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Comprehensive modelling of full-scale nitrifying biofilters and validation under different configurations

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Summary of key findings

A biofiltration model has been developed for the Seine Aval (SAV) wastewater treatment plant (WWTP) which is being upgraded. The model is based on the biofiltration models found in literature containing submodels for filtration and nitrite accumulation. Several improvements to the model are realized with respect to mass transport and biological reactions. Evaluations of energy consumption (aeration and pumping) and environmental impact (N_2O, equivalent CO_2 emission) are also integrated in the model. The model was first calibrated and validated for a BIOSTYR® nitrifying biofilter process with datasets collected before and after the upgrade of the plant. The simulation results show that the calibrated model can well describe the nitrification performance of the process for different treatment configurations using the same parameter values.

Background and relevance

Urban wastewater treatment is nowadays facing different challenges (population growth, protection water resources and ecosystems and adaptation to increasingly strict environmental laws and policies) which requires WWTP to improve their treatment capacity and quality (Carey and Migliaccio, 2009). The Seine Aval (SAV) plant, which is the largest WWTP in Europe (5 million PE), has been upgraded since 2009 in order to increase its treatment performance. More intensive processes such as membrane bioreactors (MBR) and biofilters are currently being introduced in the plant. The performance of the upgraded plant should be evaluated in terms of nutrient removal quality, economic cost and environmental impacts. As mathematical process models have become useful tools for the performance evaluation and decision-making in the life cycle of WWTP (Rieger et al., 2012), SIAAP (Interdepartmental association for sewage disposal in the Paris agglomeration) launched the NEXTSTEP project, which aims at developing a whole plant model for the Seine Aval plant.

The modelling work firstly focused on the 3-stage biofiltration process. A biofiltration model based on models available in literature (Bernier et al., 2014) has been implemented in WEST® (DHI, Horsholm, DK) with several improvements: First, in terms of mass transport, diffusion between bulk liquid and biofilm is limited by a boundary layer with variable thickness rather than the constant thickness boundary layer implemented originally (Ohashi et al., 2012). Because of the interest in effluent nitrite and greenhouse gas emissions, biological nitrification and denitrification were considered as multi-step reactions (Pocquet et al., 2016; Hiatt and Grady, 2008). Simplified equations for energy consumption for aeration and pumping have been integrated in the model (Gernaey et al., 2006; Wu et al., 2005). Using the Monte Carlo based approach of Sin et al. (2008), the model has first been calibrated for the nitrification stage over a short period (from mid-July to mid-August 2009) before the upgrade of the plant. The identified parameter values were then adjusted manually according to simulation tests over short (from mid-August to mid-October 2009) and long periods (year 2009). Final validation of the model has been realized with long period datasets collected after the upgrade (from mid-April to mid-October 2017). Several intensive measurement campaigns (with sensor data every 15 minutes) have been used for calibration and validation. A similar procedure is currently being used for calibration and validation of the pre/post-denitrification stages.

The objective of this presentation is to share the methodology and results of the comprehensive modelling work for the biofiltration treatment line in the Seine Aval WWTP as well as to show the potential of the application of the model as a tool for treatment optimisation.

Results

The simulation results for ammonia removal in the nitrification stage before and after the upgrade are shown in Figure 1.1. Statistical scores for model performance are summarized in Table 1.1. Estimations of energy consumption for aeration and pumping for 2017 are shown in Figure 1.2. The average emission factors (EF %) for N_2O for the two simulation periods are 5.75% and 6.25% respectively.

Discussion

According to the simulation results, ammonia removal in the nitrification stage is slightly overestimated by the model, but the variations of effluent NH_4^+ concentrations are well simulated. The simulated nitrate concentration is higher than that observed in the effluent which confirms the overestimations of nitrification, and also suggests that the denitrification in the deep biofilm needs to be strengthened. The model prediction performance for 2017 is better than for 2009, which is partially due to the availability of measurements of soluble COD in 2017. This allowed to improve the influent fractionation. The estimation of energy consumption for aeration and pumping is very good, and allows to perform cost and environmental impact assessment and conduct optimization studies. N_2O emission was not monitored in the simulated periods. However, the estimated N_2O emission factor falls within the range found in literature (Bollon et al., 2016). The following step of the modelling work is to apply the model for the two denitrifying stages and construct a model for the whole treatment line.

