Research outputs:

Microalgae and cyanobacteria modeling in water resource recovery facilities: A critical review
Microalgal and cyanobacterial resource recovery systems could significantly advance nutrient recovery from wastewater by achieving effluent nitrogen (N) and phosphorus (P) levels below the current limit of technology. The successful implementation of phytoplankton, however, requires the formulation of process models that balance fidelity and simplicity to accurately simulate dynamic performance in response to environmental conditions. This work synthesizes the range of model structures that have been leveraged for algae and cyanobacteria modeling and core model features that are required to enable reliable process modeling in the context of water resource recovery facilities. Results from an extensive literature review of over 300 published phytoplankton models are presented, with particular attention to similarities with and differences from existing strategies to model chemotrophic wastewater treatment processes (e.g., via the Activated Sludge Models, ASMs). Building on published process models, the core requirements of a model structure for algal and cyanobacterial processes are presented, including detailed recommendations for the prediction of growth (under phototrophic, heterotrophic, and mixotrophic conditions), nutrient uptake, carbon uptake and storage, and respiration.

General information
State: Published
Organisations: Water Technologies, Department of Environmental Engineering, University of Illinois at Urbana-Champaign, Irstea, Universite Cote d'Azur, University of Bath, Hydromantis ESS Inc., Universite de Montpellier, Aalborg University
Number of pages: 18
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Peer-reviewed: Yes

Publication information
Journal: Water Research X
Volume: 2
Article number: 100024
ISSN (Print): 0043-1354
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 7.55 SJR 2.601 SNIP 2.358
Web of Science (2017): Impact factor 7.051
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 7.49 SJR 2.663 SNIP 2.563
Web of Science (2016): Impact factor 6.942
Control of anaerobic digestion for maximal biogas production under dynamic conditions

**General information**
State: Published
Organisations: Water Technologies, Department of Environmental Engineering, Residual Resource Engineering, Technical University of Denmark, Sharif University of Technology
Pages: 40-40
Publication date: 2019

**Host publication information**
Title of host publication: 13th DWF Water Research Conference - Abstracts
Place of publication: Frederiksberg C
Publisher: University of Copenhagen
Electronic versions:

**Abstract book**
Research output: Research - peer-review › Conference abstract in proceedings – Annual report year: 2019

Monitoring of primary treatment: Estimation of the bioavailable organic carbon in wastewater by measuring the total organic solids (TSS) and turbidity

**General information**
State: Published
Organisations: Water Technologies, Department of Environmental Engineering
Contributors: Karvelas, S., Andersen, H. R., Valverde Pérez, B.
Pages: 33-34
Publication date: 2019

**Host publication information**
Title of host publication: 13th DWF Water Research Conference - Abstracts
Place of publication: Frederiksberg C
Publisher: University of Copenhagen
Electronic versions:

**Abstract book**
Research output: Research - peer-review › Conference abstract in proceedings – Annual report year: 2019

Control of anaerobic reactor treating cattle manure for maximal biogas production under dynamic conditions

**General information**
State: Published
Organisations: Water Technologies, Department of Environmental Engineering, Residual Resource Engineering, Technical University of Denmark, Sharif University of Technology, Shahid Beheshti University of Medical Sciences
Number of pages: 1
Publication date: 2018

**Host publication information**
Title of host publication: Sustain Conference 2018 : Creating Technology for a Sustainable Society
Place of publication: Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)
Editors: C. M., K. M.
Electronic versions:

**Sustain_Parisa_ghofrani_control_abstract_final_1_.pdf**
URLs:
http://www.sustain.dtu.dk/
Light attenuation in photobioreactors and algal pigmentation under different growth conditions – Model identification and complexity assessment

Microalgae are photosynthetic organisms, and thus one of the most important factors affecting their growth is light. Yet, effective design and operation of algal cultivation systems still lacks robust numerical tools. Here, a comprehensive and mathematically consistent simulation model is presented in the ASM-A framework that can accurately predict light availability and its impact on microalgal growth in photobioreactors (PBR). Three cylindrical column reactors, mimicking typical open pond reactors, with different diameters were used to conduct experiments where the light distribution was monitored inside the reactor. A batch experiment was conducted where the effect of nutrients and light availability on the pigmentation of the microalgae and light distribution was monitored. The effect of reactor size and cultivation conditions on the light distribution in PBRs was evaluated. Moreover, we assessed the effect of using different simulation model structures on the model prediction accuracy and uncertainty propagation. Results obtained show that light scattering can have a significant effect on light distribution in reactors with narrow diameter (typical to panel-type PBRs) and under cultivation conditions that promote low pigmentation or low biomass concentration. The light attenuation coefficient was estimated using the Lambert-Beer equation and it was compared to Schuster's law. The light attenuation was found to be dependent on biomass concentration and microalgae pigmentation. Using a discretized layer model to describe the light distribution in PBRs resulted in the most accurate prediction of microalgal growth and lowest uncertainty on model predictions. Due to model complexity a trade-off needs to be made between accuracy of the prediction and simulation time.

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering
Contributors: Wágner, D. S., Valverde-Pérez, B., Plósz, B. G.
Pages: 488-499
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: Algal Research
Volume: 35
ISSN (Print): 2211-9264
Ratings:
BFI (2019): BFI-level 1
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 4.43 SJR 1.142 SNIP 1.171
Web of Science (2017): Impact factor 3.745
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.45 SJR 1.465 SNIP 1.141
Web of Science (2016): Impact factor 3.994
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 5.53 SJR 1.963 SNIP 1.618
Web of Science (2015): Impact factor 4.694
Scopus rating (2014): CiteScore 4.96 SJR 1.902 SNIP 1.598
Web of Science (2014): Impact factor 5.014
Scopus rating (2013): CiteScore 4.17 SJR 1.424 SNIP 1.119
Web of Science (2013): Impact factor 4.095
ISI indexed (2013): ISI indexed no
Original language: English
Keywords: Green microalgae, Light attenuation, Model identification, Photobioreactor operation, Pigments
DOIs: 10.1016/j.algal.2018.08.019
Source: Scopus
Source-ID: 85054195903
Research output: Research - peer-review › Journal article – Annual report year: 2018
Microalgae modeling in water resource recovery facilities - Toward a consensus

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies, University of Illinois, Inria, INRIA Sophia Antipolis, University of Bath, Hydromantis ESS Inc., Université de Montpellier, Aalborg University
Number of pages: 1
Publication date: 2018
Peer-reviewed: Yes
Electronic versions:
2018_03_10_WRRmod_Poster.pdf
Source: PublicationPreSubmission
Source-ID: 144919333
Research output: Research - peer-review » Poster – Annual report year: 2018

Microbial protein as an alternative protein source enabling circular bioeconomy

General information
State: Published
Organisations: Water Technologies, Department of Environmental Engineering, Residual Resource Engineering
Contributors: Valverde Pérez, B., Angelidaki, I., Smets, B. F.
Number of pages: 1
Publication date: 2018
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Title of host publication: Sustain Conference 2018 : Creating Technology for a Sustainable Society
Place of publication: Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)
Editors: C. M., K. M.
Electronic versions:
Sustain_SCP_final.pdf
URLs:
http://www.sustain.dtu.dk/
Research output: Research - peer-review » Conference abstract in proceedings – Annual report year: 2018

Microbial protein production using a novel bubble-free membrane bioreactor
This work demonstrates the applicability of a novel bubble-free membrane bioreactor for cultivation of methanotrophic bacteria for single cell protein production. The methane and oxygen supply were optimized, so they were in contact only in the liquid phase thereby avoiding the creation of explosive atmospheres. After optimization of gas supply, the biomass accumulated protein up to 51 % of its dry weight. The microbial protein contained most of the essential amino acids needed to serve as animal feed.

