Assessing the effects of intra-granule precipitation in a full-scale industrial anaerobic digester

In this paper, a multi-scale model is used to assess the multiple mineral precipitation potential in a full-scale anaerobic granular sludge system. Reactor behaviour is analysed under different operational conditions (addition/no addition of reject water from dewatering of lime-stabilized biomass) and periods of time (short/long term). Model predictions suggest that a higher contribution of reject water promotes the risk of intra-granule CaCO₃ formation as a result of the increased quantity of calcium arriving with that stream combined with strong pH gradients within the biofilm. The distribution of these precipitates depends on: (i) reactor height; and (ii) granule size. The study also exposes the potential undesirable effects of the long-term addition of reject water (a decrease in energy recovery of 20% over a 100-day period), caused by loss in biomass activity (due to microbial displacement), and the reduced buffer capacity. This demonstrates how both short-term and long-term operational conditions may affect the formation of precipitates within anaerobic granules, and how it may influence methane production and consequently energy recovery.
Evaluation of anaerobic digestion post-treatment options using an integrated model-based approach

The objective of this paper is to present the main results of an engineering-research project dealing with model-based evaluation of waste streams treatment from a biotech company. This has been extensively done in domestic treatment systems, but is equally important, and with different challenges in industrial wastewater treatment. A new set of biological (activated sludge, anaerobic digestion), physicochemical (aqueous phase, precipitation, mass transfer) process models and model interfaces are required to describe removal of organics in an upflow anaerobic sludge blanket (UASB) reactor plus either traditional nitrification/denitrification (A1) or partial nitritation (PN)/anammox (ANX) (A2) processes. Model-based analysis shows that option A1 requires a decrease in digestion energy recovery ($E_{\text{recovery}}$) in order to have enough organic substrate for subsequent post NO3 reduction treatment (95kWh kg N$^{-1}$). In contrast, A2 in an aerobic granular sludge reactor allows for higher UASB conversion since N removal is carried out autotrophically. The study also reveals that the addition of an aerated pre-treatment unit prior to the PN/ANX (A2) reactor promotes COD and H2S oxidation, CO2 and CH4 stripping, a pH increase (up to 8.5) and a reduction of the risk of intra-granular precipitation as well as sulfide inhibition. Simulations indicate clear differences regarding the microbial distribution/abundance within the biofilm in A2 when comparing the two operational modes. Final results show the effects of different loading and operational conditions; dissolved oxygen (DO), Total Suspended Solids (TSS$_{\text{op}}$), energy recovery ($E_{\text{recovery}}$); on the overall process performance; N removal, aeration energy ($E_{\text{aeration}}$), net energy production ($E_{\text{recovery}}$); using response surfaces, highlighting the need of integrated approaches to avoid sub-optimal outcomes. The study shows the benefits of virtual plant simulation and demonstrates the potential of model-based evaluation when process engineers in industry have to decide between competing options.

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5 år og fuld fart frem "BIOPRO World Talent Campus byder endnu en gruppe talenter fra hele verden velkommen til Danmark."
BIOPRO World Talent Campus: A week of real world challenge for biotechnology post-graduate students

Focus on sustainable processes and renewable raw materials, combined with rapid advancements in technology developments across scales, makes bio-based production processes a subject of great interest to both industry and academia. Despite this increasing prominence of bio-based production processes, there is a lack of a single course that can provide a thorough overview of the state-of-the-art industrial scale bio-based production, to early stage practitioners and researchers such as post-graduate students. BIOPRO World Talent Campus (WTC), developed and initiated in the year 2013 by the BIOPRO Strategic research consortium, was specifically designed and developed to address this shortcoming, and has thus far trained more than 120 post-graduate students from related yet diverse academic backgrounds from all across the globe. This manuscript describes the general and technical organisation of BIOPRO WTC, and the unique academic and industrial collaboration that exists in Denmark, which makes WTC a reality. A special focus is also placed on discussing a 48 h industrial challenge that is set by leading Danish bio-based production companies and its impact on young post-graduate students, who get hands on experience in dealing with "real world" problems. Results from student surveys carried out during the five years of WTC are reported and discussed to understand the impact of the course. A future perspective is also presented with the focus on the possibility of employing emerging technologies to extend the outreach of the program.

