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Smart Wastewater Treatment Aeration for Reducing Operational Costs and Greenhouse Gas Emissions

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Published August 2021

Introduction

Wastewater treatment plants (WWTP) treat most of the water that is used in households and industry before it is discharged back to the environment. One of the key treatment steps in a plant is the biological treatment which reduces nutrient concentrations in the water. This protects the recipients against eutrophication and acidification and hence WWTPs are a key infrastructure in terms of securing water quality in lakes, rivers, fiords, and seas. The main catalyst in the biological treatment step is the addition of oxygen, as this activates some specialized bacteria which in return reduce nutrient concentrations. However, the addition of air to the wastewater requires a large amount of electricity to run huge blower stations. For the utility company operating the WWTP, this can be both a heavy expense and related to large emissions of greenhouse gasses. In this study, a new control algorithm for the aeration (i.e. adding air) is developed. The algorithm plans operation with respect to data from electricity markets and production and hence it helps to reduce costs and emissions to the benefit of future smart cities.

Predictive Control

A control algorithm for WWTP aeration is developed based on the Model Predictive Control (MPC) principle. This means that the optimal control actions are planned by predicting the optimized system's reactions to control. Optimal control is then found by optimization over an objective function which can be either to optimize total operational costs or to optimize greenhouse gas emissions. This also implies that a system model is needed. In this implementation a model of the alternating activated sludge process that is based on stochastic differential equations is used. In Figure 1 a simple example of a prediction using the model and the optimal control of aeration is shown.

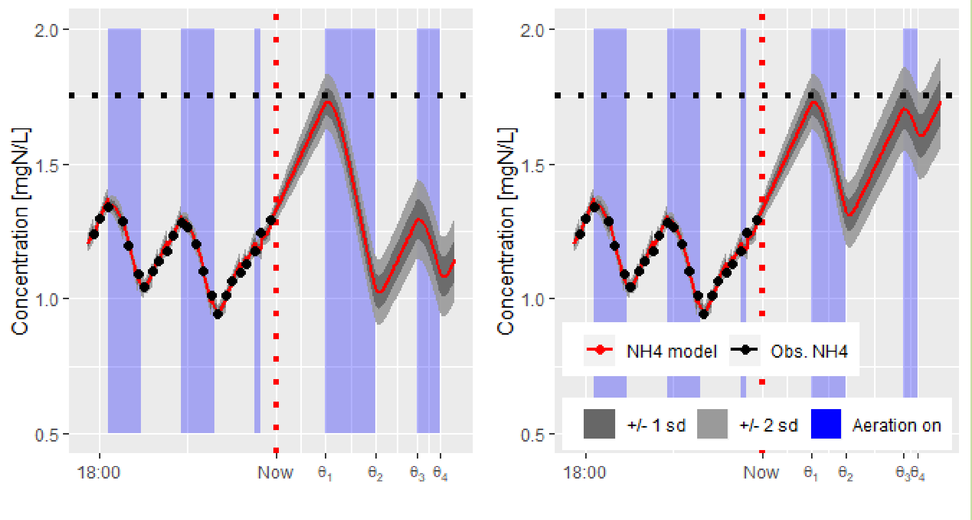

Figure 1: An example prediction of ammonium concentrations 2 hours ahead (left) and the optimal control as found using the MPC principle (right). Both scenarios keep ammonium concentrations sufficiently low (below the black line), however, the **right** scenario uses ~40% less electricity.

Results from a small Danish Wastewater Treatment Plant

The control algorithm is tested both in simulations and full-scale at a small Danish WWTP located in Nørre Snede. To evaluate performance, simulations that use electricity price and emission data (from Nordpool and Energinet) and real data from the plant are performed. Four different objective functions are developed and tested: (i) that optimizes the effluent nutrient concentrations, (ii) that optimizes electricity consumption, (iii) that optimizes operational costs in terms of taxes and electricity, and (iv) that optimizes GHG emissions in terms of nitrous oxide from the processes and emissions related to electricity production. In addition, the current installed rule-based control is evaluated. In Table 1, average findings from 51 simulated days are presented.

Table 1:Comparison of average daily costs and Greenhouse Gas (GHG) emissions when using different objective functions to control aeration at Nørre Snede WWTP. Results are based on simulations.

Objective (minimize)	Cost [DKK/day]	GHG emissions [kg-CO2-eq/day]
Effluent concentrations	409.6	269.9
Electricity consumption	298.3	406.5
Operational costs	288.5	395.7
GHG emissions	352.5	232.3
Current control	317.5	358.4

In Table 1, it is noted that the costs and GHG emissions depend on the chosen control objective. Hence the cheapest operation is found using the “Operational costs” objective and the best in terms of reducing GHG emissions is found using “GHG emissions” objective. In this context, it is important to remark that in all cases effluent concentrations satisfied the effluent requirements, however the objective “Effluent concentrations” reduced the concentrations further than what was necessary.

Conclusion

A smart control strategy for wastewater treatment aeration is developed and tested. The summarized findings are;

- A predictive control algorithm is used with online electricity data to reduce selected objectives. The control has been tested both in simulations based on real data and full-scale on municipal wastewater treatment plants.
- Optimizing operational costs was in this case 19.2%, 29.6%, and 9.2% cheaper when compared to controls optimizing for GWP, effluent N-concentrations, or the currently implemented control strategy respectively.
- Control optimizing GWP in terms of GHG emissions resulted in 40.9%, 42.5%, 13.9%, and 34.9% lower emissions compared to controls optimizing for costs, electricity consumption, effluent quality, and RBC respectively.
- The objective of aeration control should be carefully determined, as this influences heavily on the outcome. However, the objective could easily be changed if new challenges arise.
- Finally, this is considered a step towards including WWTPs in future smart cities.

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Acknowledgments: Innovation Fund Denmark. Grant 7038-00097B