting metal oxide gas sensors

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(MOX). These low cost sensors can be installed with a significantly diminished effort compared to chromatographic systems. Unfortunately, these sensors usually degrade within days when they are in direct contact with biogas. Therefore, within this new approach they are combined with a miniaturized fluidic arrangement based on a small gas-flushable chamber for the MOX. This chamber is connected to a gas supply and an extraction volume via solenoid valves. The gas supply provides humidified air or a calibration gas with known hydrogen concentration during the periods, when the dissolved hydrogen in the fermentation media equilibrates with the gas atmosphere in the extraction volume through a membrane-free gas/liquid boundary. After complete equilibration (ca. 60 min), the flushing gas flow through the sensor chamber is interrupted and the connection between sensor chamber and extraction volume is opened for 90 s to allow the extracted hydrogen to diffuse into the sensor chamber. The peak of the sensor signal after this opening is a stable measure for the hydrogen partial pressure in the fermentation media. After the diffusion step, the extraction volume is filled with fresh air again and the next equilibration/measurement cycle starts.
It could be shown that this newly developed sensor system provides quasi-continuous measurements of dissolved hydrogen partial pressure with highly stable and precise values in the range between 0.1 and 200 Pa in biogas culture broth for more than 1,000 h.

22 March 2023 | 14:00

Dr. Alastair James Ward
Aarhus University

A simple method of assessing viscosity of biological slurries

Viscosity is an important factor when handling biological slurries. A basic rule-of-thumb has been that viscosity correlates with dry matter, yet there are complex interactions between particles in slurries, including the particle size distribution, the shapes of particles and electrostatic charges that make dry matter a less good fit to laboratory measured viscosity values. Manure and digestate are non-Newtonian slurries, where the viscosity is dependent on the shear rate. More specifically, these materials are described as shear thinning or pseudoplastic (the apparent viscosity decreases with increased stress). In this study, a method of measuring viscosity in a simple way has been examined. The method is suitable for industrial-scale processes where relatively large sample sizes allow for a more representative measurement without the need for expensive laboratory equipment nor specifically trained personnel. The method has been correlated with data obtained from a laboratory viscometer (Brookfield DV2T) and a particle size analyser (Mastersizer 2000) and dry matter measurements. The method was specifically developed for the examination of manure and digestate soil infiltration during field application and how this affects ammonia emissions. However, the viscosity of typical pre-biogas slurry substrates is also of interest in terms of pumping and mixing within a biogas plant, and the process factors that may influence viscosity have been examined.

The simplified measurement method consists of an acrylic tube (44mm internal

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diameter) which can be set at a variety of angles, with a ball valve at the upper end and a feeding tube above that. Two sets of photoelectric sensors were positioned on the tube with 1700mm between them. Slurry is loaded into the feeding tube; the ball valve is opened and the time difference between the triggering of the upper and lower sets of photoelectric sensors is measured.

As the substrates were non-Newtonian, the viscometer had to make measurements at a range of shear stresses, thus producing curves. Power models were fitted to reduce the curves to a consistency coefficient (k) and a flow behaviour index (n) for correlating to other data.

From preliminary data analysis, dry matter correlated rather poorly with both k and n values, (R^2 = 0.299 and R2 = 0.265, respectively) and slightly better correlations of particle sizes >2mm (these were separated before the Mastersizer) were obtained for k (R^2 = 0.419) and n (R^2 = 0.325). A relatively good correlation of the tube time difference with k value (R^2 = 0.773) was found, while this measurement correlated very poorly with the n value (R^2 = 0.068). Substrates varied widely in their viscosities, as manures, whole digestates and liquid fractions (following separation) were examined, leading to strong weighting of the relatively few high viscosity samples. Deeper analysis of the data is being conducted, possibly dividing the materials into separate groups based on viscosity.

22 March 2023 | 14:30

Lingga Aksara Putra
Technical University of Munich

Implementation of model estimation and discrete feedback control theories for flexible biogas production

Gas prices have been volatile in Europe due to exceptionally tight supply-demand balances in energy markets. To be competitive in such volatile markets, switching biogas production from constant to demand-driven would be the best option. This requires the development of an algorithm. Considering that a biogas plant is a complex system, the algorithm developed must be precise and advanced enough to handle it. Nevertheless, the algorithm complexity must not be excessive, since otherwise the implementation will be challenging, and the plant operators will have difficulty utilizing it. The project objective is to develop an algorithm that achieves the middle ground between the two aforementioned requirements and test it in the Grub biogas plant in Bavaria, Germany.

The main components of the algorithm are an estimation model and a feedback control system. The biogas plant is modeled using mathematical connections between a step change in input (substrate feeding rate) and the resulting step response in output (biogas production flow rate).

The six estimation methods used in this project are PT1-Approximation using 63%-method, Time percentage, Turning tangent, Sum of time constants, PT1-estimator (coefficients estimation of a first-order difference equation), PT2-estimator (coefficients estimation of a second-order difference equation). Out of six estimation methods, the PT1-Approximation using 63%-Method delivers the

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best result, with a 99% correlation coefficient (R^2) between the estimated model and the measured gas production flow rate.
Based on this estimated model, a feedback control system is developed. By using this feedback control system, biogas plant operators can determine which and how much substrates they need to use to achieve the desired biogas production rate in the future.
A feedback control system was developed for this project that needed to be straightforward enough to be implemented in an open-source programming language, but advanced enough to control a complex, discrete system with manipulated variable constraints. The two controllers used in this project are the Deadbeat-Controller and the discrete PI-Controller with root locus and anti-windup modifications. The latter controller is capable of finding an optimal substrate feeding schedule, resulting in the gas production flow rate reaching the set point quickly and efficiently, without overshooting, and under the manipulated variable limits. This controller will provide plant operators with daily and three-hourly feeding schedules, which can be applied to biogas plants to achieve the desired gas production flow rate.
Additionally, the entire algorithm has been presented with a Graphical User Interface (GUI) to make the process more user-friendly.

22 March 2023 | 15:00

Simon Hellmann
Deutsches Biomasseforschungszentrum

Extended and Unscented Kalman Filter Design for mass-based ADM1 Simplification

Dynamic operation of agricultural anaerobic digestion (AD) plants requires reliable state estimators. In practical applications, there exists no direct online sensor for relevant stability indicators such as volatile fatty acids. Therefore, state estimators or soft sensors need to be developed, which use easily available online measurements and a suitable mathematical model to reconstruct individual process states. This study presents the design of Extended and Unscented Kalman Filters (EKF, UKF) which rely on a mass-based simplification of the original Anaerobic Digestion Model No. 1 (ADM1). As a prerequisite, observability of the underlying model is analyzed following a differential algebraic approach.

Weinrich and Nelles (2021) recently proposed mass-based simplifications of the ADM1 (10.1016/j.biortech.2021.125124). In the present study, the model class ADM1-R4 was slightly modified to improve practical application. More specifically, measurement equations of total and volatile solids (TS, VS) were added. The modified ADM1-R4 was analyzed for observability following a differential algebraic approach, which involves to symbolically solve a nonlinear equation system, as described in Hellmann et al. (2023) (10.48550/arXiv.2301.05068). For this purpose, we used online measurements of the gas composition as well as slowly time-varying offline measurements of TS, VS, and inorganic nitrogen. For the offline measurements,

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we assumed a sample-and-hold behavior in between measurements. Moreover, a synthetic simulation scenario was developed, which models one week of dynamic feeding with cattle manure in a pilot-scale reactor. Standard model parameters and influent concentrations were applied (10.1016/j.biortech.2021.125104). Measurement noise was considered according to data sheets of established sensor equipment. Finally, both EKF and UKF were designed based on the modified ADM1-R4. The Kalman Filter‘s tuning matrices were adjusted in accordance with best practice (10.1021/ie300415d). TBoth Kalman Filter algorithms were implemented in Matlab and tested for the synthetic simulation scenario.