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Model-based analysis and optimization of a full-scale industrial high-rate anaerobic bioreactor

The objective of this paper is to present the model-based optimization results of an anaerobic granular sludge internal circulation (IC) reactor. The International Water Association (IWA) Anaerobic Digestion Model No. 1 extended with phosphorus (P), sulphur (S) and ethanol (EtOH) is used to describe the main biological and physico-chemical processes. The high-rate conditions within the reactor are simulated using a flow + reactor model comprised of a series of continuous stirred tank reactors (CSTRs) followed by an ideal total suspended solids (TSS) separation unit. Following parameter estimation by least squares on the measured data, the model had a relative mean error of 13 % and 15 % for Dataset #1 and Dataset #2, respectively. Response surfaces (RSs) show that the reactor performance index (RPI) (a metric combining energy recovery in the form of heat and electricity, as well as chemicals needed for pH control) could be improved by 45 % when reactor pH is reduced down to 6.8. Model-based results reveal that influent S does not impose sufficient negative impacts on energy recovery (+ 5.7 %, in MWh/day, + 0.20 M€/year when influent S is removed) to warrant the cost of its removal (3.58 M€/year). In fact, the process could handle even higher S loads (ensuring the same degree of conversion) as long as the pH is maintained above 6.8. Nevertheless, a higher S load substantially increases the amount of added NaOH to maintain the desired operational pH (> 25 %) due to the acidic behaviour of HS-. CO2 stripping decreases the buffer capacity of the system and hence use of chemicals for pH control. Finally, the paper discusses possibilities and limitations of the proposed approach, and how the results of this study will be put into practice.
Optimization of energy recovery in an industrial wastewater treatment plant

Biogas production from wastewater is seen as a sustainable way to recover energy. Anaerobic digestion processes convert the organic material in wastewater to biogas, which can subsequently be converted to electricity and heat. The focus of this project is to optimize the energy recovery in an industrial wastewater treatment plant. The main objective is to study how mathematical models can be used for the description and analysis of processes, and subsequently be explored for the optimization of the reactor performance. The anaerobic digester under study is a granular sludge reactor, where the biomass is present in the form of granules. This leads to high-rate conditions and can be a challenge to model. To this end, two separate models based on the Anaerobic Digestion Model No. 1 (ADM1) were developed: i) A flow + reactor model (Model I), reaching high biomass concentrations by recycling the biomass back into the reactor through an artificial loop, and ii) a granular model (Model II), where the reactions take place within a biofilm. Both models were calibrated with two separate datasets of three weeks each. The datasets contain extensive measurements of COD, nitrogen, sulfur and phosphorus species, as well as measurements of biogas production and mineral composition. Mass balances verified the quality of the measurements, and an influent fractionation was performed. Model I was applied for optimization of the process conditions, where it was found that lowering the pH had a positive effect on the chemical dosage to the reactor and did not lead to reduced energy recovery. This strategy was applied to the full-scale reactor. Simulation results furthermore revealed that while removing sulfur compounds from the influent increased the energy recovery, the gain was less than the removal cost. Long-term simulations were performed with Model II, where precipitation within the granules was taken into account. It was shown that precipitation can have detrimental effects on the process performance on the long-term, due to the competition for space between precipitates and biomass within the granules. The impact of an increased loading rate was one of the optimization strategies that was studied, as the loading is limited by nitrogen removal. An evaluation was made on the potential implementation of the anammox process as an alternative nitrogen removal method post-anaerobic digestion, indicating significant experimental and modelling work is still needed.

Modelling an industrial anaerobic granular reactor using a multi-scale approach

The objective of this paper is to show the results of an industrial project dealing with modelling of anaerobic digesters. A multi-scale mathematical approach is developed to describe reactor hydrodynamics, granule growth/distribution and microbial competition/inhibition for substrate/space within the biofilm. The main biochemical and physico-chemical processes in the model are based on the Anaerobic Digestion Model No 1 (ADM1) extended with the fate of phosphorus (P), sulfur (S) and ethanol (Et-OH). Wastewater dynamic conditions are reproduced and data frequency increased using the Benchmark Simulation Model No 2 (BSM2) influent generator. All models are tested using two plant data sets corresponding to different operational periods (#D1, #D2). Simulation results reveal that the proposed approach can satisfactorily describe the transformation of organics, nutrients and minerals, the production of methane, carbon dioxide and sulfide and the potential formation of precipitates within the bulk (average deviation between computer simulations and measurements for both #D1, #D2 is around 10%). Model predictions suggest a stratified structure within the granule which is the result of: 1) applied loading rates, 2) mass transfer limitations and 3) specific (bacterial) affinity for substrate. Hence, inerts (XI) and methanogens (Xac) are situated in the inner zone, and this fraction lowers as the radius increases favouring the presence of acidogens (Xsu, Xaa, Xfa) and acetogens (Xc4, Xpro). Additional simulations show the effects on the overall process performance when operational (pH) and loading (S/COD) conditions are modified. Lastly, the effect of intra-granular precipitation on the overall organic/inorganic distribution is assessed at: 1) different times; and, 2) reactor heights. Finally, the possibilities and opportunities offered by the proposed approach for conducting engineering optimization projects are discussed.