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APPLICATION OF DYNAMIC MODELS (ASM1) AND SIMULATION TO MINIMIZE RENOVATION COSTS OF A MUNICIPAL ACTIVATED SLUDGE WASTEWATER TREATMENT PLANT

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ABSTRACT

Model-based scenario analysis with the ASM1 model was used to evaluate the effect of different process modifications on the biological nitrogen removal process for a specific case study (municipal wastewater treatment plant). Simulations showed that the construction of extra tank volume was needed to obtain the effluent standard of 15 mg N/l. However, the renovation scenarios resulting from a model-based analysis resulted in lower construction costs (less extra tank volume to be constructed and better reuse of existing treatment plant components) compared to a rule-of-thumb design as often applied.

KEYWORDS

ASM1, biological N removal, denitrification, modelling, nitrification, renovation

INTRODUCTION

Activated sludge models were developed as a tool to study the complex interactions that occur between the different microbial communities in an activated sludge plant. The Activated Sludge Model No.1 (ASM1) (Henze *et al.*, 1987) was primarily developed for municipal activated sludge wastewater treatment plants to describe the removal of organic carbon substances and nitrogen with simultaneous consumption of oxygen and nitrate as electron acceptors, and to yield a good description of the sludge production within the activated sludge process. Implementation of biological nutrient removal on wastewater treatment plants is often a necessity. For older wastewater treatment plants a treatment plant renovation can be a solution to comply with more advanced effluent standards. The costs related to the treatment plant renovation will to a large extent depend on the design criteria that are used to conceptualize the new plant. Activated sludge models such as ASM1 can be useful to increase the understanding about the influence of process modifications on treatment process efficiency. Dynamic models are therefore increasingly used for scenario evaluations aiming at the optimisation of activated sludge processes (Stokes *et al*., 1993; de la Sota *et al*., 1994; Coen *et al*., 1997 among many others).
In this paper an application of ASM1 is described for a specific treatment plant renovation case study. Simulations with a calibrated activated sludge model were used to exploit the possibilities for a treatment plant renovation that aims at a minimization of the renovation costs, i.e. optimally reuse existing treatment plant elements in the new design.

CASE-STUDY

The studied municipal wastewater treatment plant was constructed in 1983 for a design capacity of 50000 inhabitant equivalents. The influent of the WWTP consists for 40 % of household wastewater and 60 % industrial wastewater. The influent is divided over two parallel rectangular primary clarifiers with a total volume of 712 m^3 after the pretreatment step (coarse grit removal, fine grit removal, sand

and grease removal). The effluent of the primary clarifier flows to the biological activated sludge treatment, where it is mixed with recycle sludge. The activated sludge tank consists of one plug flow aeration tank that is divided into 6 lanes of about 400 m^3 each. The mixed liquor flows to two secondary clarifiers through an open aerated rectangular channel of about 200 m^3. The clarifiers each have a diameter of 33 m and a volume of 2050 m^3. The final effluent is discharged into a nearby stream. The underflow from the secondary clarifier flows back to the aeration tank through an aerated sludge recycle channel with a volume of 400 m^3.

The plant was originally designed for COD removal only and is now going through a stepwise renovation process. The aim of the renovation was to obtain an effluent quality that complies with the new effluent standards (125 mg COD/l; 15 mg total N/l; 2 mg total P/l; as yearly averages) at minimum costs. P removal will be obtained by chemical P precipitation. The main problem is to obtain effluent total N concentrations below 15 mg N/l.

A first renovation phase in 1997 included the installation of a new fine bubble aeration system. The improved aeration efficiency resulted in a better COD removal and a stable nitrification activity, also in winter. Still, during winter time the plant does not reach full nitrification due to low temperatures, and the improved aeration efficiency did not result in overall lower effluent total N concentrations. For the period between January 1997 and November 1998 the average total N concentration was 19.6 mg/l. This high concentration is mainly because the treatment plant operation was not aiming for denitrification.

A one week intensive measurement campaign was carried out in the autumn of 1998 to characterize influent and effluent of the treatment plant. In addition, respirometric and titrimetric experiments were performed to characterize wastewater and activated sludge. With the data of the measurement campaign the ASM1 model was calibrated. All simulations were done using WEST (Hemmis NV, Kortrijk, Belgium). A detailed description of the model calibration results can be found elsewhere (Petersen, 2000; Petersen *et al.*, 2000). The calibrated model was used to propose modifications to the existing treatment plant operation and, if necessary, treatment plant lay-out to reach the 15 mg total N effluent standard. One basic rule in the simulated treatment plant scenarios was the maximum reuse of existing treatment plant components (e.g. the aeration tank with renovated aeration system).