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Beijing Jiaotong University, Technical University of Denmark
Number of pages: 4
Publication date: 2018
Peer-reviewed: Yes
Keywords: Single Cell Protein, Methane Oxidizing Bacteria, Nutrient Recovery
Electronic versions:
NRR18_SCP_final.pdf
Source: PublicationPreSubmission
Source-ID: 161802353
Research output: Research - peer-review » Conference abstract for conference – Annual report year: 2018
Model-based optimization biofilm based systems performing autotrophic nitrogen removal using the comprehensive NDHA model

Completely autotrophic nitrogen removal (CANR) can be obtained in single stage biofilm-based bioreactors. However, their environmental footprint is compromised due to elevated N2O emissions. We developed novel spatially explicit biochemical process model of biofilm based CANR systems that predicts N2O dynamics and stripping, using the biological NDHA model coupled with a simple and robust pH calculator. In this work we present two case studies: i) membrane aerated biofilm reactor (MABR) with focus on model calibration; and ii) granular system with focus on process optimization.

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies, Technical University of Denmark, University of Santiago de Compostela
Contributors: Valverde Pérez, B., Ma, Y., Morset, M., Domingo-Felez, C., Mauricio-Iglesias, M., Smets, B. F.
Number of pages: 4
Publication date: 2018
Peer-reviewed: Yes
Keywords: Biofilm, Nitrous oxide, Scenario analysis, Model calibration, Optimization
Electronic versions:
WRRmod2018_biofilmN2O_vs3.pdf
Source: PublicationPreSubmission
Source-ID: 144919385
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2018

Model identification for hindered-compression settling velocity

Two of the key questions regarding secondary settling are (a) Does a process model exist for which all hindered and compression settling velocity parameters can be estimated using experimental data?; (b) What is the minimum data that need be inferred, from a settling sensor setup to identify process models?” This international research effort aimed to address these questions by carrying out a comprehensive practical identifiability assessment of constitutive functions for hindered and compression settling velocity using laboratory-scale measurements and one-dimensional (1-D) simulation models. For model validation, the triangulation technique was used, including independent laboratory- and full-scale measurements as well as 1-D and computational fluid dynamics (CFD) simulation models.

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies, Jaume I University, University of Bath, Bioras
Contributors: Plósz, B. G., Climent, J., Griffith, C., Haecky, P., Blackburn, N., Chiva, S., Valverde Pérez, B.
Number of pages: 10
Publication date: 2018
Peer-reviewed: Yes
Keywords: Activated sludge settling velocity, Computational fluid dynamics (CFD), Model identification
Electronic versions:
WRRmod2018_Settling_model_identification_Plosz_et_al_full_paper.pdf
Source: PublicationPreSubmission
Source-ID: 144919354
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2018

Nutrient recovery from industrial wastewater as single cell protein by a co-culture of green microalgae and methanotrophs

Conventional water treatment technologies remove nutrients via resource intensive processes. However, new approaches for nutrient recycling are needed to provide food to the increasing population. This work explores the use of microbial biomass as a means to recover nutrients from industrial wastewater and upcycle them to feed grade single cell protein. Results demonstrated that both algae and bacteria could remove or assimilate most of the organic carbon present in the wastewater (~95% removal for monocultures and 91% for the algal-bacterial consortium). However, their growth stopped before nutrients and substrates in the gas phase (i.e., methane and oxygen for methanotrophs and carbon dioxide for algae) were depleted. Likely, algal growth was light limited and stopped after organic carbon was consumed. Methanotrophs growth could be limited by trace elements (e.g., copper). Nevertheless, for all cultures the protein content (45% of dry weight, DW, for methanotrophs; 52.5% of DW for algae; and 27.6% of DW for consortium) and amino acid profile was suitable for substitution of conventional protein sources. Further research should focus on increasing productivity of biomass grown on wastewater resources.
Research in organic waste as resources: How to implement circular bio-economy in the urban context?

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies
Publication date: 2018
Media of output: PowerPoint

Event information
Event: Natur & miljø 2018
Location: Herning, Denmark
Electronic versions:
Natur_Miljo.pdf
Source: PublicationPreSubmission
Source-ID: 149423814
Research output: Research › Sound/Visual production (digital) – Annual report year: 2018

The pH dependency of N-converting enzymatic processes, pathways and microbes: effect on net N₂O production
Nitrous oxide (N₂O) is emitted during microbiological nitrogen (N) conversion processes, when N₂O production exceeds N₂O consumption. The magnitude of N₂O production vs. consumption varies with pH and controlling net N₂O production might be feasible by choice of system pH. This article reviews how pH affects enzymes, pathways and microorganisms that are involved in N-conversions in water engineering applications. At a molecular level, pH affects activity of cofactors and structural elements of relevant enzymes by protonation or deprotonation of amino acid residues or solvent ligands, thus causing steric changes in catalytic sites or proton/electron transfer routes that alter the enzymes’ overall activity. Augmenting molecular information with, e.g., nitritation or denitrification rates yields explanations of changes in net N₂O production with pH. Ammonia oxidizing bacteria are of highest relevance for N₂O production, while heterotrophic denitrifiers are relevant for N₂O consumption at pH > 7.5. Net N₂O production in N-cycling water engineering systems is predicted to display a 'bell-shaped' curve in the range of pH 6.0-9.0 with a maximum at pH 7.0-7.5. Net N₂O production at acidic pH is dominated by N₂O production, whereas N₂O consumption can outweigh production at alkaline pH. Thus, pH 8.0 may be a favourable pH set-point for water treatment applications regarding net N₂O production.

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering
Contributors: Blum, J., Su, Q., Ma, Y., Valverde Pérez, B., Domingo-Felez, C., Jensen, M. M., Smets, B. F.
Pages: 1623-1640
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: Environmental Microbiology
Volume: 20
Issue number: 5
ISSN (Print): 1462-2912
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.83 SJR 2.209 SNIP 1.31
Web of Science (2017): Impact factor 4.974
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 5.02 SJR 2.377 SNIP 1.383
Web of Science (2016): Impact factor 5.395
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.61 SJR 3.02 SNIP 1.571
Web of Science (2015): Impact factor 5.932
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.6 SJR 2.862 SNIP 1.599
Web of Science (2014): Impact factor 6.201
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.37 SJR 3.273 SNIP 1.823
Web of Science (2013): Impact factor 6.24
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.94 SJR 3.165 SNIP 1.639
Web of Science (2012): Impact factor 5.756
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 6.1 SJR 3.368 SNIP 1.7
Web of Science (2011): Impact factor 5.843
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.775 SNIP 1.551
Web of Science (2010): Impact factor 5.537
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.502 SNIP 1.378
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.495 SNIP 1.322
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.303 SNIP 1.498
Scopus rating (2006): SJR 2.451 SNIP 1.517
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.431 SNIP 1.519
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.08 SNIP 1.239
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.794 SNIP 1.241
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.378 SNIP 1.028
Scopus rating (2001): SJR 1.317 SNIP 1.228
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 1.075 SNIP 0.859
Web of Science (2000): Indexed yes
Use of Forward Osmosis to Harvest Methane Oxidizing Bacteria Producing Single Cell Protein

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies, Technical University of Denmark
Pages: 25-25
Publication date: 2018

Host publication information
Title of host publication: Danish Water Forum Annual Water Conference 2018 - abstract book
Place of publication: Lyngby, Denmark
Publisher: Danish Water Forum

Valoirisation of Effluents from Anaerobic Digestion as Single Cell Protein – Focus on Safe Gas Supply

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Water Technologies, Technical University of Denmark
Number of pages: 2
Publication date: 2018
Peer-reviewed: Yes
Event: Abstract from 6th International Conference on Sustainable Solid Waste Management (NAXOS 2018), Naxos Island, Greece.