The differential algebraic approach delivered a unique solution of the symbolic equation system, which suggests global observability of the modified ADM1-R4. The state estimates of the Kalman Filters were used to reconstruct the model outputs, which showed a good agreement with synthetic noisy measurements. The implemented Kalman Filters can be applied to monitor biogas quality and volume flow, as well as TS and VS of the digestate. Further research will be directed at implementing higher-order model classes such as the ADM1-R3; considering real measurement data; offline measurement latency; and joint state and parameter estimation.

PILOT-SCALE & INDUSTRY SESSION

22 March 2023 | 16:00

Carolina Feickert Fenske
Technical University of Munich

Biogas upgrading in a pilot-scale trickle bed reactor

The current energy crisis demonstrates the importance of energy conversion technologies, such as the biological methanation of H_2 and CO_2 in trickle bed reactors. Important investigations on trickle bed reactors were performed on lab-scale, but information about the upscaling and the integration of the technology on real application conditions are still limited. Therefore, a pilot-scale trickle bed reactor with a reaction volume of 0.8 m^3 was constructed and installed on a wastewater treatment plant (WWTP) to upgrade raw biogas from a local digester. The WWTP furthermore provides resources for the reactor startup and operation, such as the archaea-rich inoculum and necessary nutrients.

The pilot reactor was operated for 447 days with two standby periods, demonstrating the benefits and challenges of the technology. A decreasing pH value while volatile fatty acids accumulated indicated a partial conversion through the homoacetogenesis pathway. Sufficient ammonium and sulfur supply were identified as effective measures for a stable methanation performance. The H_2S concentration in the biogas with < 200 ppm reduced during the methanation but was probably too low to satisfy the sulfur demand of the archaea. Finally, a stable biogas upgrading with a CH_4 production of 6.1 $m^3/(m^3_{RV} \cdot d)$ with CH_4 concentrations > 98 % was maintained. Considering the inert CH_4 in the biogas, a

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high performance with a CH_4 flow rate in the product gas of up to 17.1 $m^3/(m^3_{RV}{\cdot}d)$ was reached. The results give evidence for further performance improvement, promoting energy conversion in trickle bed reactors.

22 March 2023 | 16:30

Dr. Fabian Giebner
MicroPro GmbH

HyPerFerment II – Hydrogen from Biomass

Hydrogen technologies, in combination with sector coupling, offer the potential to decarbonize sectors that cannot be electrified (e.g. the chemical industry, steel industry, etc.).

In 2030, hydrogen will account for 0.5 % of the electricity mix, according to studies by DNV. In 2050, DNV expects it to be 5 %. However, according to the Paris Agreement, at least 15 % hydrogen is required in the electricity mix.

However, expanding renewable energy and electrolysis technologies at the pace required to achieve this will be nearly impossible. Both renewables and electrolysis-ready water are critical resources that could lead to supply insecurities.

For this reason, we need new technologies for the production of hydrogen in the course of decarbonization. In the HyPerFerment project, we are focusing on the production of hydrogen from biomass and, at the same time, increasing its efficiency by coupling with existing biogas plants.

Dark fermentation is a microbial process that allows the conversion of organic substances (e.g. carbohydrates, proteins, lipids) to hydrogen (H_2) and carbon

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dioxide (CO_2). The process occurs anaerobically at 30 °C to 80 °C without light. Under the right conditions, we can produce a reasonably clean gas mixture of ≈ 50 % H2 and ≈ 50 % CO2, which contains neither methane nor any interfering components such as hydrogen sulfide.

In the HyPerFerment II project, the Fraunhofer IFF is working under the direction of MicroPro GmbH and, in collaboration with STREICHER Anlagenbau GmbH & Co. KG, is working on integrating fermentation in existing biogas plants. The plant is currently under construction and is expected to be commissioned in the spring of 2023. Initial laboratory and pilot plant scale tests, suggest a significant increase in efficiency, which is to be demonstrated in a 10 m^3 scale demonstration plant.

In the presentation, the HyPerFerment process and the current state of development will be described and underpinned by current measurement data from the laboratory and demonstration plants.

22 March 2023 | 16:30

Thomas H. Weißer
Envirochemie GmbH

Plants and Services for industrial water

When processing milk, different wastes are collected in dairies. Fat-containing sludge, sludge from wastewater treatment (WWTP) as well as product waste or whey (permeates) are treated with the Biomar Liquid Solid Digestion System.

Biogas is obtained by anaerobic microorganisms. The objective is the biodegradation of organic components into biogas for use e.g. in a steam boiler.

Dairy WWTP generates concentrated organic flotation sludge (mainly fat and grease) and excess biological sludge. In production, a significant amount of whey and expired milk is rejected. These organic products require a digestion plant for biogas production and waste reduction.
The ideal conditions for the anaerobic Biomar® LSD reactor are a homogenous environment within the entire reactor. Finely structured biomasses build up quickly. Processes necessary for decomposition benefit from the intensive contact between the contents of the sludge and the anaerobic microorganisms. A regulated distribution system within the reactor supported by a strong mixing aggregate prevents inactive zones in the reactor. A highly effective degassing unit separates biogas from sludge. Nutrients and conditioning solutions contribute to optimal operation even with inconsistent feed

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conditions. The biogas is removed from the reactor and is send to a steam boiler. The sludge is then dewatered in the existing centrifuge. The filtrate is pumped to the WWTP.

The waste volume is considerably reduced and passes through a hygienisation step before disposal. Liquid output is send to existing WWTP. 1 ton of input sludge results in a gain of 20 m^3 of Biogas. Dry matter is reduced to half of input dry matter.

The Biomar® LSD process is highly effective for treating waste containing high amounts of organic solids. It combines moderate space requirements with maximum stability and minimal chemical usage.

22 March 2023 | 16:30

Karlheinz Meier
VORN Bioenergy GmbH

HyPerFerment – Hydrogen from Biomass

As the owners and contractors for plant operations of biomethane plants we use our „BiORecs“ data system as central data hab for plant data. Therefore we have approximately 90% of all on plant sensors in the system, along with the daily combination of substrates wich are fed into the feed hopper.

As energy consumption is both an environmental and economical issue (feedstock costs total to up to 60% of a plants total costs), we use the data of 4 years of real world biomethane production to estimate the impact of different substrate mixtures on the total energy consumption of different plants.

Our preliminary results show that for a total of nearly 1500 daily energy usage measurements with a total of approx. 3 million kwh used and a total of more than 200.000 tons fed on a single plant, the mixture of how the different substrates are balanced out against each other in a constant technically set daily needed amount can statistically account for 50% of the plants energy usage in the non-upgrading parts. We will furthermore compare these findings between different time scales (weekly, monthly) and between different plants of comparable size which also produce biomethane and conclude with the comparism against 3 smaller plants which have no biomethane upgrading unit and use a significantly smaller daily feedstock number.