The following scenarios were tested: (1) Reduction of sludge waste to increase sludge age/sludge concentration in the plant; (2) Modification of primary clarifiers into an anoxic zone; (3) Construction of an extra anoxic tank (712 m^3) between the primary clarifiers and the aeration tank + internal nitrate recycle flow.

RESULTS AND DISCUSSION

Scenario 1

A first series of simulations showed that a reduction of the sludge waste with 15 to 25 % could result in full nitrification, also during winter (Table 1). However, such an approach leads to increased sludge concentrations in the activated sludge system, where in practice it appeared that the sludge concentration in the plant (around 3.5 g SS/l) could not be increased due to sludge sedimentation problems at higher sludge concentrations. Evidently, improving sludge settleability would allow for this approach.

Table 1. Dynamic model: Influence of a decrease of the daily sludge waste flow (Qw) on the average effluent S_S, S_{NH} and S_{NO} concentrations (averages are calculated for the effluent concentrations simulated during the period with dynamic influent data)

	Effluent S_S mg COD/l	Effluent S_{NH} mg N/l	Effluent S_{NO} mg N/l	Effluent S_{NH}+S_{NO} mg N/l
Calibrated model, Qw	4.9	6.0	6.0	12.0
0,85 * Qw	4.4	2.9	8.6	11.5
0,75 * Qw	4.2	1.7	9.7	11.4

From then on the main concern was to include a denitrification compartment in the plant to decrease the total N concentration in the effluent, since nitrification on its own does not result in a decrease of the effluent total N concentrations (Table 1). Under winter conditions the plant could not denitrify within existing volumes, as could be concluded from full-scale tests with intermittent aeration.

Scenario 2

For this scenario the primary clarifiers (two rectangular clarifiers with a total volume of 712 m^3) were converted into a predenitrification zone. In this configuration all recycle sludge was pumped to the anoxic zone instead of to the aeration tank. The main problem here was the choice of an appropriate influent composition for the model. Based on the data of a separate measurement campaign on the primary clarifiers the following assumptions were made when converting the influent file of the calibrated model to the raw influent file used for this simulation: (1) For an influent flow higher than 13000 m^3/d the primary clarifiers do not remove anything from the wastewater, probably because the hydraulic residence time in the primary clarifiers becomes too short; (2) When the flow rate is lower than 13000 m^3/d the primary clarifiers remove 51 % of S_S, 17 % of S_{ND} and S_{NH} and 50 % of the particulate fractions. Removal efficiency for S_I in the primary clarifiers was assumed to be 0.

Compared to the calibrated model, the use of the primary clarifiers as anoxic zone appeared not to be a good idea under winter conditions. The sludge concentration in the aeration tank became much higher when the parameters of the calibrated model were applied, since particulate material was no longer removed in the primary clarifiers. This means that the load on the secondary clarifiers is higher, and this is exactly the weak point at the treatment plant under study. When extrapolating these results to practice, it means that removal efficiencies in practice will even be lower than the ones predicted with the model since it will not be possible to keep the sludge concentration in the plant as high as it was in the simulated scenario. In addition, the percentage of nitrifying biomass in the activated sludge decreases considerably compared to the calibrated model because the primary clarifiers especially removed organic carbon. This carbon load is now included in the raw influent entering the anoxic zone and causes extra growth of heterotrophic biomass. As a consequence effluent S_{NH} concentrations were high (8.0 mg N/l on the average for the period with dynamic data compared to 6.0 mg N/l for the calibrated model) while effluent S_{NO} concentrations were only 1.1 mg N/l (6.0 for calibrated model). These values indicate that there is only little nitrification activity left in the treatment plant under such operating conditions which will eventually endanger the complete biological nitrogen removal process in the treatment plant.

Scenario 3-5

For the other scenarios that were simulated, the primary clarifiers were restored to their original function, and it was tried to add extra tank volume to the treatment plant. An anoxic zone was included in the treatment plant configuration (predenitrification system, V anoxic zone = 712 m^3). Aeration control (on/off controller, DO measurement in 5th lane, setpoint = 2.0 mg DO/l) was implemented in the aeration tank to minimize the amount of oxygen that is recycled to the anoxic zone through the internal recycle of nitrate-rich mixed liquor.