A systematic model identification method for chemical transformation pathways – the case of heroin biomarkers in wastewater
This study presents a novel statistical approach for identifying sequenced chemical transformation pathways in combination with reaction kinetics models. The proposed method relies on sound uncertainty propagation by considering parameter ranges and associated probability distribution obtained at any given transformation pathway levels as priors for parameter estimation at any subsequent transformation levels. The method was applied to calibrate a model predicting the transformation in untreated wastewater of six biomarkers, excreted following human metabolism of heroin and codeine. The method developed was compared to parameter estimation methods commonly encountered in literature (i.e., estimation of all parameters at the same time and parameter estimation with fix values for upstream parameters) by assessing the model prediction accuracy, parameter identifiability and uncertainty analysis. Results obtained suggest that the method developed has the potential to outperform conventional approaches in terms of prediction accuracy, transformation pathway identification and parameter identifiability. This method can be used in conjunction with optimal experimental designs to effectively identify model structures and parameters. This method can also offer a platform to promote a closer interaction between analytical chemists and modellers to identify models for biochemical transformation pathways, being a prominent example for the emerging field of wastewater-based epidemiology.
Co-cultivation of Green Microalgae and Methanotrophic Bacteria for Single Cell Protein Production from Wastewater

Conventional water treatment technologies remove nutrients via resource intensive processes. However, new approaches for residual nutrient recycling are needed to provide food to the increasing world population. This work explores the use of microbial biomass – methane oxidizing bacteria and green microalgae – as a means to recover nutrients from industrial wastewater and upcycle them to feed grade single cell protein. Results demonstrated that both algae and bacteria could remove or assimilate most of the organic carbon present in the wastewater. However, their growth stopped before nutrients and substrates in the gas phase (i.e., methane and oxygen for methanotrophs and carbon dioxide for algae) were depleted. Likely, algal growth was light limited and stopped after organic carbon was consumed, whilst growth of methanotrophic bacteria could be limited by trace elements (e.g., copper). Nevertheless, the amino acid profile of both the monocultures and the algal-bacteria consortium was suitable for substitution of conventional protein sources. Further research should focus on increasing productivity of biomass grown on wastewater resources.

Development and validation of a novel monitoring system for batch flocculant solids settling process

Secondary sedimentation is the main hydraulic bottleneck of effective pollution control WWTP under wet-weather flow conditions. Therefore, online monitoring tools are required for control and optimization of the settling process under dynamic conditions. In this work we propose a novel monitoring system able to monitor batch settling tests by tracking the sludge blanket height and solid concentration along the column in the range of 1 to 8 g L-1. The system could be efficiently applied to monitor the batch settling tests of several full scale treatment plants run under different operational conditions.

In-situ UV-Vis Probe to Monitor Algal Photobioreactors Treating Municipal Wastewater

General information

State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark, Swiss Federal Institute of Aquatic Science and Technology
Contributors: Valverde Pérez, B., Wágner, D. S., Steidl, M., Villez, K., Plósz, B. G.
Model-based identification of chemicals transformation pathways combined with reaction kinetics models– the case of heroin biomarkers in wastewater

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Environmental Chemistry
Contributors: Ramin, P., Valverde Pérez, B., Polesel, F., Gernaey, K., Plósz, B. G.
Number of pages: 4
Publication date: 2017
Peer-reviewed: Yes
Event: Abstract from Frontiers International Conference on Wastewater Treatment (FICWTM2017), Palermo, Italy.
Electronic versions:
FICWTM2017_Ramin_et_al_final_1_.pdf
Source: PublicationPreSubmission
Source-ID: 130185006
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2017

Modelling biotransformation of drug biomarkers by sewer biofilms

General information
State: Published
Organisations: Water Technologies, Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Department of Environmental Engineering, Environmental Chemistry, University of Bath
Number of pages: 4
Publication date: 2017
Peer-reviewed: Yes
Event: Abstract from 10th International Conference on Biofilm Reactors, Dublin, Ireland.
Electronic versions:
BIOFILM_2017_abstract_final_1_.pdf
Source: PublicationPreSubmission
Source-ID: 130184990
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2017

Modelling of green microalgal growth and algal storage processes using wastewater resources
Recent research focuses on the recovery of nutrients, water and energy from wastewater. Microalgal cultivation on wastewater resources is considered as a more sustainable means to produce fertilizers or biofuels. Innovative systems that incorporate microalgal cultivation into conventional wastewater processes have been developed. The effective design, optimisation and control of these systems require modelling tools that can readily extend existing benchmark models with new sub-models. Several process models have been developed to simulate algal growth. Some models include only one variable, e.g., light, whereas others include multiple variables, such as pH, nitrogen, phosphorus and organic carbon. This chapter aims to collect and describe green microalgal process models that can be used in wastewater resource recovery systems together with their limitations. Some of the listed models have been developed according to the activated sludge modelling (ASM) framework to facilitate the integration with existing modelling frameworks in water treatment. This chapter presents in detail the recently developed ASM-A biokinetic green microalgal process model. The model includes photoautotrophic and heterotrophic algal growth and uptake and storage of nutrients, including both nitrogen and phosphorus.
Nitrogen recovery from wastewater to produce microbial protein using methane oxidizing bacteria

**General information**
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering, Technical University of Denmark
Contributors: Xing, W., Valverde Pérez, B., Pape, M. L., De Francisci, D., Smets, B. F.
Number of pages: 2
Publication date: 2017
Peer-reviewed: Yes
Event: Abstract from Conference on Sustainable Wastewater Treatment and Resource Recovery: Research, Planning, Design and Operation, Chongqing, China.
Keywords: Nutrient recovery, Single cell protein (SCP), Methane oxidizing bacteria (MOB)
Electronic versions: Abstract_2017_NRR_ChongQing_F.pdf
Source: PublicationPreSubmission
Source-ID: 139066476
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2017

$N_2O$ emissions from a single-stage partial nitritation/anammox granule-based reactor – a model based assessment

**General information**
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark, University of Santiago de Compostela
Contributors: Morset, M., Valverde Pérez, B., Blum, J., Domingo Felez, C., Mauricio-Iglesias, M., Smets, B. F.
Number of pages: 1
Publication date: 2017
Peer-reviewed: Yes
Event: Poster session presented at 10th International Conference on Biofilm Reactors, Dublin, Ireland.
Source: PublicationPreSubmission
Source-ID: 132025832
Research output: Research - peer-review › Poster – Annual report year: 2017

Simple control rules for mitigating $N_2O$ emissions in phase isolated fullscale WWTPs

**General information**
State: Published
Number of pages: 1
Publication date: 2017

**Host publication information**
Title of host publication: Book of Abstracts Sustain 2017
Simple control strategy for mitigating N₂O emissions in phase isolated full-scale WWTPs
Nitrous oxide (N₂O) is a strong greenhouse gas (GHG) and ozone depleter, with a warming potential 300 times higher than carbon dioxide (CO₂). 1.2% of the total anthropogenic N₂O emissions are believed to originate from the wastewater treatment (WWT) sector. Conventional biological nutrient removal processes relying on nitrification and denitrification are known to produce N₂O. A one year long-term study of N₂O production and emissions was performed at Lynetten, Denmark’s largest WWTP. Nitrification and denitrification takes place by alternating process conditions as well as influent and effluent flows in 20 pairs of interconnected and surface aerated reactors. The long-term data revealed that the N₂O emissions contribute to as much as 30% of the total CO₂ footprint from the WWTP. High ammonium concentrations and long aeration phases lead to high N₂O production and emissions rates. Nitrification phases were identified to produce and emit most of the N₂O. High production and emissions were also associated with the afternoon loading peaks at the WWTP. During denitrification phases N₂O was produced initially but consumed consequently. An effective control strategy was implemented, whereby N₂O emissions were reduced from 0.8% to 0.3% of the nitrogen load during the mitigation period.

