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Control structure design for an EBP2R process operated as a sequencing batch reactor

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Summary of key findings

The TRENS system is a train of biological units designed for resource recovery from wastewater (8). It is a sequence of a modified enhanced biological phosphorus removal and recovery system (EBP2R, 5) coupled with a photobioreactor (PBR). The bacteria-based system constructs an optimal culture media for the downstream algae cultivation. In this work, we develop a sequencing batch reactor (SBR) model, which is calibrated using a lab-scale EBPR system. The calibrated model is used to design 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 60% of the influent P load, while keeping an optimal N-to-P ratio of 17 (8) 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. Further research is needed in order to assess the controllability of the PBR and the possible impact on the upstream operation conditions.

Background and relevance

Conventionally, the arrangement of biological and physical unit processes in wastewater treatment systems is chosen to remove organic carbon, nitrogen and phosphorus. This treatment approach, without focus on recycling water and nutrients (N and P), is no longer regarded as sustainable (7). Particular scientific interest is currently focusing on the development of cost-effective ways to recover N and P from wastewater. A complete biological process for wastewater resources recovery has been designed, able to recover both nitrogen and phosphorus through optimal algae cultivation (5). This innovative system, referred to as TRENS, is defined as an EBP2R system coupled with a PBR. Previous work showed that the algal growth in the PBR, as well as the effluent quality, highly depends in the nutrient content of the constructed cultivation media (8). The outcome of our work is the model based design and assessment of a control structure for a sequencing batch reactor (SBR) that should construct a stable and optimal culture media for downstream algal cultivation. To this end, the ASM-2d has been implemented as part of a SBR model and calibrated using data from a lab scale EBPR system.

Lab scale EBPR

A SBR with 8 L volume was operated at hydraulic retention time (HRT) of 18 h and at solids retention time (SRT) of 8 days for 1 month. The SBR was operated as follows: filling; anaerobic phase (2 h); aerobic phase (3 h); settling and idle phase (1 h); drawing. The SBR was fed with pre-clarified wastewater spiked with volatile fatty acids, propionate for this study, and phosphate.

TRENS process description

The system is defined as a sequence of tanks. In the downstream of the EBP2R, modelled as the lab scale SBR defined above, an equalization tank is placed, used to combine both P and N streams before feeding them to the PBR (last tank in the sequence). As a side stream process, a completely autotrophic nitrogen removal (CANR) system is used to remove the fraction of influent N which cannot be recovered by the PBR. The SBR operation is modified according to the EBP2R concept (5). A settling phase is included between the anaerobic and the aerobic phase, so that a phosphorus rich stream (P-stream) can be discharged. At the end of the second settling phase a nitrogen rich stream, referred to as N-stream, is discharged and combined with the P-stream, thereby constructing the optimal N-to-P ratio for downstream algal cultivation.

Process modelling
Two different biological models were used to model system. The EBP2R system is modelled using the activated sludge model 2d (ASM-2d, (2)) adapted by Flores-Alsina et al. (1). The simulation model was implemented in Matlab-Simulink (The MathWorks, Natick, MA). The model was manually calibrated following the procedure by Insel et al. (3) by fitting the simulations to experimental data collected during one cycle at steady state.

Control design procedure
The controllers were designed following a methodology adapted from the plantwide control procedure (4) detailed in Valverde-Pérez et al. (5).

Results and discussion

Model calibration
Simulation results were fit to the experimental data collected along 1 cycle from the SBR. Importantly, the calibrated model is able to accurately predict the bulk concentrations at the time when the P-stream (i.e. 2 h) and N-stream (i.e. 6 h) are discharged (Fig.1).

