

Modeling external carbon addition in combined N-P activated sludge systems with an extension of the IWA Activated Sludge Models

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Background

External carbon sources are readily biodegradable compounds which are added to enhance the denitrification process (accomplished by “ordinary” heterotrophs) and improve the overall efficiency of N removal within the existing capacities of activated sludge systems. In the combined N-P removal systems, the external carbon sources may also interact with the enhanced biological P removal (EBPR) process (accomplished by Polyphosphate Accumulating Organisms (PAOs)). For optimization of the dosages of external carbon sources, mathematical models have been proven to be useful tools. In the existing activated sludge models for combined N-P systems, readily biodegradable compounds are divided into two groups in order to tackle the problem of competition between “ordinary” heterotrophs and PAOs for the substrates. Fermentation products (S_A) are assumed to be only acetate (although covering a wide range of compounds) and directly available for PAOs, whereas fermentable readily biodegradable compounds (S_F) are not directly available for PAOs but can ultimately be transformed to S_A . In practice, however, there are compounds (e.g. ethanol) which are known to be fermentation products but reported not to be utilized by PAOs (Satoh et al., 2000). These authors proposed a modified conceptual model for anaerobic COD metabolisms that assumes the presence of soluble substrate, $S_{A'}$, which is not utilized by PAOs either directly or via fermentation. The $S_{A'}$ type of substrate becomes, however, available for “ordinary” heterotrophs in the presence of oxygen or nitrate.

The aim of this study was first to develop an extension of the IWA Activated Sludge Model No. 2d (ASM2d) considering a new readily biodegradable substrate, not available for the PAOs. The concept was derived from the observations of Swinarski et al. (2009) that some substrates (e.g. ethanol and distillery waste products) had hardly any impact on the behavior of PO_4 -P during nitrate utilization rate (NUR) measurements (in contrast to other substrates, such as acetic acid or readily biodegradable fraction of settled wastewater). Secondly, the new model was compared with the original ASM2d based on predictions of laboratory experiments and field measurements in a full-scale plant (MUCT process configuration). The study is part of the on-going EU supported project carried out in cooperation with the Water Environment Research Foundation (WERF) Nutrient Removal Challenge Program.

Material and methods

A conceptual model of the ASM2d extension considering a readily biodegradable substrate ($S_{A,1}$) not available for PAOs is presented in Figure 1. GPS-X ver. 5.0.2 was used as a simulator environment for implementing the developed model and running simulations. Field measurements and lab experiments were conducted at the “Wschod” WWTP (570,000 PE) in Gdansk, northern Poland. The ASM2d was calibrated under dynamic conditions with the results of both batch tests with the settled wastewater and process biomass, and a 96-hour measurement campaign conducted in the full-scale bioreactor (MUCT process configuration). In addition, two types of the batch tests with ethanol and distillery by-products were used to determine the specific denitrification rates including “conventional” measurements (carbon source and KNO_3 added at the beginning) and measurements during phosphate uptake rate under anoxic conditions (carbon source and KNO_3 added after an anaerobic phase with the settled wastewater). The results of these two tests were used to compare predictions of the new model and ASM2d. Finally, the addition of external carbon source to an anoxic zone of the full scale bioreactor was simulated with both models.

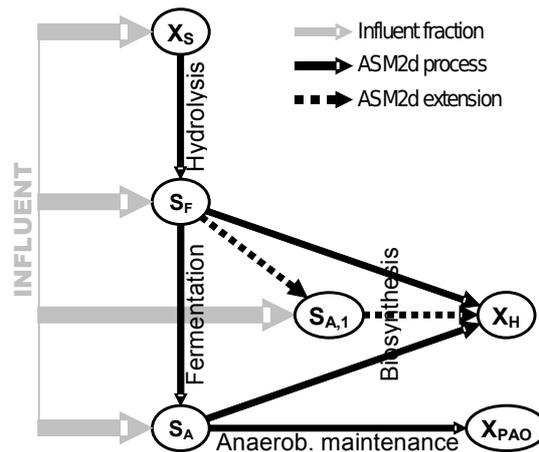


Figure 1. Model concept considering a readily biodegradable substrate not available for PAOs

Results and significance of the findings

Only minor effects of ethanol and distillery waste products on the behavior of $\text{PO}_4\text{-P}$ were observed in the conventional denitrification rate measurements (Figure 2, left). For comparison, $\text{PO}_4\text{-P}$ was apparently released during similar experiments with wastewater until the readily biodegradable fraction was present in the batch reactor (data not shown). When the external carbon sources were treated as $S_{A,1}$ in the new model, predictions matched the experimental data by adjusting three parameters (maximum growth rate constant, half-saturation coefficient and yield coefficient) in the growth process of “ordinary” heterotrophs on the new substrate ($S_{A,1}$). When the external carbon source was assumed to be S_F in ASM2d, much higher denitrification rates and COD utilization rates were predicted with that model (Figure 2, left).

For simulations of the full scale bioreactor, it was assumed that 1 m^3 of the external carbon source (at the concentration of $1,200,000 \text{ g COD/m}^3$) was added to the anoxic zone of the bioreactor. The relative deviations between both model predictions of the effluent $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ concentrations did not exceed 10% (Figure 2, right). In spite of these small differences, the overall results of this study suggest that it is mechanistically inappropriate approach to treat some external sources as the ASM2d components.

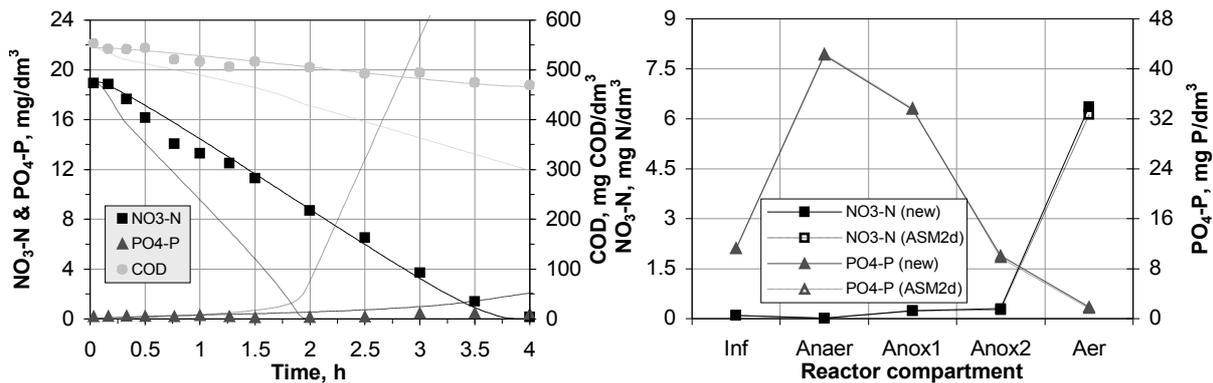


Figure 2. Measured vs. predicted concentrations of $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$ and COD in a “conventional” batch experiment (left) and model predictions (the new model and ASM2d) of the $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ concentration profiles in the MUCT reactor

References

- Satoh, H., Okuda, E., Mino, T. and Matsuo, T. (2000). Calibration of kinetic parameters in the IAWQ Activated Sludge Model: a pilot scale experience. *Water Sci. Technol.*, 42 (3-4), 29-34.
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