Transformation and sorption of illicit drug biomarkers in sewer biofilms
In-sewer transformation of drug biomarkers (excreted parent drugs and metabolites) can be influenced by the presence of biomass in suspended form as well as attached to sewer walls (biofilms). Biofilms are likely the most abundant and biologically active biomass fraction in sewers. In this study, 16 drug biomarkers were selected, including the major human metabolites of mephedrone, methadone, cocaine, heroin, codeine and tetrahydrocannabinol (THC). Transformation and sorption of these substances were assessed in targeted batch experiments using laboratory-scale biofilm reactors operated under aerobic and anaerobic conditions. A one-dimensional model was developed to simulate diffusive transport, abiotic and biotic transformation and partitioning of drug biomarkers. Model calibration to experimental results allowed estimating transformation rate constants in sewer biofilms, which were compared to those obtained using in-sewer suspended biomass. Our results suggest that sewer biofilms can enhance the transformation of most compounds. Through scenario simulations, we demonstrated that the estimation of transformation rate constants in biofilm can be significantly biased if the boundary layer thickness is not accurately estimated. This study complements our previous investigation on the transformation and sorption of drug biomarkers in the presence of only suspended biomass in untreated sewage. A better understanding of the role of sewer biofilms—also relative to the in-sewer suspended solids—and improved prediction of associated fate processes can lead to more accurate estimation of daily drug consumption in urban areas in wastewater-based epidemiological assessments.
UV-Vis spectrophotometry for Wastewater Resource Recovery with Algae Photobioreactors

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark, Swiss Federal Institute of Aquatic Science and Technology
Contributors: Valverde Pérez, B., Wágner, D. S., Steidl, M., Villez, K., Plósz, B. G.
Publication date: 2017
Media of output: PowerPoint

Event information
Event: 12th IWA Specialized Conference on Instrumentation, Control and Automation
Location: Quebec, Canada

Electronic versions:
ICA_PBR.pdf
Source: PublicationPreSubmission
Source-ID: 133237415
Research output: Research - Sound/Visual production (digital) – Annual report year: 2017

A novel bioflocculation method to separate microalgal biomass cultivated on wastewater resources

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark
Contributors: Wágner, D. S., Radovici, M., Valverde Perez, B., Plósz, B. G.
Number of pages: 2
Publication date: 2016
Peer-reviewed: Yes
Event: Abstract from 2nd Young Water Professionals Denmark Conference and Workshop, Aarhus, Denmark.
Electronic versions:
YWPDK_2nd_conf_abstract.pdf
Source: PublicationPreSubmission
Source-ID: 123735445
Research output: Research - Conference abstract for conference – Annual report year: 2016
Bioflocculation of green microalgae using activated sludge and potential for biogas production

General information
State: Published
Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering, Technical University of Denmark
Contributors: Radovici, M., Wágner, D. S., Angelidaki, I., Valverde Pérez, B., Plósz, B. G.
Number of pages: 1
Publication date: 2016
Peer-reviewed: Yes
Event: Poster session presented at 13th IWA Leading Edge Conference on Water and Wastewater Technologies, Jerez da la Frontera, Spain.
Electronic versions: LET_poster_final.pdf
Source: PublicationPreSubmission
Source-ID: 125031600
Research output: Research - peer-review › Poster – Annual report year: 2016

Co-digestion of microalgae and activated sludge following a novel bioflocculation method

General information
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Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering, Technical University of Denmark
Contributors: Wágner, D. S., Radovici, M., Angelidaki, I., Valverde Perez, B., Plósz, B. G.
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Control structure design for resource recovery using the enhanced biological phosphorus removal and recovery (EBP2R) activated sludge process

Nowadays, wastewater is considered as a set of resources to be recovered rather than a mixture of pollutants that should be removed. Many resource recovery schemes have been proposed, involving the use of novel technologies whose controllability is poorly studied. In this paper we present a control structure for the novel enhanced biological phosphorus removal and recovery (EBP2R) process, which is currently under development. The aim of the EBP2R is to maximize phosphorus recovery through optimal green micro-algal cultivation, which is achieved by controlling the nitrogen to phosphorus ratio (N-to-P ratio) fed to the algae. Process control structures are developed for a sequencing batch reactor (SBR) and a continuous flow reactor system (CFS). Results, obtained using the Benchmark Simulation Model No. 1 (BSM1) dynamic input disturbance time series, suggest that the SBR can maintain a stable N-to-P ratio in the effluent (16.9 ± 0.07) and can recover about 72% of the influent phosphorus. The phosphorus recovered by the CFS is limited by the influent nitrogen (65% of the influent phosphorus load). Using the CFS configuration the effluent N-to-P ratio cannot be effectively controlled (16.45 ± 2.48). Therefore, it is concluded that the SBR is the most effective reactor configuration for the EBP2R process. Importantly, the designed control structures rely on control loops that do not require chemical dosing for nutrient management, thereby reducing the environmental footprint of the EBP2R process. The proposed control strategies can be applied to other phosphorus recovery schemes where short sludge age EBPR systems play an important role.

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Contributors: Valverde Perez, B., Fuentes-Martínez, J. M., Flores Alsina, X., Gernaey, K., Huusom, J. K., Plósz, B. G.
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Publication information
Harvesting microalgae using activated sludge can decrease polymer dosing and enhance methane production via co-digestion in a bacterial-microalgal process

Third generation biofuels, e.g. biofuels production from algal biomass, have gained attention due to increased interest on global renewable energy. However, crop-based biofuels compete with food production and should be avoided. Microalgal cultivation for biofuel production offers an alternative to crops and can become economically viable when combined with the use of used water resources. Besides nutrients and water, harvesting microalgal biomass represents one of the major costs related to biofuel production and thus efficient and cheap solutions are needed. In bacterial-algal systems, there is the potential to produce energy by co-digesting the two types of biomass. We present an innovative approach to recover microalgal biomass via a two-step flocculation using bacterial biomass after the destabilisation of microalgae with conventional cationic polymer. A short solids retention time (SRT) enhanced biological phosphorus removal (EBPR) system was combined with microalgal cultivation. Two different bacterial biomass removal strategies were assessed whereby bacterial biomass was collected from the solid-liquid separation after the anaerobic phase and after the aerobic phase. Microalgal recovery was tested by jar tests where three different chemical coagulants in coagulation-flocculation tests (AlCl3, PDADMAC and Greenfloc 120) were assessed. Furthermore, jar tests were conducted to assess the microalgal biomass recovery by a two-step flocculation method, involving chemical coagulants in the first step and bacterial biomass used in the second step to enhance the flocculation. Up to 97% of the microalgal biomass was recovered using 16 mg polymer/g algae and 0.1 g algae/g bacterial biomass. Moreover, the energy recovery by the short-SRT EBPR system combined with microalgal cultivation was assessed via biomethane potential tests. Up to 560 ± 24 mL CH4/gVS methane yield was obtained by co-digesting bacterial biomass collected after the anaerobic phase and microalgal biomass. The energy recovery in terms of methane production obtained in the short-SRT EBPR system is about 40% of the influent chemical energy.

