A paradigm shift is promoted in wastewater treatment whereby wastewater is considered as a source of nutrients, water and energy, rather than waste and it is referred to as used water. Microalgal cultivation on used water resources offers the potential to recover nitrogen, phosphorus, water and energy. When coupling with used water treatment, microalgae is mostly considered to produce energy through biofuel production. A novel used water resource recovery approach was presented earlier, referred to as TRENs – a fully biochemical process for the removal, recovery and reuse of used water resources promoting sustainable urban water management. The system consists of a low solids retention time (SRT) enhanced biological phosphorus removal and recovery (EBP2R) system that can provide optimal cultivation medium – in terms of nutrients and water – for downstream microalgal cultivation. The microalgal suspension cultivated in the photobioreactor (PBR) can be then used for e.g., “fertigation” on agricultural land whereby the water and the nutrients are recovered. Alternatively, the algal biomass can be harvested and can be used for co-digestion in existing anaerobic digesters, whereas the water content can be used for aquifer recharge.

Design and optimization of bacterial-microalgal systems requires process models that can be readily combined with consensus used water treatment models, e.g., the activated sludge models (ASM). Previous microalgal process models cannot be used for such purposes as a result of their deficiencies. Some lack e.g., accounting for the storage of nitrogen and phosphorus and for the potential for microalgae to grow heterotrophic on organic carbon that are relevant processes for used water resource recovery systems.

Therefore, the first objective of this thesis is to develop a consensus-based microalgal process model (ASM-A) accounting for photoautotrophic and heterotrophic microalgal growth, the uptake and storage of nitrogen and phosphorus and decay. The model was developed in the ASM framework as an extension to ASM-2d, thus it can be readily connected to bacterial unit processes. The process rates of the microalgal model were identified based on extensive literature review. Laboratory experiments in differently scaled batch PBRs were conducted in order to provide proper measurement data for model identification, comprising the selection of process rate equations as well as the estimation of the stoichiometric and kinetic model parameter distribution. The model identifiability analysis was conducted using the Latin Hypercube Sampling based Simplex (LHSS) method, adapted from the literature. The process model identified can effectively describe microalgal biomass concentration, soluble ammonium and phosphate concentrations as well as the phosphorus storage. The nitrogen storage is found to be affected by substrate availability, whilst the soluble nitrate concentration depends on the culture history, thereby requiring scenario specific model calibration. One of the most important factors affecting microalgal growth is the available light. Thus, for predicting the light distribution, the effect of using different simulation model structures on the model accuracy and uncertainty was assessed. Moreover, the effects of light scattering, biomass concentration and pigmentation on light attenuation in PBRs were investigated, using laboratory-scale experimental data. The light attenuation coefficient was estimated using the Lambert-Beer equation. Results suggest that light attenuation depends primarily on the pigmentation of the microalgae and also on the biomass concentration. Moreover, using a discretized layer-model to describe the light distribution in PBRs can result in more accurate prediction of the microalgal growth as well as the reduction of the uncertainty of the model predictions.

Furthermore, the effect of the variation of influent N-to-P ratio on the reactor performance was assessed in a mixed consortium of Chlorella and Scenedesmus sp. as well as in a monoculture of Chlorella sp. (both commonly used in used water treatment systems) in continuous cultivation using the treated used water from the upstream EBP2R system. When the N-to-P ratio in the influent was lowered to a sub-optimal level diatoms proliferated in the PBR cultivating the mixed green microalgal consortium. Once the ratio was increased again, the diatoms could be washed out of the system. Model predictive accuracy deteriorated as a result of the changes in culture composition due to the possible change in microalgal kinetics. The variation of the N-to-P ratio did not have an effect on the composition of the monoculture of Chlorella sp., no contamination was encountered during the 85 days of cultivation on used water. The upstream bacterial unit process in the second case was operated at a higher SRT (16 d), suggesting that longer SRT might be able to mitigate the potential of contamination by other microalgal species.

Lastly, an innovative method was developed to harvest microalgal biomass grown in suspended cultures in the TRENs system. A two-step flocculation was applied, whereby in the first step cationic polymer was added to the microalgae to destabilize the cells, then in the second step the aggregation of flocs was enhanced by the addition of bacterial biomass wasted in the upstream short-SRT EBPR process. Effective recovery was obtained (97%), by the significant (40%) reduction in the amount of cationic polymer required compared to the case when only cationic polymer was used for the flocculation without the addition of bacteria, thus further reducing harvesting costs. The biomethane potential of the harvested microalgal-bacterial biomass was estimated at mesophilic conditions, obtaining synergistic effect when co-digesting the two substrates and resulting in a maximum methane yield of 560±24 mlCH4/gVS.

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