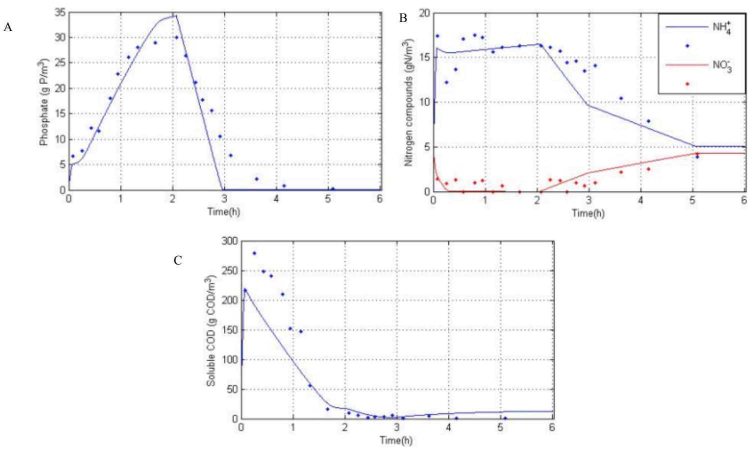

Figure 1 SBR cycle performance: a) phosphate concentration; b) ammonia and nitrate concentrations; c) soluble COD concentration. Dots represent the experimental data, while the full line represents the simulated results.

Control structure design and assessment
The primary objective of the control structure is to maximize the phosphorus recovered through algal cultivation, while the secondary is to obtain an optimal and stable nutrient balance to feed to the downstream PBR. We assume that the mixed green microalgae culture grown in the PBR is the one reported by Wágner et al. (8), whose optimal nitrogen to phosphorus ratio in the cultivation medium is 17 mol-N/mol-P. Scenario simulations were carried out to assess the process performance in terms of both nutrient load and balance fed to the PBR. Fig.2 A shows that the P-recovery may be limited by the SRT in the system or by nitrifiers activity (5). Fig. 2 B shows that at SRTs higher than 5.5 days the ratio drastically drops due to nitrogen removal. Hence, the SRT is fixed at 4.5, avoiding nitrogen removal and feeding ammonia to the PBR and the CANR. In order to have flexibility in the operation of the SBR, the P-stream volume was set at 50% of the influent volume. Fig. 2 A shows that at the selected operation conditions up to 60% of the influent phosphate can be recovered. This optimization has been done at constant oxygen level (3 mg/L).

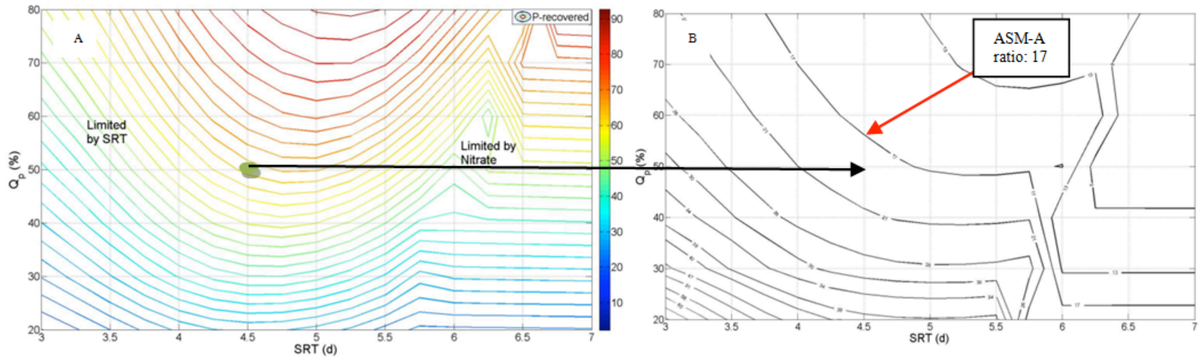

Figure 2 a) Process performance as the N to P molar ratio fed to the downstream PBR as a function of the P-stream flow and the SRT; b) process performance as a percentage of P recovered from the influent as a function of the P-stream flow and the SRT.

The next step is to identify the available actuators, referred to as manipulated variables (MVs), of the system: effluent pump, mixer and air supply. The effluent pump controls the HRT of the system. At the end of each cycle a fraction of the sludge is wasted, by the effluent pump, in order to keep the desirable SRT. In addition, this pump can be used to balance the nutrient loads fed to the PBR. A run-to-run control strategy is used to determine the effluent volume pumped after the anaerobic phase (P-stream) as function of the phosphorus concentration in the previous cycle. Then, through a ratio controller that operates during the batch, the volume of N-stream conveyed to the PBR is estimated. This estimation takes into account the nitrogen concentration, both ammonia and nitrate, at the end of the aerobic phase and the phosphate concentration at the end of the anaerobic phase. The air supply is modelled as the oxygen transfer coefficient (kLa). The air supply is used to keep the oxygen level at 1.5 mg/l (5, 6) during the batch using a feedback control loop. Since the effect of the mixing is not modelled it is not considered as a suitable actuator. The main disturbances considered in this work are the ammonia, phosphate and chemical oxygen demand (COD) influent loads.