General information

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Web of Science (2015): Impact factor 4.694
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Impact of influent quality on green microalgal cultivation with used water resources – experimental assessment combined with image analysis

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Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark
Contributors: Wágner, D. S., Valverde Pérez, B., Cazzaniga, C., Steidl, M., Dechesne, A., Plósz, B. G.
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Life cycle assessment as development and decision support tool for wastewater resource recovery technology

Life cycle assessment (LCA) has been increasingly used in the field of wastewater treatment where the focus has been to identify environmental trade-offs of current technologies. In a novel approach, we use LCA to support early stage research and development of a biochemical system for wastewater resource recovery. The freshwater and nutrient content of wastewater are recognized as potential valuable resources that can be recovered for beneficial reuse. Both recovery and reuse are intended to address existing environmental concerns, for example, water scarcity and use of non-renewable phosphorus. However, the resource recovery may come at the cost of unintended environmental impacts. One promising recovery system, referred to as TRENs, consists of an enhanced biological phosphorus removal and recovery system (EBP2R) connected to a photobioreactor. Based on a simulation of a full-scale nutrient and water recovery system in its potential operating environment, we assess the potential environmental impacts of such a system using the EASETECH model. In the simulation, recovered water and nutrients are used in scenarios of agricultural irrigation-fertilization and aquifer recharge. In these scenarios, TRENs reduces global warming up to 15% and marine eutrophication impacts up to 9% compared to conventional treatment. This is due to the recovery and reuse of nutrient resources, primarily nitrogen. The key environmental concerns obtained through the LCA are linked to increased human toxicity impacts from the chosen end use of wastewater recovery products. The toxicity impacts are from both heavy metals release associated with land application of recovered nutrients and production of AlCl3, which is required for advanced wastewater treatment prior to aquifer recharge. Perturbation analysis of the LCA pinpointed nutrient substitution and heavy metals content of algae biofertilizer as critical areas for further research if the performance of nutrient recovery systems such as TRENs is to be better characterized. Our study provides valuable feedback to the TRENs developers and identifies the importance of system expansion to include impacts outside the immediate nutrient recovery system itself. The study also show for the first time the successful evaluation of urban-to-agricultural water systems in EASETECH.
Low-sludge age EBPR process for resource recovery – microbial and biochemical process characterization

**General information**
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Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark

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Low-sludge age EBPR process for resource recovery – microbial and biochemical process characterization

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Microbial and biochemical process characterization of a low-sludge age EBPR process for resource recovery

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Modelling and control of nitrogen and phosphorus removing systems

General information
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Organisations: Department of Environmental Engineering, Water Technologies, Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Krüger Veolia Water Technologies, University of Santiago de Compostela
Contributors: Valverde Pérez, B., Flores Alsina, X., Vangsgaard, A. K., Mauricio-Iglesias, M.
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Modelling of two-stage WWT systems: a faster road towards resource recovery

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Organisations: Department of Environmental Engineering, Water Technologies
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Optimal algal cultivation for used water resource recovery

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Protocol for settling velocity model calibration using an innovative batch settling test– focus on identifiability analysis of the hindered-transient-compression model

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Organisations: Department of Environmental Engineering, Water Technologies, Technical University of Denmark
Contributors: Valverde Pérez, B., Penkarski-Rodon, E., Zhang, X., Wágner, D. S., Plósz, B. G.
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Secondary settling sensor setup development – testing prototypes and compression models via practical model parameter identifiability assessment

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Short-sludge age EBPR process – Microbial and biochemical process characterisation during reactor start-up and operation
The new paradigm for used water treatment suggests the use of short solid retention times (SRT) to minimize organic substrate mineralization and to maximize resource recovery. However, little is known about the microbes and the underlying biogeochemical mechanisms driving these short-SRT systems. In this paper, we report the start-up and operation of a short-SRT enhanced biological phosphorus removal (EBPR) system operated as a sequencing batch reactor (SBR) fed with preclarified municipal wastewater, which is supplemented with propionate. The microbial community was analysed via 16S rRNA amplicon sequencing. During start-up (SRT = 8 d), the EBPR was removing up to 99% of the influent phosphate and completely oxidized the incoming ammonia. Furthermore, the sludge showed excellent settling properties. However, once the SRT was shifted to 3.5 days nitrification was inhibited and bacteria of the Thiothrix taxon proliferated in the reactor, thereby leading to filamentous bulking (sludge volume index up to SVI = 1100 mL/g). Phosphorus removal deteriorated during this period, likely due to the out-competition of polyphosphate accumulating organisms (PAO) by sulphate reducing bacteria (SRB). Subsequently, SRB activity was suppressed by reducing the anaerobic SRT from 1.2 day to 0.68 day, with a consequent rapid SVI decrease to ~200 mL/g. The short-SRT EBPR effectively removed phosphate and nitrification was mitigated at SRT = 3 days and oxygen levels ranging from 2 to 3 mg/L.

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Sources and propagation of uncertainty in N2O model predictions

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Organisations: Department of Environmental Engineering, Water Technologies, Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Contributors: Domingo Felez, C., Valverde Pérez, B., Plósz, B. G., Sin, G., Smets, B. F.
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Systematic design of an optimal control system for the SHARON-Anammox process

A systematic design of an optimal control structure for the SHARON-Anammox nitrogen removal process is studied. The methodology incorporates two novel features to assess the controllability of the design variables candidate for the regulatory control layer: (i) H- control method, which formulates the control problem as a mathematical optimization problem, and (ii) close-loop disturbance gain (CLDG) plots. It is shown that the methodology is especially appropriate for bioreactors. The solution of the mixed sensitivity stacked H control problem ranked the combinations of controlled variables (CVs). The best candidates to CVs were paired with the manipulated variables using the relative gain array. The proposed control structure was further analyzed and verified for disturbance rejection using the CLDG plots. The optimal pairing of CVs with the actuators (kLa and acid/base addition) is found to be dissolved oxygen (DO) and pH in the SHARON reactor. Furthermore, to relate the controller actions to process operation objective, nitrogen removal efficiency, two cascade control systems are designed. The first cascade loop controls TNN/TAN ratio in the influent to the Anammox reactor by adjusting the set point for DO in the regulatory layer, while the second cascade loop controls the nitrogen removal efficiency (i.e. effluent TNN and TAN) by adjusting the TNN/TAN ratio at the effluent of the SHARON reactor. The control system is evaluated and benchmarked using a set of realistic dynamic scenario simulations, demonstrating that the different control strategies successfully maintain stable and high nitrogen removal efficiency. The nested cascade control structure shows the best performance, removing up to 95% of the influent ammonia. Both the control design methodology and the resulting optimal control structures are expected to contribute to stable operation and control of these emerging nitrogen removal technologies.