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22 March 2023 | 16:30

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Biogas Batch Fermentation System

No information submitted

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22 March 2023 | 16:30

Robert Gast
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Mobile Gas Leak Detection Solutions

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22 March 2023 | 16:30

Mihaela Nistor
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Automated platforms for optimisation of biogasproduction

No information submitted

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MODELLING SESSION

23 March 2023 | 9:00

Dr. Pâmela T. Couto
University of São Paulo Brasil / INRAE French National Research Institute for Agriculture, Food and Environment

Modelling of an acidogenic anaerobic fixed-bed reactor with a dynamic model descretized by Method of Lines

Research related with green hydrogen is increasing over the years due to the eminent necessity of renewable sources of energy. In this context, the development of mathematical models has contributed to a better understanding of the metabolic pathways involved in anaerobic digestion processes, thus facilitating the simulation in other scenarios. The most widely used model to describe these processes is the Anaerobic Digestion Model #1 (ADM1), which involves biochemical and physico-chemical equations in its structure. In this work, a mesophilic (25ºC) anaerobic fixed-bed reactor (AFBR) used for hydrogen production from glucose (2000 mgCOD m-3), operated during 60 days, was modelled. This reactor presented 3.5L of total volume, 0.7m of length and was composed of three parts, a mixed (0.1m), a bed (0.5m) and an effluent zone (0.1m). According to hydrodynamics tests, the AFBR behaved as a plug-flow reactor, thus the substrate and products inside the reactor changed their concentrations along time and space, configuring a system of partial differential equations (PDE) to be solved. It was assumed diffusion-convection in the mixed and effluent zone and diffusion-convection-reaction in the bed zone. Analyzing the experimental data, hypotheses about the metabolic pathways were put forward in ADM1 to describe the reaction in the bed zone: glucose → acetate + H_2, glucose → lactate, glucose → acetate + ethanol + H_2 and glucose → butyrate , lactate → butyrate + H_2, lactate → acetate + ethanol + H_2, lactate →

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propionate .These equations differ from the ADM1 originally implemented by the IWA Task group because the AFBR is an acidogenic reactor, i.e., it is an incomplete anaerobic digestion process. For PDEs, the Danckwerts boundary conditions were assumed, allowing the continuity of the flow in the initial and final sections of the reactor. The components concentration at the entrance of the reactor were updated daily according to the measurements. The model was implemented in the software Matlab R2021b and the solution of the PDE system was carried out with the method of lines (MOL). This method consists in discretizing the space using finite difference techniques such as five biased-upwind points to calculate the first derivative (convection) and five centralized points for the calculation of the second derivative (diffusion). Subsequently, the integration in time was performed by the integrator ODE15s, used to solve stiff ODEs systems, as in the case of ADM1. The model was able to describe the experimental data for substrate consumption, volatile fatty acids and hydrogen production during the reactor operation, however a refining in modelling can be achieved by the optimization of the free parameters. These results indicate that the novelties related with the incorporation of the assumed metabolic pathways and the discretization of the ADM1 were relevant, making possible to apply this discretization in future researches for different kinds of real wastewaters and plug-flow bioreactors.

23 March 2023 | 9:30

Dirk Kirchner
University of Leipzig

Optimization of an HRES Energy System with Biogas-Plant with flexible-demand driven biogas production

Island grids are often supplied by diesel Engines or oil power plants with high emissions.

With the use of HRES Energy systems with high renewable energy production content, pollution can be minimized. In this energy system, the use of a diesel engine is still necessary to balance the fluctuating energy production of wind and solar power plants. With the use of biogas plants for balancing fluctuating wind and solar power, the use of diesel engines can be reduced.

HRES standard energy System with a biogas plant used a biogas plant with continuous feed with continuous biogas production. For the balanced of the fluctuated energy production with this kind of biogas plant, a big biogas storage or a high demand of energy production of diesel engine is necessary, because the gas production and the energy need are not in time. With a biogas system with flexible demand-oriented biogas production, the necessary biogas storage and use of diesel engines can be minimized.

This study presents a method for the optimization of the size of the components of the biogas based HRES Energy system. The biogas process is modelled with

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the AM2 biogas model with acid inhibition and hydrolysis kinetics by Arzate. For optimization, particle swarm optimization is employed. The program developed at Matlab.

The result shows that in HRES energy systems through the flexible production of biogas, the production of energy from diesel engines and with that the CO_2 emissions are reduced.

With a rising of the diesel costs, it was also able to observe a reduction of the energy production from diesel engines and a rising of the energy production from the biogas plant. It was also possible to see a fall in biogas production during the summer.

23 March 2023 | 10:00

Hans Gelten
Saxion University of Applied Sciences

Smart process control of an anaerobic digester using Machine Learning algorithms

Keeping anaerobic digesters of organic waste streams stable in operation, is a challenge. Many digesters run suboptimal, with economic losses for the farmer or suppliers of biodigesters due to less conversion of circular raw materials. A recent article in 2019 presented a tailored recurrent neural network structure for learning multi-step ahead predictions of complex dynamic system.

The main objective of this study is to establish an Machine Learning model capable of predicting the anaerobic digestion process under different conditions based on data obtained from both literature review and conducted experiments.

Machine Learning enables a computer system to make predictions or make certain decisions using historical data without being explicitly programmed. Machine Learning uses large amounts of structured and semi-structured data so that a model can learn which parameter values generate accurate results in order to make predictions. For this study supervised learning is used, meaning that the model uses known data of the predicted parameter and can be checked with the real value. The algorithm first learns on a lot of data in order to be able to make predictions.

An artificial neural network consists of an input layer of neurons, one or multiple hidden layers of neurons, and a final layer of output neurons. The input layer consists of all the information supplied to the model. The number of input nodes are equal to the number of input variables. Weights are the factors between nodes that multiply the incoming

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number with its factor and forward the result to the next node. During the learning phase, the weights are being constantly changed by an optimization algorithm to find the best fit. The used reactor is a 6L test-setup, which is inoculated with micro-organisms from a well-running digester. The analytical methods carried out during this study are Chemical Oxygen Demand, dry matter content, FOS/TAC and gas composition and -production.
A mix of interpolation and extrapolation was tested by alternating between 250 training datapoints and 150 validation datapoints. In this case the model learns at different reaction conditions, but cannot use closest neighbour to make predictions. The best prediction is made with a model structure of 11 input nodes, 2 hidden layers of 16 nodes and 1 output node. The achieved RMSE was 0.089 and 49.6 % of the predictions were within 5 % of the actual gas production.
It is expected that if more parameters are measured and given as input to the model, even more accurate predictions can be made. Results show that Machine Learning gives the opportunity to anticipate a future change in analysis values and to control the feed height or additives. It is not possible with Machine Learning to let the model determine its own limits or to apply a trained model 1-to-1 to another digester. Future research focuses on testing with other Machine Learning techniques, such as an adaptive network-based fuzzy inference system or a long short-term memory/gated recurrent unit.

23 March 2023 | 10:30

Alberto Meola
Deutsches Biomasseforschungszentrum

Model-based Prediction of Dynamic Methane Production at Laboratory-Scale with Machine Learning

The possibility of using Anaerobic Digestion (AD) processes to provide demand-oriented power represents a potential solution to compensate for the irregularity of renewable energy conversion. Model-based automation procedures provide efficient and robust concepts for non-linear process optimization. Typically, the Anaerobic Digestion Model No. 1 (ADM1) is applied for AD process modelling. However, since most measurements needed for reliable model application are not available in required qualities and quantities, the established ADM1 still cannot be implemented during regular operation of industrial AD plants.

Since many dependencies and influencing factors of the AD process are still unknown, stochastic modelling techniques, such as Machine Learning (ML), show great potential for non-linear process simulation. However, prediction of dynamic process behaviour represents a challenge for data-driven models, since detailed measurements of dynamic or inhibitory process conditions are rarely available.