The proposed control structure is able to reject the influent disturbances. Fig. 3 shows the effect of an influent step change on phosphate. Due to the nature of the SBR operation, there are small oscillations around the set point for phosphorus load (Fig.3 a). Similar behaviour has been found when introducing step disturbances in the influent COD or ammonia (data not shown). We conclude the control structure is effective rejecting disturbances.

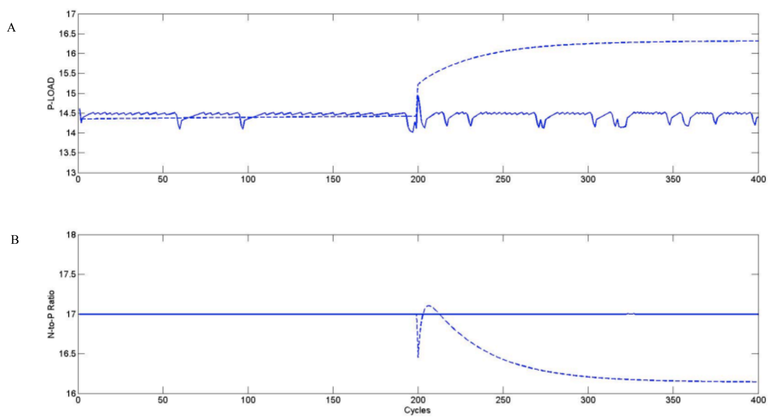

Figure 3 Effect of a step change of 20% on the influent phosphorus: a) P-load in the P-stream; b) N-to-P ratio in the EBP2R effluent. In full line is presented the process response under controlled conditions and in dashed lines the process response without control. The step is introduced in cycle 200 (50 days).

References

1. Flores-Alsina, X., Gernaey, K.V. and Jeppsson, U., 2012. Benchmarking biological nutrient removal in wastewater treatment plants: influence of mathematical model assumptions. Water Science and Technology, 65(8), 1496-1505.

2. Henze, M., Gujer, W., Mino, T., Matsuo, T., & Van Loosdrecht, M. C. M., 2000. Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. London: IWA Publishing.

3. Insel, G., Sin, G., Lee, D.S., Nopens, I., and Vanrolleghem, P.A., 2006. A calibration methodology and model-based systems analysis for SBRs removing nutrients under limited aeration conditions. Journal of Chemical and Biochemical Technol., 81, 679-687.

4. Larsson, T., and Skogestad, S., 2000. Plantwide control- A review and a new design procedure. Modeling, identification and control, 21(4), 209-240.

5. Valverde-Pérez, B., Ramin, E., Smets, B.F. and Plósz, B.Gy., 2015a. An innovative enhanced biological nutrient recovery activated sludge system – evaluation of the combined operation with a photobioreactor. Water Research, 68, 821-830.

6. Valverde-Pérez, B., Fuentes-Martínez, J.M., Flores-Alsina, X., Gernaey, K.V., Huusom, J.K., Plósz, B.Gy., 2015b. Control Structure Design of an Innovative Enhanced Biological Nutrient Recovery Activated Sludge System Coupled with a Photobioreactor. Computer Aided Chemical Engineering, 37, 2555 – 2560

7. Verstraete,W., Van de Caveye, P., Diamantis, V., 2009. Maximum use of resources present in domestic ‘‘used water’’. Bioresource Technology, 100(23), 5537–554.

8. Wágner, D.S., Valverde-Pérez, B., Sæbø, M., Bregua de la Sotilla, M., Van Wagenen, J., Smets, B.F., and Plósz, B. Gy., 2015. Towards a consensus microalgal growth model (ASM-A) – uptake and storage of nutrients. In preparation.