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State: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Environmental Engineering, Water Technologies, CAPEC-PROCESS
Contributors: Valverde Perez, B., Mauricio Iglesias, M., Sin, G.
Scopus rating (2005): SJR 0.931 SNIP 2.347
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**Systematic design of optimal control systems for WWTPs: case study of the SHARON-Anammox process**

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**Towards a consensus-based biokinetic model for green microalgae – The ASM-A**
Cultivation of microalgae in open ponds and closed photobioreactors (PBRs) using wastewater resources offers an opportunity for biochemical nutrient recovery. Effective reactor system design and process control of PBRs requires process models. Several models with different complexities have been developed to predict microalgal growth. However, none of these models can effectively describe all the relevant processes when microalgal growth is coupled with nutrient removal and recovery from wastewaters. Here, we present a mathematical model developed to simulate green microalgal growth (ASM-A) using the systematic approach of the activated sludge modelling (ASM) framework. The process model – identified based on a literature review and using new experimental data – accounts for factors influencing photoautotrophic and heterotrophic microalgal growth, nutrient uptake and storage (i.e. Droop model) and decay of microalgae. Model parameters were estimated using laboratory-scale batch and sequenced batch experiments using the novel Latin Hypercube Sampling based Simplex (LHSS) method. The model was evaluated using independent data obtained in a 24-L PBR operated in sequenced batch mode. Identifiability of the model was assessed. The model can effectively describe microalgal biomass growth, ammonia and phosphate concentrations as well as the phosphorus storage using a set of average parameter values estimated with the experimental data. A statistical analysis of simulation and measured data suggests that culture history and substrate availability can introduce significant variability on parameter values for predicting the reaction rates for bulk nitrate and the intracellularly stored nitrogen state-variables, thereby requiring scenario specific model calibration. ASM-A was identified using standard cultivation medium and it can provide a platform for extensions accounting for factors influencing algal growth and nutrient storage using wastewater resources.

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Organisations: Department of Environmental Engineering, Water Technologies, Residual Resource Engineering, Technical University of Denmark
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Towards an optimal experimental design for N2O model calibration during biological nitrogen removal

Process models describing nitrous oxide (N2O) production during biological nitrogen removal allow for the development of mitigation strategies of this potent greenhouse gas. N2O is an intermediate of nitrogen removal, hence its prediction is negatively affected by the uncertainty associated to its substrates. Improving experimental designs for model calibration reduces prediction uncertainties. Moreover, the individual analysis of autotrophic and heterotrophic contribution to the total NO and N2O pool was assessed for already proposed model structures under different experimental scenarios. The results show the need for information-rich experimental designs to assess the predicting capabilities of N2O models. This work represents a step further in understanding the N2O production and emissions associated to conventional wastewater treatment. Moreover, it will facilitate the development of strategies to minimize the carbon footprint of wastewater treatment plants.

Control Structure Design for an EBP2R Process Operated as a Sequencing Batch Reactor

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**Control Structure Design of an Innovative Enhanced Biological Nutrient Recovery Activated Sludge System Coupled with a Photobioreactor**

The TRENS system is a train of biological units designed for resource recovery from wastewater. It is a sequence of a modified enhanced biological phosphorus removal and recovery system (EBP2R) coupled with a photobioreactor (PBR). The bacteria-based system constructs an optimal culture media for the downstream algae cultivation. In this work, we present a control strategy to ensure an optimal nutrient balance to feed to the PBR, so the grown algal suspension is suitable for fertigation (irrigation and fertilization of agricultural crops). The system is able to recover up to 75% of the influent load, while keeping an optimal N-to-P ratio of 16 in the influent to the PBR. The system is tested under different scenarios, where the influent quality is disturbed following a step change. The control system is able to reject most of the disturbances. However, when the P-recovery is limited by the bacteria in the reactor, the control system is not able to keep the optimal phosphorus load, but only the optimal percentage recovery from the influent phosphorus. In this scenario, the system is kept under optimal conditions – in terms of nutrient balance – because the N-to-P ratio is still at 16, so the green microalgae can take up most of the incoming nutrients into the PBR. The control system is able to keep the optimal phosphorus load during dynamic conditions. However when the influent nitrogen is limiting the process, the N-to-P ratio drops under the optimal value. Further research is needed in order to assess the controllability of the PBR and the possible impact on the upstream operation conditions.

**General information**

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BFI (2015): BFI-level 1
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Scopus rating (2011): CiteScore 0.3 SJR 0.205 SNIP 0.261
ISI indexed (2011): ISI indexed no
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EBP2R – An innovative enhanced biological nutrient recovery activated sludge system to produce growth medium for green microalgae cultivation

Current research considers wastewater as a source of energy, nutrients and water and not just a source of pollution. So far, mainly energy intensive physical and chemical unit processes have been developed to recover some of these resources, and less energy and resource demanding alternatives are needed. Here, we present a modified enhanced biological phosphorus removal and recovery system (referred to as EBP2R) that can produce optimal culture media for downstream micro-algal growth in terms of N and P content. Phosphorus is recovered as a P-stream by diversion of some of the effluent from the upstream anaerobic reactor. By operating the process at comparably low solids retention times (SRT), the nitrogen content of wastewater is retained as free and saline ammonia, the preferred form of nitrogen for most micro-algae. Scenario simulations were carried out to assess the capacity of the EBP2R system to produce nutrient rich organic-carbon depleted algal cultivation media of target composition. Via SRT control, the quality of the constructed cultivation media can be optimized to support a wide range of green micro-algal growth requirements. Up to 75% of the influent phosphorus can be recovered, by diverting 30% of the influent flow as a P-stream at an SRT of 5 days. Through global sensitivity analysis we find that the effluent N-to-P ratio and the P recovered are mainly dependent on the influent quality rather than on biokinetics or stoichiometry. Further research is needed to demonstrate that the system performance predicted through the model-based design can be achieved in reality.

General information

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Scopus rating (2017): CiteScore 7.55 SJR 2.601 SNIP 2.358
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Web of Science (2015): Impact factor 5.991
Web of Science (2015): Indexed yes
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Web of Science (2014): Impact factor 5.528
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BFI (2013): BFI-level 2
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Web of Science (2013): Impact factor 5.323
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.15 SJR 2.914 SNIP 2.442
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 5.43 SJR 2.862 SNIP 2.355
Web of Science (2011): Impact factor 4.865
ISI indexed (2011): ISI indexed yes
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Web of Science (2010): Impact factor 4.546
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.319 SNIP 2.224
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.073 SNIP 2.178
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.94 SNIP 2.184
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.902 SNIP 2.233
Web of Science (2006): Indexed yes
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Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.209 SNIP 2.108
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.702 SNIP 1.908
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.568 SNIP 1.757
Web of Science (2002): Indexed yes
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Impact of operational conditions and reactor configuration on process performance and microbial community in short solid retention time EBPR systems

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Life cycle assessment as decision support tool for development of a resource recovery technology

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Residual Resource Engineering, Technical University of Denmark
Contributors: Fang, L. L., Valverde Perez, B., Damgaard, A., Plósz, B. G., Rygaard, M.
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Life cycle assessment as decision support tool in early stage development of a new technology for wastewater resource recovery

Life cycle assessment (LCA) has been increasingly used in the field of wastewater treatment where the focus has been to identify environmental trade-offs of current technologies. In a novel approach, we use LCA to support early stage research and development of a biochemical system for wastewater resource recovery. The freshwater and nutrient content of wastewater are to a large extent recognized as potential valuable resources that can be recovered for beneficial reuse. Both recovery and reuse are intended to address existing environmental concerns, for example water scarcity and use of non-renewable phosphorus. However, the resource recovery may come at the cost of unintended environmental impacts.