This study aims to evaluate the generalization capabilities of several ML algorithms for prediction of dynamic AD. Thus, two laboratory Continuous Stirred Tank Reactors (CSTRs) with a reaction volume of 12 L were operated at variable Organic Loading Rates (OLR) between 1.0 and 5.25 kg Volatile Solids (VS) L^{-1} d^{-1}. Three different substrate types (straw pellets, ProtiGrain and cattle manure) were evaluated at different feeding quantities. Training data consisted of 70 % (119 days) of the entire experiment, com-

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prising periods in which all the substrates were fed. OLR within the training data was set to 1.0, 1.5, 2.0, 3.0 and 4.5 g VS L^{-1} d^{-1}. Validation and test datasets comprise only periods with straw pellets and cattle manure feeding, with OLRs within the validation dataset set to 2.0, 2.5, 4.0 and 5.0 g VS L^{-1} d^{-1}, while it was randomly set between 2.73 and 5.25 g VS L^{-1} d^{-1} within the test data.

Biogas production rate and composition were measured online, while analyses of volatile fatty acids and pH were performed each weekday. Concentration of ammonia nitrogen (NH_4-N), total solids (TS) and VS were measured once a week. Data were resampled to daily resolution. Several ML models were tested, such as bayesian and linear regression, k-nearest neighbours and Adaboost regressor, and were all optimized through a standardized data optimization pipeline. Results show that Adaboost regressor can predict methane production one day ahead with a root mean squared scaled error (RMSSE) of 90 % for the test dataset, using sensor data, VS analysis of the substrate mix, and feeding mass of each substrate type.

This investigation demonstrates how ML models can successfully predict daily methane production from AD under dynamic process conditions. Thus, individual models can be applied to full-scale AD and set the basis for stochastic model-based control.

POSTER SESSION

22. März 2023 | 11:30 - 12:30

Dr. Simón Gonzáles-Martinez
National University of Mexico

Microbial changes during OFMSW acid fermentation under different pH

Fermentation of the organic fraction of municipal solid waste (OFMSW) is considered part of the concept of biorefinery when distinctive volatile fatty acids (VFA), ethanol, and lactic acid are target products. During the last years, VFA from fermentations has been considered a source of valuable chemicals; ethanol production from OFMSW is promising as an energy source, and lactic acid is an essential molecule in the chemical industry (Kamm and Kamm, 2004). There is limited information on how the naturally occurring microorganisms in OFMSW can be used for the aforementioned fermentations. (Jojoa-Unigarro and González-Martínez, 2023). This research analyzed OFMSW acid fermentations under different pH values to determine the fermentations‘ products and the microbial communities‘ changes under the selected environmental conditions.

A three-liter reactor with mechanical mixing, a thermal jacket and ph control was used for the experiment . The first stage started with pH 6 and 4% volatile solids in the reactor to avoid product inhibition. The HRT and SRT were the same at 6 days. The genes 16S rRNA and 18S rRNA were used mainly to characterize bacteria and eukaryotic communities.

During the first days, the OFMSW fermentation at pH 4 was selective for ethanol and lactic acid; after day three, ethanol and lactic acid production decreased, and acetic

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acid production increased. The fermentation at pH 5 was also selective to ethanol and lactic acid. The fermentation at pH 6 shows butyric acid reaches the highest concentration on day 3, decreasing slowly as acetic acid increases again due to the acetogenesis of butyric acid.

At pH 4, the genus Acetobacter is responsible for the acetogenesis of ethanol and lactic acid and the increasing acetic acid concentrations. Lactobacillus is predominant at pH 5 with 43% of the relative abundance

The molecular identification of Eukaryote microorganisms showed that OFMSW contains large amounts of yeast from the genus Pichia, which is responsible for alcoholic fermentations. These results differ from the information in the review by Hafid et al. (2017), which indicates that ethanol production is caused by organisms from the genus Zymomonas and Zymomonas was not present in this research.

The taxonomic distribution of bacteria decreases drastically at lower pH values. Genus Pichia is responsible for ethanol production. Kingdom Bacteria is responsible for VFA, lactic acid production, and acetogenesis. Acetogenesis is the main pathway accountable for decreasing lactic acid and ethanol over time.

22. März 2023 | 11:30 - 12:30

Dr. Simon Hageman
Saxion University of Applied Sciences

Digesting organic waste with a new PFR reactor concept

The Dutch Climate Agreement has the ambition to produce 70 PJ of green gas by 2030. This is equivalent to 2 billion m^3 of green gas. Currently, 230 million m^3 of green gas is produced per year in the Netherlands. This ambition indicates that the production of green gas from biomass has a long future ahead in the Netherlands. Unfortunately, some residual flows, such as low organic pig manure or thin fraction calf manure, are not yet economically profitable to convert to green gas.

HoSt, Stichting Mestverwerking Gelderland (SMG) and Saxion University of Applied Sciences focus in this project on lowering costs for anaerobic mono-digestion and green gas production. The lower costs can be achieved by reducing the CAPEX and OPEX of the anaerobic mono-digester installation. To reduce the CAPEX and OPEX a Plug Flow Reactor (PFR) is used and as a result the reactor volume and retention time decreases. Preliminary research carried out by HoSt has shown that digestion in a PFR can reduce the time needed to effectively convert thin manure into biogas, with a conversion rate of 90% in just 15 days. This is a significant improvement of the retention time compared to the 45 days that is required for anaerobic mono-digestion using a conventional stirred tank reactor (CSTR). In the total process, calf manure is first separated into a thin and thick fraction. The thick

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fraction is digested in a CSTR. The thin fraction is digested in a PFR. In this way, the overall CAPEX and OPEX will decrease by 13,3% and 0,5% respectively.
First, a 100L PFR lab-scale setup is designed, built and tested. The lab-scale PFR provides insight into plug flow digestion mechanisms applied to different types of thin manure. The small-scale PFR offers the possibility to test and optimize process parameters relatively easily. The performance of the 100L lab-scale PFR is compared to the performance of a conventional 100L lab-scale CSTR reactor. Second, a 100,000L PFR pilot-scale is designed, built and put into operation. The purpose of this is to test the PFR on a larger scale to gain more insight into PFR fermentation by monitoring gas production, HRT, SRT, etc. Finally, an economically feasibility analysis is carried out.

The result of this project is the reactor design, construction and techno-economic analysis of a PFR digester with thin manure fraction as substrate. The aim is to achieve a cost reduction of 5 €/MWh green gas. The cost reduction enables the use of low-organic-content manure

22. März 2023 | 11:30 - 12:30

Lars Jaspers
Saxion University of Applied Sciences

Regeneration of gas separation membranes

Biogas upgrading via membrane technology from biogas (~60% methane, ~40% carbon dioxide) to high methane concentration (99%) is technically feasible. The high 99% concentration methane is used to produce green gas (~82% methane). Although cost savings of up to 25% have been achieved through standardization of the membrane technology in recent years, further cost reduction for gas processing (in OPEX and CAPEX) within the current membrane configuration seems to be impossible.

Bright Renewables in Enschede (NL) and Saxion University of Applied Sciences want to lower the Dutch subsidy by developing and demonstrating a new gas reprocessing process. The new gas reprocessing process consists of a two-stage operation with a CO2 separation technique (liquefaction), with 0% methane loss. A reduction in the number of membranes requires a smaller compressor and lowers the CAPEX. However, an investment in a new CO_2 two-stage separation technique increases the overall CAPEX minimally. In contrast to CAPEX, operating costs (OPEX) in the form of electricity consumption, membrane replacement costs and methane loss decreases sharply. The net result of this two-stage separation technique is a saving of 1 euro per MWh to produce green gas.