Table 2. Dynamic model: Influence of the incorporation of an anoxic zone (712 m^3) in the treatment plant configuration with aeration control (setpoint = 2.0), for a constant internal recycle of nitrate-rich mixed liquor to the anoxic zone

Scenario	Q internal recycle to anoxic zone (m^3/d)	Effluent S_S mg COD/l	Effluent S_{NH} Mg N/l	Effluent S_{NO} mg N/l	Effluent $S_{NH}+S_{NO}$ mg N/l
Calibrated model	-	4.9	6.0	6.0	12.0
4800 m^3/d internal recycle	4800	6.8	3.9	3.9	7.8
7200 m^3/d internal recycle	7200	7.0	3.9	3.8	7.6
9600 m^3/d internal recycle	9600	7.1	3.8	3.6	7.5

Results of the simulations for different internal nitrate recycle flow rates are summarized in Table 2. The values shown are again averages of the output of the model during the period for which dynamic influent data were available. It is clear that the biological nitrogen removal process benefits from the implementation of the anoxic tank in the plant configuration, since the sum of S_{NH} and S_{NO} effluent concentrations decreases considerably compared to the calibrated model. A second observation is that an increase of the internal recycle flow does not result in a considerably higher N removal. This could possibly be explained by S_S limitation for denitrification during the periods with low load (weekends and nights). Coen *et al*. (1997) made similar observations.

Evaluation

It was tried to compare the costs of the proposed model-based treatment alternatives (with and without a safety factor) to the costs for rule-of-thumb renovation designs (that would otherwise have been applied to the plant). Variables representing investment costs were considered to be the extra volume to be constructed, and the reuse of existing plant components. Results of this comparision are summarized in Table 3. It is clear that model-based design resulted in construction cost savings (less volume to be constructed) and a better reuse of existing treatment plant components, leading to a plant renovation that is less expensive.

Table 3. Comparison in terms of tank volume and reuse of existing treatment plant components for model-based and rule-of-thumb design (MB = Model-based, RT = Rule of Thumb, PreSed = Presedimentation tank, Anae = Anaerobic zone, Anox = Anoxic zone, Aer = aeration tank)

Scenario	Configuration (volumes in m^3 between parentheses)	Extra volume to be constructed (m^3)	Reuse of existing primary clarifiers	Reuse of existing renovated aeration system
MB	PreSed (712) + Anox (712) + Aer (2400)	712	Yes	Yes
MB + safety factor	PreSed (712) + Anox/Aer (2000)+ Aer (2400)	2000	Yes	Yes
RT design 1	PreSed (712 + 700) + Aer (2400 + 2500)	3200	Yes	Yes
RT design 2	Anae (712) + Aer (2400 + 6000)	6000	Yes, modified	Yes

CONCLUSIONS

Model-based scenarios can be applied to evaluate the influence of treatment plant design modifications on treatment plant performance. It was shown in this paper how model-based scenario analysis can lead to an efficient reuse of existing treatment plant components, resulting in reduced renovation costs.

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REFERENCES

Coen F., Vanderhaegen B., Boonen I., Vanrolleghem P.A. and Van Meenen P. (1997) Improved design and control of industrial and municipal nutrient removal plants using dynamic models. Water Sci. Technol., **35**(10), 53-61.

de la Sota A., Larrea L., Novak L., Grau P. and Henze M. (1994) Performance and model calibration of R-D-N processes in pilot plant. Water Sci. Technol., **30**(6), 355–364.

Henze M., Grady C.P.L.Jr., Gujer W., Marais G.V.R. and Matsuo T. (1987) Activated Sludge Model No. 1. IAWPRC Scientific and Technical Reports No. 1. London, UK.

Petersen B. (2000) Optimal experimental design for wastewater and sludge characterisation, Ph.D. thesis. BIOMATH Department, Ghent University, Belgium. In preparation.

Petersen B., Gernaey K., Henze M. and Vanrolleghem P.A. (2000) Evaluation of an ASM1 model calibration procedure on a municipal-industrial wastewater treatment plant. Journal of Hydroinformatics (Submitted)

Stokes L., Takács I., Watson B. and Watts J.B. (1993) Dynamic modelling of an A.S.P. sewage works - A case study. Water Sci. Technol., **28**(11-12), 151-161.