One promising recovery system, referred to as TRENs, consists of an enhanced biological phosphorus removal and recovery system (EBP2R) connected to a photobioreactor. We present the environmental impact results of the first simulated full-scale TRENs system in its potential operating environment as a side-stream process to an existing Copenhagen wastewater treatment plant. The system recovers water and nutrients that can be used in scenarios of agricultural irrigation-fertilization and aquifer recharge. The environmental performance of the system has been evaluated through life cycle assessment using EASETECH software.

For the chosen scenarios, TRENs reduces global warming up to 15% and marine eutrophication impacts up to 9% compared to conventional treatment. This is due to the TRENs system’s lower aeration demands, and thus energy consumption, as well as recovery of nitrogen. The key environmental concerns obtained through the LCA are linked to increased human toxicity impacts from the chosen end use of TRENs products. The toxicity impacts are from both heavy metals release associated with land application of recovered wastewater nutrients and production of AlCl3, which is required for advanced treatment prior to aquifer recharge.

Perturbation analysis of the LCA model in EASETECH pinpointed nutrient substitution and heavy metals content of algae biofertilizer as critical areas for further research if TRENs performance is to be better characterized. These findings...
provided the first iteration in addressing the environmental performance of TRENS as it progresses from concept to commercial implementation. In conclusion, our study provided valuable feedback to the TRENS developers and identified the importance of system expansion to include impacts outside the immediate biological system of TRENS itself. Also the study showed for the first time the successful evaluation of urban-to-agricultural water systems in EASETECH.

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**Modeling green microalgal growth, nutrient uptake and storage in the ASM framework**

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**Wastewater resource recovery via the Enhanced Biological Phosphorus Removal and Recovery (EBP2R) process coupled with green microalgae cultivation**

Conventionally, the objective of wastewater treatment has been the elimination of organic and inorganic pollutants, such as nitrogen and phosphorus, from wastewater. Current research promotes a paradigm shift, whereby wastewater is considered not only as a source of pollution but also as a source of nutrients, fresh water and renewable energy. This new approach redefines the conventional wastewater treatment plant (WWTP) as a biorefinery where different streams are split, each of them rich in different resources. Since many wastewater treatment infrastructures were built about 30 years ago, there is an opportunity of including these novel technologies as part of the future retrofitting and enlargements of the plants. Nevertheless, most of the proposed resource recovery strategies suffer from intensive use of chemicals or energy. In extreme cases, the environmental impact of the technology by itself completely counters the benefit of resource recovery. As an alternative, this thesis proposes a new fully biochemical resource recovery process, referred to as TRENS. The TRENS consists of an enhanced biological phosphorus removal and recovery (EBP2R) process combined with a photobioreactor (PBR). The EBP2R process is operated at relatively low solid retention time (SRT). Hence the bulk of nitrogen is preserved as ammonium, which is the preferred nitrogen source for green micro-algal growth. The effluent criterion for the EBP2R is set to meet the micro-algal nutrient requirements in terms of nitrogen and phosphorus. To this end a phosphorus-rich stream (referred to as P-stream) is diverted from the anaerobic phase of the EBP2R and combined with a nitrogen-rich stream (referred to as N-stream). As a function of the SRT and the P-stream diversion rate, different nitrogen-to-phosphorus ratios (N-to-P ratio) can be produced, thereby meeting the nutrient requirements of different micro-algal species. Organic carbon oxidation is minimized due to the low SRT. Therefore, most of the organic carbon is
inorporated to the sludge via microbial assimilation or storage and conveyed to the anaerobic digester for biogas production. The fraction of nitrogen which cannot be recovered is removed via completely autotrophic nitrogen removal (CANR). First, a feasibility assessment of the EBPR process as an algal culture media generator was carried out using continuous-flow and sequencing batch reactor (SBR) configurations. Systems were modelled using the activated sludge model 2d (ASM-2d). Regardless of the process configuration, factors that can potentially limit nutrient recovery comprise the system SRT and the nitrate recirculated to the anaerobic phase/reactor. Additionally, continuous-flow EBPR systems can suffer from phosphorus starvation in the aerobic reactors as a result of excessive P-stream diversion. Furthermore, in continuous-flow mode, the P-stream diversion increases the aerobic SRT, while the system SRT is kept. Consequently, nitrifying bacteria can proliferate in the continuous system oxidizing ammonia to nitrate. Therefore, at high P-stream flow diversions polyphosphate accumulating organisms (PAOs) may be outcompeted by denitrifying bacteria. The sequencing EBPR yielded no higher phosphorus recovery than the continuous flow system. For each of the EBPR configurations a control structure has been developed and tested using a set of dynamic influent disturbance scenarios. The sequencing EBPR system was found to be sensitive to large input disturbances. Special care should be taken when tuning the controllers for the sequencing EBPR to avoid too aggressive control actions that can potentially destabilize the system. Under dynamic conditions, the sequencing EBPR show better performance in terms of phosphorus recovery and effluent quality (i.e. optimal N-to-P ratio fed to the PBR) than the continuous flow system. Second, two short SRT EBPR systems were implemented as laboratory-scale continuous-flow and SBR reactor systems. Both systems suffered from extreme filamentous bulking (sludge volume index, SVI>1000 ml/g). Via 16rRNA amplicon sequencing we identified Thiobthrix as the main filamentous bacteria driving activated sludge settleability. Thiobthrix proliferated in the reactors when sulphate was reduced to sulphur reduced compounds, such as sulphide, by sulphate reducing bacteria (SRBs). Phosphorus removal was poor during the filamentous bulking event, which was a consequence of the interactions between SRBs and PAOs in the anaerobic phase. SRBs can compete with PAOs for volatile fatty acids under anaerobic conditions. Additionally, sulphide can inhibit phosphorus release by PAOs. As a result, PAOs were washed out from the systems. Filamentous bulking was mitigated and phosphorus removal was restored by reducing the anaerobic SRT of the SBR. However, this strategy failed when applied to the continuous flow system, where only the SVI could be improved. When extending the aforementioned studies to include the PBR, we identified the lack of a model suitable to describe resource recovery from wastewater via green micro-algal cultivation. Furthermore, neither of models published in literature were compatible to interface with ASM-2d. Therefore, the third part of the PhD project focusses on the development of a process model for micro-algal growth and substrate storage kinetics (referred to as ASM-A). To facilitate the integration in already well-established simulation platforms for wastewater treatment, e.g., the Benchmark Simulation Models 1 and 2, ASM-A was implemented as an extension to the ASM-2d. A set of experiments at different laboratory-scales (microbatch, 1-litre and 24-litre SBR) was designed to generate data for model identification. Furthermore, an independent data set was used for model evaluation. The ASM-A can effectively predict the algal biomass growth, as well as the ammonium and phosphorus concentrations in the bulk liquid and the microbial stored phosphorus. Conversely, our results suggest that the maximum uptake rate parameter for nitrate can be significantly affected by culture history. Therefore the prediction of bulk nitrate concentration and the microbial stored nitrogen requires case-specific model calibration. Finally, the models developed in PhD project were used to provide data for the inventory of a life cycle assessment (LCA) of the TRENs system implemented in the Copenhagen area. The LCA highlighted the benefits of recovering nutrients but also suggested that heavy metals can potentially impose a bottleneck when reusing water and nutrients from the used water. Overall, this thesis describes the early stage design of the TRENs system, where model-based studies and laboratory-scale experiments have been used to define the optimal process operation and address future research needs.
Microalgae cultivation conditions in microplates will differ from large-scale photobioreactors in crucial parameters such as light profile, mixing and gas transfer. Hence volumetric productivity \( (P_v) \) measurements made in microplates cannot be
directly scaled up. Here we demonstrate that it is possible to use microplates to measure characteristic exponential growth rates and determine the specific growth rate light intensity dependency (μ-I curve), which is useful as the key input for several models that predict Pv. Nannochloropsis salina and Chlorella sorokiniana specific growth rates were measured by repeated batch culture in microplates supplied with continuous light at different intensities. Exponential growth unlimited by gas transfer or self-shading was observable for a period of several days using fluorescence, which is an order of magnitude more sensitive than optical density. The microplate datasets were comparable to similar datasets obtained in photobioreactors and were used an input for the Huesemann model to accurately predict Pv.

