Using modeling to optimize a full-scale WWTP for energy reduction and increased biological nitrogen removal

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INTRODUCTION

Increasing demands on treatment efficiency and the need for more sustainable treatment systems make it necessary to upgrade and optimize biological nutrient removal (BNR) processes at existing wastewater treatment plants (WWTP). The availability of reliable and affordable on-line sensors and progress in automation and control technology have led to the development of new and more efficient control strategies for BNR processes in wastewater treatment. In this respect, dynamic models have been proven to be an efficient engineering tool for the design of automated control strategies.

Problem statement

The existing mode of operation of the Vall del Ges WWTP, located in NE Spain is based on manual control making it difficult to deal with process disturbances. Automatic control should be implemented that allows reducing the operational costs and at the same time enhance the efficiency of the nitrification and denitrification processes. The objective of this work is to find the best control option using the existing infrastructure and instrumentation. The task of coming up with an efficient control strategy is challenging since the plant presents some limitations regarding the aeration system and the analyzer used.

MATERIALS AND METHODS

In a first stage of the study a numeric model of the WWTP has been developed that properly describes the process dynamics. Then, the control system has been designed and implemented into the model and many scenarios have been tested before finding the optimal parameters for the controller. Finally, the tested and tuned control concept is being implemented at a full-scale plant.

Wastewater treatment plant of Vall del Ges

Description. The WWTP of Vall del Ges (North-East, Spain) is an Orbal plant designed to biologically remove organic carbon and nitrogen. Phosphorus is removed using chemical precipitation. It was constructed in 1993 for a design capacity of 42000 Population Equivalent (PE) but it receives only 30000 PE with an organic and nitrogen load of 1946 kg $COD \cdot d^{-1}$ and 167 kg $N \cdot d^{-1}$ respectively (more information can be found in Corominas *et al.*, 2008). The studied WWTP is depicted in Figure 1.

Aeration system. The aeration is transferred through surface aerators. The external channel has 6 surface aerators that remain idle because it is used as the anoxic zone of the treatment. The inner and middle channels represent the aerobic zone with 8 surface aerators (four in each channel) but working in pairwise fashion because there are only 4 motors. Each of the motors has three modes of operation (Off, On at fast speed and On at low speed), what limits the flexibility to operate the plant. The current mode of operation in the aerobic zone is using 2 motors at a time at fast speed.

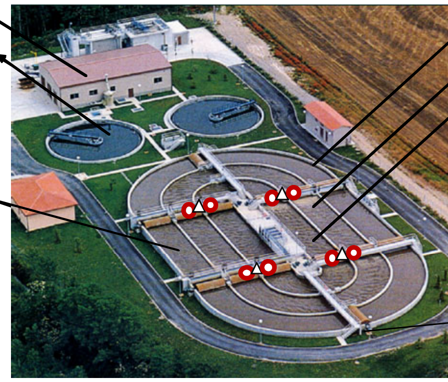

Figure 1. Representation of the studied WWTP

Instrumentation. An on-line analyzer (DiaMon, Bran+Luebbe, Germany) is available in the plant which measures ammonium and nitrate concentrations. The limitation of this analyzer is that it has a delay of 30 minutes. Also DO, pH and ORP on-line sensors are installed in each of the three Orbal channels. At this moment, all these signals are just used for periodic monitoring purposes, not for control.

WWTP Model

The complete WWTP model is based on hydraulic, oxygen transfer, biokinetic (Activated Sludge Model nº1; see Henze *et al.*, 2000), settling (Takács model; see Takács *et al.*, 1991) and sensor models (see Rieger *et al.*, 2003). One year historical data was collected for the influent and effluent characteristics, as well as the operating parameters. Influent wastewater characterization and a hydrodynamic study (tracer test) of the WWTP were conducted. A calibration of the model was conducted in order to fit the experimental and simulated values over 333 days. More information on this modeling study can be found in Corominas *et al.* (2008).

Control strategies

The objective of the control strategy is to minimize the cost of operation, while keeping the effluent concentration limits below the legislation boundaries (in Spain the total nitrogen concentration must be below 10 $mgN\cdot L^{-1}$). The degrees of freedom for the operation of aeration system are the number of motors turned On and their speed. Different strategies were tested using the model and compared to the actual mode of operation.

Strategy 0. Actual mode of operation with constant aeration.

Strategy 1. Decision tree using only the DO signal in the middle of aerobic zone as input

Strategy 2. Decision tree using the DO signal together with ammonia and nitrate signals (DiMon analyzer) at the end of aerobic zone.

Strategy 3. It is the same as strategy 2 but using an ammonia and nitrate sensor with no delay (this would require some investment in the plant).

For each strategy a decision tree based on expert knowledge was developed. These trees are automatically evaluated every 30 minutes. For strategy 1 the tree presented in Figure 2 was used.

For strategies 2 and 3 a tree has been developed which combines the DO, ammonia and nitrate signals (Figure 3).