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For the two-stage upgrading with CO_2 separation technology, CO_2 liquefaction is used after a single membrane separation step. Temperature and pressure are maintained at a point where CO_2 becomes liquid and CH4 remains in gaseous form. This enables a gas-liquid separation process.

This project also focusses on membranes cleaning. With the current cleaning method the original membrane quality is not restored, also called irreversible pollution. With an increase in irreversible pollution, the resistance increases and with it the electricity consumption. If the irreversible pollution and therefore the electricity costs become too high, it is financially beneficial to replace the membrane. By developing an improved cleaning method, membranes can be used longer, so that materials and costs can be saved.

22. März 2023 | 11:30 - 12:30

Jurek Häner
Münster University of Applied Sciences

Disentangling the Influence Factors on Biogas Production from Pig Manure

About 18% of greenhouse gas emissions in agriculture are due to pig farming. One possibility to reduce these emissions is the anaerobic digestion of pig manure and slurries. A major challenge that obstructs the use of the biogas potential of liquid manure is the economic efficiency of the application of these substrates. The objective of the MOVE project, in the context of which these investigations are being carried out, is to analyze the prerequisites for the use of pig manure for energy and emission-reducing purposes from an economic and technical point of view and to develop practically applicable measures and concepts that will lead to the exploitation of the available biogas potential.

Within the scope of the substrate characterization and the planned tests on the influence of different pre-treatment processes, different samples from farms will be examined regarding nutrient content, trace element supply, Weender parameters, pH, temperature, chemical oxygen demand (COD), biochemical oxygen demand after five days (BOD5), dry matter (DM), organic dry matter (oDM), age of the sample and biogas potential. For the analysis of the biogas potential, eudiometer tests according to VDI 4630 are carried out.

In the first series of experiments, two farms were considered. Samples were taken

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from different sites, taking individual substrate handling strategies (e. g. sedimentation and separate storage of the thick and thinner phases) and different growth stages of the animals into account, which already shows in terms of DM- and oDM-contents.

There are significant differences in the biogas potential determined. Depending on storage location and growth stage, methane yields of 0.4 to 20.6 There are significant differences in the biogas potential determined. Depending on storage location and growth stage, methane yields of 0.4 to 20.6 L/kg FM and 35.18 to 360.84 L/kg oDM are obtained. It is striking that the FM-specific biogas potential increases with rising DM-content. An exception is a sample from the slurry cellar of farm 1. Despite the highest DM-content, the sample shows only the second-highest FM-specific methane yield and a comparatively low oDM-specific yield of 90.12 L/kg oDM.

At present, eleven farms with 29 different residual materials from pig farming have been sampled. The cause of the strong deviations in methane yields is now being identified, as are the interrelationships at work there. Further investigations in the project refer to the pretreatment of these residues.

22. März 2023 | 11:30 - 12:30

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22. März 2023 | 11:30 - 12:30

Mohideen Abu Haniffa Sultan Mohideen
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Development of a packed foam bed bioreactor for biological methanation

Due to the climate crisis, renewable natural gas (biomethane) upgraded from anaerobic digestion is required to replace fossil natural gas. It can be applied in almost all energy-demand sectors and the infrastructure for storage, distribution and export already exists. Furthermore, it can be used as an option to handle a surplus of renewable electricity, and for feeding biogas (anaerobic digestion gas containing 40 to 75% CH_4) into the natural gas grid, where upgrading to biomethane (CH_4>96%) is essential. For efficient technical use, however, the transfer of H_2 from the gas phase into the aqueous phase is a rate-limiting step. H_2 transfer can be controlled via pressure, gas holdup, and gas-liquid interfacial area.
In this study, a foaming agent (Pluronic® F-68 at a concentration of 1.5% w/v) was added to the liquid medium of a packed foam bed bioreactor (PFBR) for biological methanation. The reactor was filled with plastic Hiflow® rings, working volume 3.8 L and operated for more than a month (T=55 °C, P_{max}=1.1 bar). Headspace gas composition and productivity were monitored online by gas chromatography. Moreover, the composition of the microbial community in the PFBR was analysed by metaproteomics on the taxonomic and functional level.
Use of the foaming agent resulted in stabilised fine bubbles. This allowed to improve the gas-liquid interfacial area and gas-hold-up within the PFBR. The productivity of the PFBR was about 2.3 $L_{CH4}/L_R/d$, while the percentage of CH_4 in the off-gas

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was about 95%. The maximum productivity of 4.0 L_{CH4}/L_R/d was reached with about 77% of CH_4 in the off-gas. The abundance of archaea in the suspended microbial community shifted from 25% in the inoculum towards 62% after 23 days. The archaeal community mainly comprised Methanobacteria (97%), well-known hydrogenotrophic methanogens often found in thermophilic conditions. The microbial biofilm attached to the packed material contained slightly less archaea, but still mainly Methanobacteria (87%, after 36 days). Here, the bacterial community decreased from 25% in inoculum to 9% in the suspension and the biofilm (36 days).

Compared to a tubular foam bed bioreactor (TFBR) achieving 31.5 L_{CH4}/L_R/d the productivity of the PFBR was low. Since the analysis of the microbial community showed a successful enrichment of archaea in suspension as well in the biofilm of the packed bed, it can be assumed that the gas transfer in the new PFBR system was still limiting. Apparently, a TFBR with a small diameter and long tube length is more efficient. Consequently, up-scaling would require highly parallelised small scale TFBR.

22. März 2023 | 11:30 - 12:30

Fabiany de Jesús Morgado-León
National University of Mexico

Methane production from fermented cacao waste husks

A common practice for disposing of agricultural wastes is open-air incineration or just accumulation in the field, leading to fouling and soil contamination. The wastes from cocoa production have been identified as substrates with great potential for methane generation, calculated by 922 L/kgVS with a methane content of 51%. The general strategy in most studies is co-digestion with food or organic wastes obtaining less than 200 mlCH4/gVS. This research proposes to analyze the cocoa husk from the tropical regions of Mexico and determine the methane production in a two-stage anaerobic digestion process: acid fermentation and methanization.
The proposed strategy consists of 1) preparation and characterization of the cacao pods. 2) In a four-liter semicontinuous reactor, at 35 °C, without pH control, the ground substrate was fermented under organic loading rates (OLR) of 1.30 to 4.90 gCOD/L·d. 3) Methanization of ground cacao husks and products from the fermentation under different substrate concentrations. UASB-washed sludge was used as inoculum for the methanization. The biogas was quantified using the AMPTS II system, and the composition was determined by chromatography.

The products from the fermentation of the ground cacao husks were monitored over more than 150 days. The lowest OLR corresponds to a 19-day solids retention time (SRT), and the highest to 4.8 days. During the lower OLR, the main products were lactic,

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butyric, and acetic acids; the pH stabilized at 4.7. After increasing the OLR to 2.5 gCOD/L·d, lactic acid was primarily produced, and butyric acid decreased. After 20 days, the composition changed drastically. Lactic bacteria were washed out, and propionic acid slightly increased. At higher OLR, lactic acid production did not recover, and propionic acid production increased as all other acids strongly decreased.

Drastic changes in methane production of the fermentation effluents under different organic loads cannot be observed. This may be mainly because, unlike the first OLR, the three subsequent ones contained similar fermentation metabolites. Only acetic acid was detected in the flasks at the end of methanization, except in the flasks containing the lowest substrate concentration, where this metabolite was wholly consumed. The COD at the methanization's end is very low: higher than 6.5 and lower than 35.8 mg-COD/L. These values increased as the initial substrate concentration increased.