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Modelling and assessment of the storage of nutrients in a mixed green microalgae culture

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The Effect Of Light On Mixed Green Micro-Algal Growth: Experimental Assessment And Modelling

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Residual Resource Engineering, Technical University of Denmark
A Mixed Green Micro-Algal Model (MAMO) – Model Identification And Calibration Using Synthetic Medium And Nutrient Rich Carbon Depleted Wastewater

The reuse of wastewater resources via micro-algal cultivation is a cost-effective and sustainable solution for third generation biofuel production. A process model, describing photobioreactor operation – also in combination with activated sludge processes, however, is still missing. In this paper, we present a mathematical model, accounting for photoautotrophic and heterotrophic algal growth, nutrient uptake and storage in a mixed microalgae culture cultivated on nutrient rich carbon depleted (NRCD) wastewater. The process model is developed as an extension to the Activated Sludge Model 2d, ASM2d (Henze et al., 1999), and thus it also accounts for bacterial growth in the photobioreactor. We assess the factors, influencing algae growth and nutrient uptake, including macro-nutrient availability and light irradiance rate. Model parameters were estimated through microplate screenings and a series of batch experiments using a mixed green microalgal culture isolated in a wastewater pond, growing strictly in suspension.

Innovative Two-stage Engineering Solutions for Resource Recovery via Downstream Cultivation of Green Microalgae

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Microalgae Biorefinery - Industrial Symbiosis

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A pH simulator consisting of an efficient numerical solver of a system of nine nonlinear equations was constructed and implemented in the modeling software MATLAB. The pH simulator was integrated in a granular biofilm model and used to simulate the pH profiles within granules performing the nitritation-anammox process for a range of operating points. The simulation results showed that pH profiles were consistently increasing with increasing depth into the granule, since the proton producing aerobic ammonium oxidizers (AOB) were located close to the granule surface. Despite this pH profile, more NH3 was available for AOB than for anaerobic ammonium oxidizers (AnAOB), located in the center of the granules. However, operating at a higher oxygen loading resulted in steeper changes in pH over the depth of the granule and caused the NH3 concentration profile to increase from the granule surface towards the center. The initial value of the background charge and influent bicarbonate concentration were found to greatly influence the simulation result and should be accurately measured. Since the change in pH over the depth of the biofilm was relatively small, the activity potential of the microbial groups affected by the pH did not change more than 5% over the depth of the granules.
Selection of controlled variables in bioprocesses. Application to a SHARON-Anammox process for autotrophic nitrogen removal

Selecting the right controlled variables in a bioprocess is challenging since the objectives of the process (yields, product or substrate concentration) are difficult to relate with a given actuator. We apply here process control tools that can be used to assist in the selection of controlled variables to the case of the SHARON-Anammox process for autotrophic nitrogen removal.
Control of SHARON reactor for autotrophic nitrogen removal in two-reactor configuration

With the perspective of investigating a suitable control design for autotrophic nitrogen removal, this work explores the control design for a SHARON reactor. With this aim, a full model is developed, including the pH dependency, in order to simulate the reactor and determine the optimal operating conditions. Then, the screening of controlled variables and pairing is carried out by an assessment of the effect of the disturbances based on the closed loop disturbance gain plots. Two controlled structures are obtained and benchmarked by their capacity to reject the disturbances before the Anammox reactor.

Incremental design of control system of SHARON-Anammox process for autotrophic nitrogen removal

With the perspective of investigating a suitable control design for autotrophic nitrogen removal, this work explores the control design for a SHARON-Anammox reactor sequence. With this aim, a full model is developed, including the pH dependency, in order to simulate the reactor and determine the optimal operating conditions. Then, the screening of controlled variables and pairing is carried out by an assessment of the effect of the disturbances based on the closed loop disturbance gain plots. Three control structures are obtained and benchmarked by their capacity to reject the disturbances before the Anammox reactor.

Incremental design of control system of SHARON-Anammox process for autotrophic nitrogen removal

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Contributors: Mauricio Iglesias, M., Valverde Perez, B., Sin, G.
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Modelling and control design for SHARON/Anammox reactor sequence

With the perspective of investigating a suitable control design for autotrophic nitrogen removal, this work presents a complete model of the SHARON/Anammox reactor sequence. The dynamics of the reactor were explored pointing out the different scales of the rates in the system: slow microbial metabolism against fast chemical reaction and mass transfer. Likewise, the analysis of the dynamics contributed to establish qualitatively the requirements for control of the reactors, both for regulation and for optimal operation. Work in progress on quantitatively analysing different control structure (pairing of controlled variables with manipulated variables) as well as exploring the feasibility of advanced process control including model predictive control.

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Contributors: Valverde Perez, B., Mauricio Iglesias, M., Sin, G.
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pH variation and influence in an autotrophic nitrogen removing biofilm system: An efficient numerical solution strategy

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pH variation and influence in a nitrogen converting biofilm

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**Projects:**

Microalga-based bio-electro-remediation technology for antibiotic-dominated wastewater treatment and microalgal resource utilization study
Pan, M., PhD Student, Department of Environmental Engineering
Angelidaki, I., Main Supervisor
Valverde Pérez, B., Supervisor, Department of Environmental Engineering
Pan, G., Supervisor
01/12/2018 → 30/11/2021
Project: PhD

Wastewater resource recovery via the Enhanced Biological Phosphorus Removal and Recovery (EBP2R) process coupled with green microalgal cultivation
Valverde Pérez, B., PhD Student, Department of Environmental Engineering
Plósz, B. G., Main Supervisor
Smets, B. F., Supervisor
Trapp, S., Examiner
Oehmen, A., Examiner
Villez, K., Examiner
Technical University of Denmark
01/10/2012 → 27/01/2016
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Activities:

Feasibility-test of a complete autotrophic nitrogen removal process treating the effluent of an industrial anaerobic digester

Period: 9 May 2017 → 12 May 2017
Hannah Feldman (Other)
Xavier Flores Alsina (Other)
Kasper Kjellberg (Other)
Jan-Michael Blum (Other)
Borja Valverde Pérez (Other)
Gürkan Sin (Other)
Barth F. Smets (Other)
Krist V. Gernaey (Other)

Department of Chemical and Biochemical Engineering

PROSYS - Process and Systems Engineering Centre

Department of Environmental Engineering

Degree of recognition: International

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10th International Conference on Biofilm Reactors
09/05/2017 → 12/05/2017
Dublin, Ireland

Activity: Talks and presentations › Conference presentations

Where to direct modelling efforts for a faster road towards resource recovery?

Period: 31 Mar 2016
Borja Valverde Pérez (Invited speaker)

Department of Environmental Engineering

Water Technologies

Related event

5th IWA/WEF Wastewater Treatment Modelling Seminar 2016: Where to direct modelling efforts for a faster road towards resource recovery?
02/04/2016 → 06/04/2016
Annecy, France

Activity: Talks and presentations › Guest lectures, external teaching and course activities at other universities