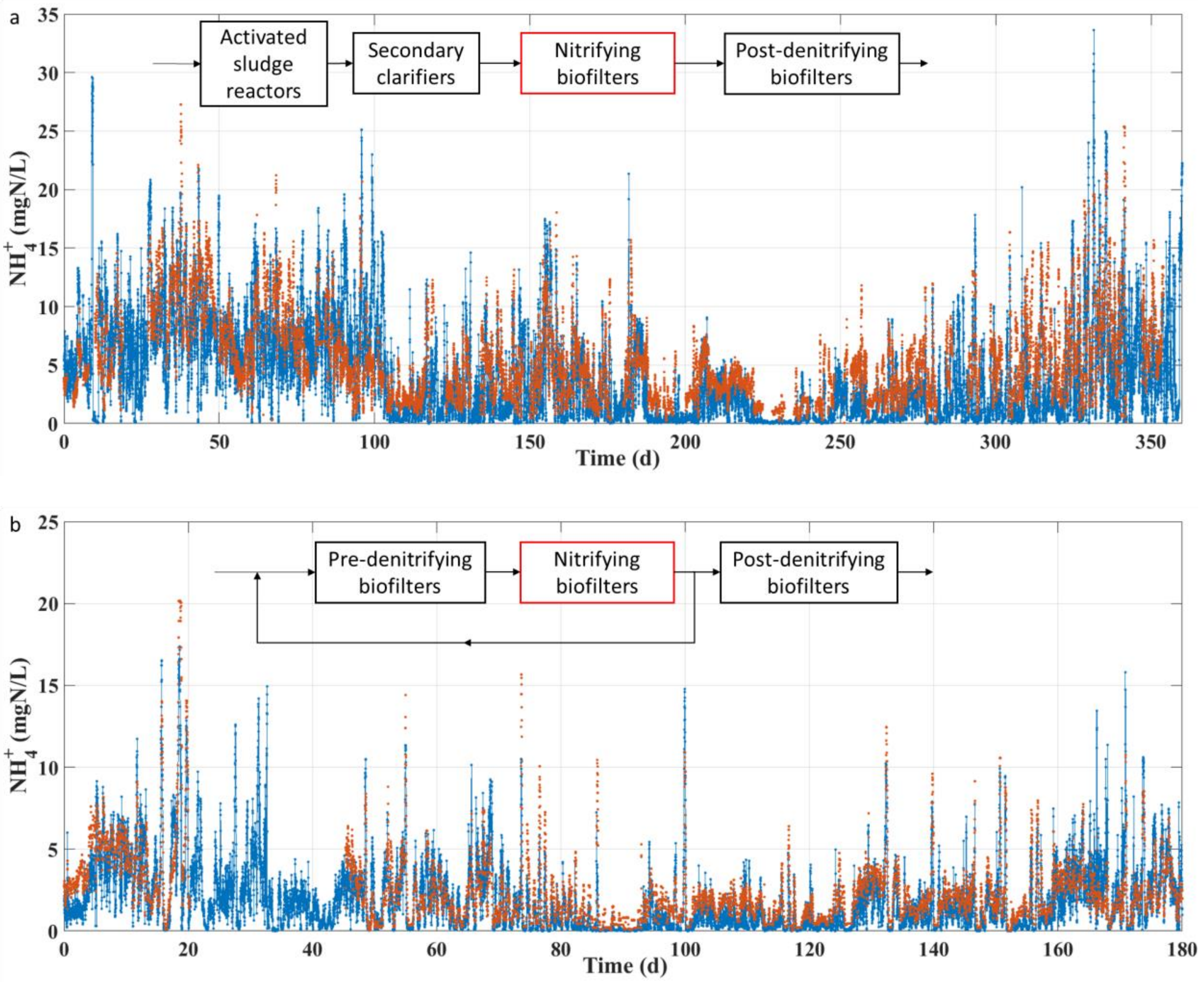

Figure 1.1 Simulation results (blue line with dots) and observations (orange dots) for the effluent NH_4^+ concentration of the nitrification stage under different configurations. a Before upgrade; b After upgrade