The specific productions range from 67 to 228 LCH4/kgTS. Unusual behaviors were detected for the substrate from organic loads of 1.3, 2.5 gCOD/L·d, and in the ground cocoa husk. The unusual behavior can be related to inhibition.

Conclusions. The occurrence of specific microorganisms is highly dependent on the solid's retention time. During fermentation, metabolic changes can be observed after more than 2 SRT. The fermentation of the ground cocoa husk enhances methane production mainly under organic loading rates of 1.3 and 4.9 gCOD/L·d.

22. März 2023 | 11:30 - 12:30

Eva Maria Prem
University of Innsbruck

Effects of phenyl acids on the active AD community at different pH conditions.

Biogas production out of organic waste materials does not influence food prices, can prevent the expansion of monocultures and supports the infrastructure in remote areas. To increase the contribution of organic wastes for biogas production, several chemical, physical, and (micro)biological pre-treatment procedures have been established over the last decades. One drawback of using (pre-treated) organic wastes is the possible release of aromatic compounds like phenyl acids (PA); their effects on the AD microbiome are still not thoroughly understood and might depend on several biological and physico-chemical parameters like inoculum, operation temperature, substrate or pH value. As phenylacetic acid (PAA), phenylpropionic acid (PPA) and phenylbutyric acid (PBA) have a pKa value of 4.28, 4.66 and 4.76, respectively, they are mainly dissociated thus charged around a neutral pH. The permeability of small, charged molecules through the cell membrane is more restricted than of uncharged molecules; however, uncharged PAA, PPA and PBA still account for about 1% of the respective PA at a pH 7 and at 55 °C. At this current stage of research, it is unclear i) how these phenyl acids affect biogas production at a constant pH, ii) whether these small amounts of uncharged phenyl acids can considerably inhibit (specific) microbial groups under anaerobic conditions and iii) whether pH changes (thus an increase or decrease in the concentration of uncharged phenyl acids) are relevant within the AD range (pH 6 – 8).

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For this purpose, thermophilic AD was established in a 5 L chemostat which allowed temperature and pH control. After reaching a stability phase at pH 6, phenyl acids were continuously added. The reactor was biochemically (GC, HPLC) and microbiologically monitored (RNA extraction and sequencing). The experiment was repeated at a pH of 8. Same start community was ensured with a thoroughly mixed thermophilic AD sludge aliquoted and frozen prior the start of the experiment. First signs of inhibition in the pH 6 reactor were a decrease in methane production (271 NmL CH4 per day) at 48 mM PA-sum after 26 days of phenyl acid addition, followed by a considerable increase in acetate concentration (9 mM) at a PA-sum concentration of 58 mM after 34 days. Preliminary results on the pH 8 reactor showed that the reactor could cope far better with higher phenyl acid concentrations: On day 53 at a PA sum concentration of 64 mM, methane production was still constant (484 NmL per day) and acetate levels were low (1.56 mM). These first results are promising and further research might lead to a better understanding of the impact of aromatic acids on AD.

22. März 2023 | 11:30 - 12:30

Juliana Rolf
FH Münster

Biological Hydrogen Production for a Sustainable Energy Economy – Development and Application of Dark Fermentation for Hydrogen Production

Dark fermentation (DF) is regarded as a promising solution for the greenhouse gas emission free production of hydrogen. Using DF hydrogen is produced regeneratively as part of the HyTech research project. For this purpose, a 2-stage process is operated on a semi-industrial scale and within a comprehensive test program the data basis for a scale-up is created. In addition, biogenic residual and wastewater streams are tested for suitability and hydrogen yield. DF produces mainly hydrogen (H_2), carbon dioxide (CO_2), and organic acids from biomass by means of anaerobic fermentation.

The 2-stage process can ensure the future security of the supply of hydrogen and is independent of fluctuating renewable energies. In addition, previously unused biomass potentials, such as heavily polluted wastewater and residual material streams from predominantly the food industry, can be utilized for biological hydrogen production. This opens up further use of wastewater streams at the industrial site. The spatial separation of the biogas process into two stages enables the biological production of hydrogen by DF in the first stage (hydrogen reactor) and the subsequent production of methane in the downstream second stage (methane reactor). In the project, two different reactor concepts are being tested for the first stage of the process, a fixed-bed reactor (FBR) and a continuous stirred tank

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reactor (CSTR). Both reactors are operated with microorganism retention. This concentrates the microorganisms in the reactors and enables higher efficiency and higher substrate throughputs. The aim of the test program is to increase the hydrogen yield and substrate degradation rates.

At first, various wastewater samples were investigated in 1 l batch test to assess the hydrogen yield. The batch process of single-stage DF is a method that allows the procedures for treating wastewater and organic waste to be evaluated. The method is fast but also reliable and can be applied to all anaerobically degradable substrates. The comparison of the gas mixtures produced allows the processes to be evaluated and the conditions required for the 2-stage test plant of DF to be estimated. The batch test identified a wastewater sample from a brewery as suitable. In the test series, the sample achieved a hydrogen yield of 123 lN/kg_{FM} at a hydrogen concentration of 43 %. The wastewater is now used in the 2-stage test plant for the test series. After the hydrogen potential was determined, promising samples were used in the 2-stage test plant at different hydraulic retention times (HRT) (36-9 h) for the first stage (VR=10 l). The second stage has a volume of 30 l.

22. März 2023 | 11:30 - 12:30

Nguyen Van Than
University of Wismar

Modelling of anaerobic digestion process stability on the basis of chemical equilibria

In full-scale operation, anaerobic digestion (AD) biogas plants have to be stable with high COD degradation efficiencies. A deterioration of an AD process causes severe disposal problems for the digester content and the substrate. A deterioration of an AD process is, due to the enormous costs associated with it, a heavy burden for the feasibility.
AD of readily acidifying substrates is unfortunately an inherently instable process. An accumulation of volatile organic acids (VOA) as a consequence of a strong increase of COD in the substrate is for such substrates not avoidable. It has however to be safeguarded that the unavoidable accumulations of VOA shall not cause an inhibition of the methanogenic microorganisms. An inhibition of the methanogenic microorganisms shall cause in case of a readily acidifying substrate, an AD process imbalance that shall be self-propelling and lead to process deterioration if not realized, and controlled with adequate actions in time.
Maintaining the concentration of un-dissociated VOA below the level causing an inhibition of the methanogenic microorganisms is essential for maintaining the stability of the AD process. The concentration of un-dissociated VOA is, however, not directly measurable. In this study shall be demonstrated, that the concentration of un-dissociated acetic acid HAc can be calculated as a function of VOA/Alkalinity ratio (FOS/TAC) and carbon dioxide partial pressure (pCO_2). The concen-

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tration of un-dissociated acetic acid HAc is linked directly to the degree of inhibition of the methanogenic microorganisms. It shall also be shown that pH is not a suitable parameter for detecting an accumulation of VOA as with a pH decrease of ΔpH > 0.15 pH units already an inhibition of methanogenic microorganisms often begins.
Two-point titration is a method for measuring VOA and alkalinity in digestates, easy to perform and cost effective. As, however, FOS/TAC measurement becomes the key parameter for monitoring the process stability, reliability and accuracy of measuring FOS/TAC using the Nordmann-2-point-titration method was analyzed and tested. FOS/TAC measurement was done with FOS/TAC 2000 analyzer Pronova (Germany). Acid consumption of titration from pH = 5.0 to pH = 4.4 is evaluated with empirically deduced McGhee equation [McGhee (1968)]. Physicochemical background of the McGhee equation was investigated.
It shall be shown that long used stability criteria – FOS/TAC < 0.3 indicates a stable process and FOS/TAC > 0.8 is indicating a process becoming or already instable – correlate well with absence or beginning of an inhibition of methanogenic microorganisms, and it shall be shown that Nordmann 2-point titration method for FOS/TAC measurement with evaluation with the McGhee equation shall in most cases render reliable and sufficiently accurate results.

