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Characterization and Modelling of Soluble Microbial Products in Membrane Bioreactors

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Summary

Membrane bioreactors (MBRs) refer to the combination of membrane technology and high rate biological process technology for wastewater treatment. MBRs produce excellent effluent quality (reusable) and only require a small footprint. Strict EU effluent discharge standards and decreasing membrane costs have been the main driving force for MBR applications in EU countries. However, membrane fouling occurring on the membrane surface and within the pores reduces the long-term stability of the membrane filtration performance. The understanding of MBR fouling is still limited and at this moment, neither the evolution of membrane permeability under certain operating conditions nor the effect of cleaning measures can be predicted. These uncertainties therefore cause considerable difficulties in MBR design and operation.

Recent studies have shown that the colloidal and soluble fraction of the sludge (sludge water) correlates well with MBR fouling. Soluble microbial products (SMP) are the main constituent of MBR sludge water. However, it is not clear how to predict the foulant concentrations, how foulants are deposited onto the membrane, and how to predict the impact of deposited foulants on membrane permeability. The goal of this thesis was therefore to characterize the foulants in MBRs and to develop a mathematical model to predict both membrane fouling and effluent quality. The focus of this study is the interaction between the MBR biology and membrane fouling.

A lab-scale MBR reactor was constructed for biological nutrient removal, equipped with a tubular membrane (0.03 µm) in side-stream configuration. The SRT and HRT were set at 17 days and 6.4 hours, respectively. The sludge obtained from this MBR was used in specifically designed batch experiments to produce BAP (biomass associated products) and UAP (utilization associated products) separately, which allowed their characterisation using a new tool, LC-OCD (liquid chromatography - organic carbon detection). Both BAP and UAP exhibited a very wide molecular weight (MW) distribution. The biopolymer fraction of SMP exhibited a very high MW and a good correlation with MBR fouling. The UAP produced during the

biomass growth phase exhibited a lower MW than the BAP, suggesting UAP has a lower fouling potential than BAP.

The study of the impact of complete sludge retention on MBR biology benefits from the available ASM models. The existing Activated Sludge Model No. 2d (ASM2d) model structure can be directly applied in MBR modelling and most default parameters suggested for conventional activated sludge (CAS) hold for MBR as well. However, the MBR sludge exhibited higher substrate and oxygen affinities due to the smaller floc sizes and reduced diffusion limitation. The comparison of the ASM modelling approach as applied to MBR and CAS processes was discussed.

The impact of MBR biology on membrane fouling is very complex. A new model, called ASM2dSMP, was developed with the power to predict both effluent quality and SMP concentration. Attention was paid in the model development to minimize parameter correlation and to obtain reasonable parameter estimates. The possibility of SMP deposition can be predicted by an extended hydrodynamic model. Simulations under typical MBR operational conditions suggest that the particles with radii around 0.1 μm have the highest likelihood to deposit. The high fouling potential and high deposition possibility of SMP are demonstrated to be the main characteristics correlated with MBR fouling.

The deposited SMP can either irreversibly block the membrane or build up a hydraulically reversible cake layer. This dynamic process under crossflow and periodical backwashing conditions was modelled successfully by a newly developed filtration model. With the SMP concentration simulated by the ASM2dSMP model as input, the filtration model is able to dynamically predict the impact of MBR operational conditions (e.g., SRT and HRT) on both the short-term transmembrane pressure (TMP) increase in one filtration cycle and the long-term TMP increase between two chemical cleanings.