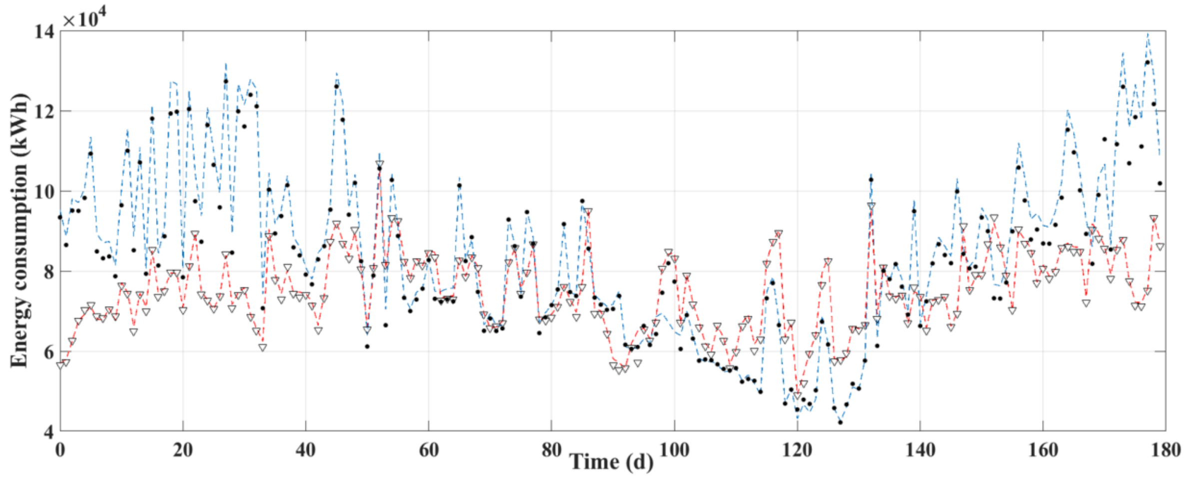

Figure 1.2 Estimation of daily energy consumption for aeration and pumping of the nitrification stage in 2017 (blue dotted line: simulated aeration energy consumption; black dots: observed aeration energy consumption; red dotted line: simulated pumping energy consumption; Triangles: observed pumping energy consumption).

Table 1.1 Statistical score results for the nitrification stage simulation in 2009 and 2017.

Scores for 2009	**NH_4^+**	**NO_3^-**	**DO**	**NO_2^-**	**COD**	**TSS**	**PO_4^{3-}**
Number of validated observations (n)	27048	34272	33313	329	331	332	329
Observed mean (mg/L)	5.55	34.04	6.63	0.78	62.27	21.58	0.39
Root mean square error (RMSE) (mg/L)	3.55	5.34	0.88	0.61	15.07	11.84	0.16
Scores for 2017	**NH_4^+**	**NO_3^-**	**DO**	**NO_2^-**	**COD**	**TSS**	**PO_4^{3-}**
Number of validated observations (n)	14841	14841	17226	178	180	180	180
Observed mean (mg/L)	2.30	19.12	6.40	0.77	41.52	10.68	0.76
Root mean square error (RMSE) (mg/L)	1.52	3.13	1.18	1.03	5.39	3.38	0.19

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Presenting Author

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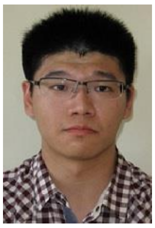
<tr><td rowspan="3"></td><td>Jialu Zhu
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