22. März 2023 | 11:30 - 12:30

Klara Wolf
Deutsches Biomasseforschungszentrum

Optimization pipeline tuning for ML-based anaerobic digestion predictive models

The application of Anaerobic Digestion (AD) processes to provide demand-oriented power represents a solution for compensating the fluctuation of renewable energy conversion. Model-based automation procedures provide efficient and robust concepts for non-linear AD process optimization, and stochastic modelling techniques, such as Machine Learning (ML) and Deep Learning (DL) are flexible tools that have been proven to successfully simulate AD processes. While pipelines for the optimization of data preparation and prediction process are being developed, the tuning of such structures is not deeply investigated.
This study aims to apply and evaluate several tuning algorithms for AD process prediction optimization pipelines. Well-tuned and optimized prediction models can be used for monitoring and subsequently controlling full-scale biogas reactors with minimal computational effort.
For validation of implemented tuning procedures full-scale experiments for AD of rye whole crop silage and cattle manure were conducted in a 188 m^3 CSTR biogas plant. An OLR of approximately 4 kg VS m^{-3} d^{-1} was maintained at all times. In total 15 online measurements and 39 offline measurements were applied, with a resolution of 1h.
The used model optimization pipeline consists of several data preparation steps – including autoencoders and outlier detection among others – and model hyperparameters optimization. The optimized models consist of several ML and DL algorithms, such as AdaBoost regressor and Long Short-Term Memory (LSTM) Neural Networks (NNs). Since

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these models vary in their functionality and complexity, the numbers of model parameters to be optimized vary as well, resulting in a total of 19 to 34 parameters to be optimized.
Several algorithms were tested for data preparation and hyperparameters' global optimization. Random search, local search algorithms, gradient based optimizers and more complex biological inspired methods such as swarm algorithms and evolutionary strategies were implemented.
Initial results show that simpler prediction models– such as Bayesian Ridge Regressor and ElasticNet – allow for low prediction errors independently from the complexity of the used optimizer, reaching a minimum of 74.4% RMSSE using hill climbing. Conversely, NNs perform poorer, especially when optimized with more complex optimizers – such as differential evolution.
These results can be explained with the necessity of parameters to be tuned for more complex optimization algorithms, that were manually tuned in this experiment.
This study demonstrates that simple ML algorithms for the simulation of AD processes can be successfully optimized by simple optimization algorithms, while DL algorithms require more complex optimizers and further tuning. A meta-optimization strategy is required to tune advanced optimizers without impacting optimization times.

22. März 2023 | 11:30 - 12:30

Mathias Wunderer
University of Innsbruck

The glutamyl tail-length of the cofactor F420 in the methanogenic Archaea Methanosarcina thermophila and Methanoculleus thermophilus

The methanogenic Archaea Methanosarcina thermophila and Methanoculleus thermophilus were batch-cultivated on different carbon sources, and their cofactor F_{420} glutamyl tail-length variants have been assayed by reversed-phase ion-pair high-performance liquid chromatography with fluorometric detection. An upstream solid-phase extraction of the F_{420} cofactor tail length variants has been developed to avoid interfering substances and enable reproducible high-performance liquid chromatography analyses.

In Methanosarcina thermophila cultivated on methanol, acetate, and a mixture of acetate and methanol, the most abundant cofactors were F_{420}-5 and F_{420}-4 and the composition of the different cofactor length variants changed during batch cultivation on all three carbon sources. Over time F_{420}- 3 and F_{420}-4 decreased while F_{420}-5 and F_{420}-6 increased in their relative proportions. A decrease of F_{420}- 3 was often accompanied by an increase of F_{420}-5 and a decrease of F_{420}-4 with an increase of F_{420}-6 and vice versa. This indicates that in Methanosarcina thermophila an enzyme exists which might be able to coevally transfer two glutamates and can still change the length of the glutamyl chain even after the cofactor has been synthesized. By contrast, in Methanoculleus thermophilus cultivated on H_2/ CO_2 (80:20) the most abundant cofactors were F_{420}-3 and F_{420}-4 and the relative

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abundance of the different F_{420} cofactor tail-length variants remained stable during batch cultivation. A distinction based on the glutamyl tail-length composition of the cofactor F_{420} between the two methanogenic Archaea was also possible. The cofactor F_{420}-5 in concentrations > 2% could only be assigned to Methanosarcina thermophila. Therefore, F_{420} tail length characterization might become a tool in the future to conclude on the predominant type of methanogenesis and gain a better insight in the distribution of hydrogenotrophic and acetoclastic methanogens during AD.

22. März 2023 | 11:30 - 12:30

Jonathan Heil & Nestor Patient Tchamba Sefekme
Fraunhofer UMSICHT

A potential approach for the integration of biogas plants into cross-industrial systems

Biogas from anaerobic digestion (AD) is a renewable carbon neutral energy source that can be used to replace dependencies of fossil fuels. Due to the complexity of the microbiological and biochemical factors, process control of biogas plants is of great importance and involves a variety of tasks, including monitoring the plants performance and making adjustments to ensure optimal operation. Nevertheless, a variety of technical solutions are available to appraise environmental parameters, economical effective operation of biogas plants is not only depending on optimizing biological parameters. In Germany recent changes in the Renewable Energy Act (EEG) and the omission of the feed-in remunerations, led to the requirement of new business strategies. Industrial symbiosis and sector coupling depict new opportunities that can be used to develop novel business means. At present, biogas from AD is predominantly used for heat and electric energy production. Throughout, coupling of renewable energy systems with power-to-X approaches, there are many different entry points to exploit potential synergies between biogas plants and other systems. While the exchange of material, waste and energy sources across different sectors has been the main focus of eco-industrial parks, recently emerging cross-industrial systems present new opportunities to produce hydrocarbons utilizing renewable energies and integrating chemical processes into existing infrastructures. Henceforth, we reveal the potential of industrial

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symbiosis and sector coupling for new business strategies in relation to the biogas industry. Here, we describe the idea of digital twinning to get an accurate evaluation of the plant and introduce the conceptualization of an encompassing AI based modeling approach to describe and predict the operation of the biogas plant via integration of cross-sectoral data.

BATCH SESSION

23 March 2023 | 13:30

PD Dr.-Ing. habil. Konrad Koch
Technical University of Munich

Better BMP – Free resources for improving the quality of biochemical methane potential tests

Biochemical methane potential (BMP) tests are an essential tool to determine the methane potential of a given substrate, to evaluate the effectiveness of a pre-treatment, or to estimate the overall efficiency of a process. However, there are several potential pitfalls in the conduction of the tests and data analysis. Over the last years, we gathered hints and resources to support less experienced colleagues, all presented on our Standard BMP methods website at www.dbfz.de/bmp. This compilation includes scientific and freely accessible documents of accepted protocols and measurement methods (including the recently developed low-cost gas density (GD-BMP) method: as well as guidelines for data processing and calculations. To assist users in data processing or to double-check their own calculations, the free “biogas package” for the software R has been developed, which is also available as an web application called the “Online Biogas App” (OBA): It includes tools for BMP planning, biogas data processing, theoretical calculations, and conversions.