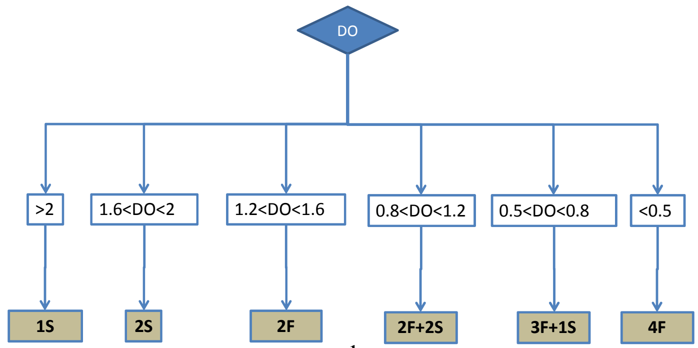

Figure 2. Decision tree for strategy 1 based on DO (mg·L^{-1}) values (F: engine at fast speed, S: engine at slow speed).

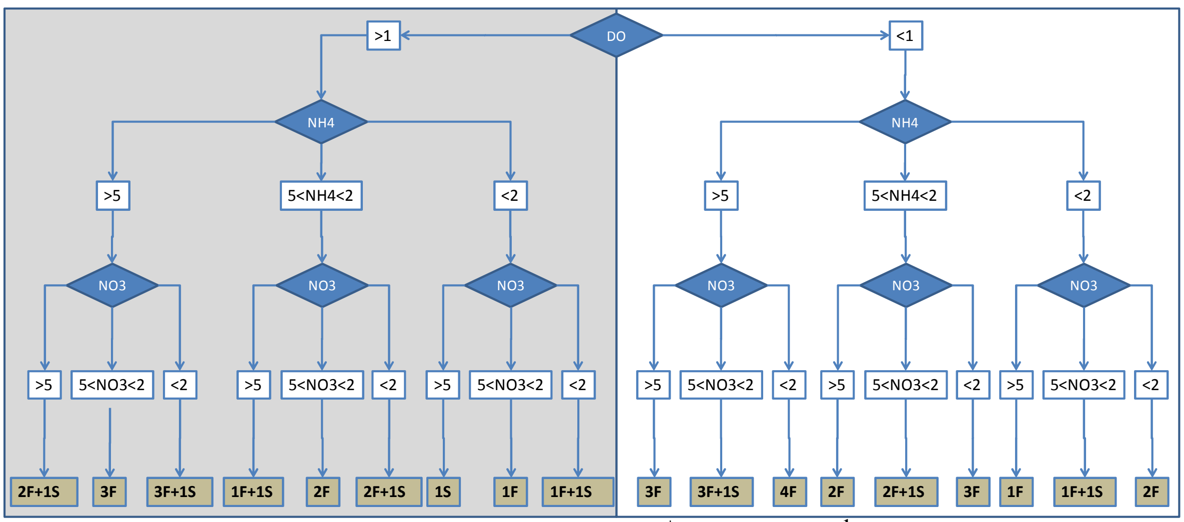

Figure 3. Decision tree for strategies 2 and 3 based on DO, NH_4^+ and NO_3 (mg·L^{-1}) (F: engine at fast speed, S: engine at slow speed).

RESULTS

The modeling study allowed comparing the system performance when using the different control strategies. Table 1 presents the results obtained for the effluent nitrogen, the aeration energy consumed and DO, calculated over the last 233 days of the simulations.

Table 1. Comparison of the calculated performance indices for the different control strategies

PERFORMANCE INDICES	Strategy0	Strategy1	Strategy2	Strategy3
Effluent average Total Nitrogen concentration (mg N·L^{-1})	8,39	7,28	7,49	8,99
Aeration energy cost (AE) (kWh·d^{-1})	706,16	475,64	405,86	391,89
Average DO value in aerobic reactor (mg DO·L^{-1})	2,35	0,77	0,3103	0,29
Standard deviation of DO in aerobic reactor (mg DO·L^{-1})	1,38	0,60	0,24	0,29

The average total nitrogen concentration (TNC) was below the legislation limits for all scenarios. Implementing control showed a reduction in the effluent average TNC for strategies 1 and 2 and a significant reduction of aeration energy cost for all cases (up to 44%). Strategy 2 (using DO, NH_4^+ and NO_3) implies 15% aeration cost reduction with respect to strategy 1 (using only DO), with only 3% increase in the effluent total nitrogen concentration. Also, with Strategy 2 it is possible to minimize the ammonia peaks. The use of a faster ammonia and nitrate sensor (Strategy 3) would allow faster adaptation of the system to the influent fluctuations. The average DO concentration in the system decreases considerably when implementing the control strategies. This means that during some periods the aerobic volume is used as anoxic zone. The standard deviation of the DO decreases significantly with Strategies 2 and 3, what means that the control action is less aggressive (what is good for the life of the equipment). Considering the constraint that the WWTP will not invest on instrumentation at this moment, Strategy 2 will be implemented at full-scale. The control strategy 1 will also be implemented as fall-back strategy in case the ammonia and nitrate analyzer fails. The solution achieved is cost-effective since only an update of the SCADA system will be required to implement the control strategy. Assuming a value of 0,15USD/kWh, the savings would be around 11000 USD·year^{-1}.

Full-scale implementation

The development of the control strategy using a model is less risky than implementing directly at full-scale and long-term effects can be predicted. The next step is the fine-tuning of the controller's parameters directly at full-scale in order to overcome limitations due to model assumptions.

CONCLUSIONS

The developed procedure combining experimental work and modeling allowed defining a control strategy to optimize the Biological Nitrogen Removal processes at a full-scale WWTP. A cost-effective solution has been achieved to reduce energy consumption with the implementation of control in the plant. Energy savings up to 43% can be achieved, while maintaining good effluent quality.

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