All recommendations are based on peer-reviewed publications and are continuously updated. For instance, the important validation criteria published in the widely-applied guidelines of Holliger et al. from 2016 has been recently revised based on results from a large international interlaboratory test Although

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this update has been published as a comment to the original guidelines to ensure its visibility the protocols on the website are always kept upto-date based on recently published progress. Furthermore, information about the power and limitations of BMP tests is provided to emphasize for which questions these tests are suitable and for which not.

In addition to the final value of methane potential (i.e., the BMP), degradation kinetics include valuable information for detailed substrate characterization and process modelling. While several studies have extracted kinetic information (often by presenting the first-order rate constant k) from BMP tests, data from IIS-BMP show that reproducibility is poor and clearly indicate that these values need to be handled with care. In general, the shape of BMP curve matters and can give at least an indication of potential flaws in the experimental setup and execution even without extraction of kinetic parameters.

In this presentation, we will present fundamental requirements and useful hints based on recent scientific findings and free resources for improving quality and reproducibility of BMP tests for biogas research or application.

23 March 2023 | 14:00

Matthias Steindl
Bavarian State Research Center for Agriculture

Towards improving the estimation of the kinetic parameter in BMP tests

Anaerobic batch experiments are a widespread and approved method to determine the Biochemical Methane Potential (BMP) and the corresponding kinetic parameter, often defined as rate constant k, of substrates. To date, detailed guidelines have been published to validate the parameter BMP obtained from these tests. Yet, no such guidelines exist for the determination of k. Here we propose a straightforward method to fill the gap with a special emphasize on the specific methane production rate from the blanks. Our results show that excluding those blanks that show a distinct lag-phase helps to retrieve more consistent estimates for k. We demonstrate this by using different types of inocula and performing the same BMP tests multiple times. The results also indicate that for determining k, it is beneficial to pre-incubate the inoculum if it is sourced from an agricultural biogas plant.

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23 March 2023 | 14:30

Manuel Winkler
Deutsches Biomasseforschungszentrum

Comparative Model-based Estimation of Biochemical Methane Potential and Degradation Kinetics in Batch and Continuous Operation at Two Scales

A detailed understanding of the distinct characteristics of substrates for anaerobic digestion (AD) between continuous and batch operation has not yet been established. Also, the critical comparison of different scales of continuous stirred tank reactors (CSTR) for AD is rarely published in the literature. In this contribution, mesophilic anaerobic co-digestion of maize silage and cattle manure was conducted at both laboratory (8 L reaction volume) and full-scale (163 m^3 reaction volume) continuous digesters. All reactors were operated at an average organic loading rate (OLR) of 1.1 kg volatile solids (VS) m^{-3} d-^{1}. In order to increase process dynamics, three feeding events were deliberately altered, using 2 to 4 times the daily dose, followed by a feeding pause of additional 2 to 4 days. Also, biochemical methane potential (BMP) tests of the same substrate mixture were performed, using the AMPTS II system (BPC Instruments AB, Sweden).

Mean methane yields ranged between 251.8 to 284.9 L CH_4 kg^{-1} VS d^{-1} in continuous, and 297.2 L CH_4 kg^{-1} VS in batch operation. Daily yields of individual continuous reactors compared very well between both scales. To estimate ultimate BMP and degradation kinetics of each experiment, a two-fraction first-order VS-based algebraic process model was applied. Parameter estimates revealed BMPs of 301.1 L CH_4 kg^{-1} VS in batch and 280.0 to 318.1 L CH_4 kg^{-1} VS in continuous

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operation. Kinetic constants were 0.0861 and 0.898 d^{-1} in batch, and between 0.0746 to 0.183 d^{-1} and 1.234 to 1.607 d_{-1} in continuous for the slow and fast VS fraction, respectively. When estimating semi-continuous operation followed by a prolonged decay phase (lab-scale only), the model parameters did not vary greatly, but model efficiency increased significantly.

The results suggest that the use of simplified AD models can help in making different scales and operating regimes comparable, and due to their easy implementation and short computation times, should be applied wherever possible.

23 March 2023 | 15:00

Cristiane Romio
Aarhus University

Optimizing the energy recovery from agricultural-based digestates

The recovery of biogas from digestate could offer opportunities for lowering the demand for biomass feedstock and reduce the emissions of greenhouse gases during digestate storage and final application. This could be accomplished by processing the whole digestate or its solid fraction, and recirculating it to the main digester or feeding it to a following digester. Due to the recalcitrance of agricultural digestates, a post-treatment prior to re-digestion might be necessary. Since lignin remains mostly unaltered during anaerobic digestion, a post-treatment, such as alkaline, targeting this fraction could be beneficious, as cellulose and hemicellulose could become more available for enzymatic attack.

In the first part of this study, the residual biogas potential of 31 digestate samples were determined, along with their compositions. The selected plants operated at temperatures between 30 and 52 °C, with hydraulic retention times (HRT) between 13 and 130 days. The samples were re-digested for 110 days at the temperatures of the original digesters, and the methane production was modelled by the first-order kinetic model. Some samples displayed high volatile fatty acids (VFA) and total ammoniacal nitrogen (TAN) concentrations, up to 6.7 and 4.4 g/l, respectively. Total solids (TS) contents varied between 3.1 and 78.9 %, and volatile solids (VS) contents ranged from 62.5 to 78.9% TS. Protein, lignin, cellulose and hemicellulose ranges

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were 13.3-22.1, 7.2-23.9, 7.6-23.4, and 0.9-17.8% TS, respectively. The ultimate methane yields varied between 48.6 and 226.7 ml/g VS, decaying logarithmically with the HRT ($r^2 = 0.40$, $p < 0.05$).

Since significant residual methane yields in digestate were found, a second experiment was carried out, where the effectiveness of an alkaline post-treatment on the solid fraction of digestate (SFD), which should concentrate the organic matter, was assessed. KOH was selected as the alkaline agent due to the agronomic value of potassium, considering the final application of digestate. 3 samples of SFD were post-treated with KOH at the concentrations of 1, 2, 4, 8, and 12% (TS basis) at 20 °C and 20% TS during 1, 4, and 8 days, and re-digested for 90 days at 51 °C. The methane production was modelled by the Gompertz-modified model. The ultimate methane yields of treated samples corresponded to 73-144% of the yields of the untreated samples, which were 115-132 ml/g VS. The maximum methane rates of treated samples corresponded to 79-210% of the rates of the untreated samples, while the lag-phase durations corresponded to 3-184% of the lag-phase durations of the untreated SFD.

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DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH

Our mission

The DBFZ was founded in 2008 by the former Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) with the aim of establishing a central research institution for all relevant fields of bioenergy research and to network the results of the very complex German research landscape in this sector. The scientific mission of the DBFZ is to provide comprehensive scientific support for the efficient integration of biomass as a valuable resource for sustainable energy supply within the framework of applied research. This mission includes technical, ecological, economic, social and energy management aspects along the entire process chain (from production, supply and use). The development of new processes, procedures and concepts is accompanied and supported by the DBFZ in close cooperation with industrial partners. At the same time, there is close networking with German public research in the agricultural, forestry and environmental sectors, as well as with European and international institutions. Based on this broad research background, the DBFZ also develops scientifically sound decision-making aids for policy makers.


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Bundesministerium
für Ernährung
und Landwirtschaft

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