Optimizing Biotreatment: Integrated Process Models and Control Strategies

Biological process models are increasingly used in the design of wastewater treatment plants, especially in design of upgrades for biological nutrient removal (BNR). In the past two decades, a series of sophisticated activated sludge models (ASMs) such as ASM1, ASM2, ASM2D, and ASM3 were introduced that simulate biochemical oxygen demand/chemical oxygen demand (BOD/COD removal, nitrification, denitrification, and biological phosphate removal. These newer models are highly accurate and useful for design, research, and other off-line activities. Automated process control technologies and sensors are also being used extensively at more and more treatment plants. There are many reasons for increased use of automation including improved process knowledge, better instruments that require less maintenance, easier networking, personal computers with more capabilities, and PC-based software. In particular, improvements in online instrumentation for measuring the various nitrogen species have been a boon for automatic control of BNR processes. The underlying driving forces behind automation, however, are process optimization and cost minimization.

Stamford control room with operator stations and large screen display.

The greatest potential for optimizing biotreatment exists with the integration of these two technology areas – process models and control technology. Such use of model-based control (known as model predictive control) is widely used in some process industries but rarely in the utility industry. Model-based control has the potential benefit of being proactive rather than always reactive. By estimating future inputs, plant process operational adjustments can be started to correct for future conditions to optimally control the entire treatment process. Improvements could be realized in effluent quality, energy efficiency, reduced chemical usage, and labor savings at existing and new wastewater treatment plants.

The specific objective of this research was to develop and demonstrate real-time models for BNR and an integrated modeling and process control approach at a full-scale treatment plant using BNR. The real-time model was developed during a first phase and the integrated modeling and process control approach in a second phase. The final report documents the methodology, identifies the necessary components for successful implementation, and documents the process and economic benefits of the automated process control system.

The research team developed real-time artificial neural network (ANN) models for biological nutrient removal. It also demonstrated an integrated modeling and process control approach at the Stamford Water Pollution Control Authority's wastewater treatment plant in Stamford, Connecticut. The facility uses both pre-denitrification, as well as post-denitrification with methanol addition for nitrogen removal. The facility has two independent trains, one of which was fully instrumented for monitoring and control. Hach Company loaned the plant analyzers for the duration of the project. The loan included five ammonia, three nitrate/nitrite, two dissolved oxygen, two ORP, and one suspended solids analyzers.

BENEFITS

- Provides a discussion of key elements of artificial neural network models including their advantages and disadvantages.
- Demonstrates that artificial neural network models can adequately simulate the nitrification and denitrification processes.
- Documents the performance of online analytical instruments at a full-scale wastewater treatment plant.

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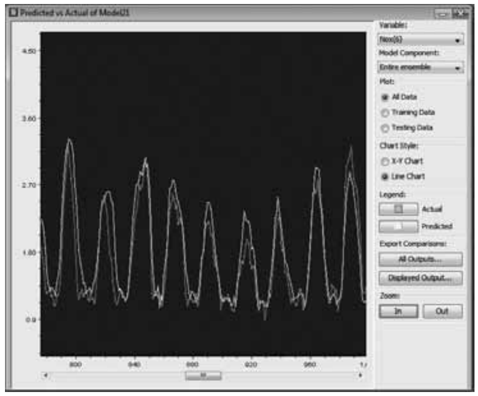
The instruments were maintained by plant staff with quarterly maintenance by the manufacturer. Most staff maintenance activities included simple cleaning of the probe or filter, running conformance tests, and changing chemical reagents.

A series of increasingly complex ANN models for nitrification were then developed to describe that process across the pre-anoxic and aerobic sections of the plant. The output of the model was the NOx-N concentration measured at the beginning of the post-anoxic zone. Flow rate and primary effluent ammonia concentration were inputs to all the models. The parameters dissolved oxygen concentration, RAS flow rate, MLSS recirculation flow rate, and MLSS concentration were progressively added as additional inputs to the models to investigate their influence on the model results. Time plots of the model prediction and the actual NOx-N concentration for the model with all the input parameters were made and a good correlation coefficient of this simulation of 0.83 was obtained. The correlation of the nitrification model with just flow rate and ammonia concentration was 0.81; almost the same as the model with all of the noted parameters as inputs. While this might imply that none of these parameters had significance to the model, the more appropriate interpretation is that their significance could not be assessed by the ANN model since they did not limit nitrification in the case of dissolved oxygen and did not vary significantly in the cases of the other parameters. Future experiments are planned to purposefully vary those parameters to refine the model.



Denitrification Model: Nine Days of Simulated and Measured Nitrate/Nitrite Concentrations.

Two ANN models for denitrification were also developed to describe that process across the post-anoxic zone of the plant. The output of the model was the NOx-N concentration measured at the end of the post-anoxic zone. Flow rate and NOx-N concentration at the entrance to the post-anoxic were inputs to both models. The methanol flow rate was added as an additional input to the second denitrification ANN model. The correlation coefficient of both models is 0.89. A time plot of the model prediction and the actual NOx-N concentration for the simpler model is shown on the following figure. Results were similar for both models.

As with the nitrification models, the significance of methanol flow rate could not initially be assessed because the methanol flow rate did not vary significantly. Additional experiments were conducted to purposefully vary the methanol flow rate to refine the model. The denitrification model was retrained on the new data set and obtained a correlation coefficient of 0.96.

The following conclusions can be made from the study:

- Online analytical instruments can provide reliable and accurate real-time measurements. These instruments all require periodic maintenance, and their level of maintenance is usually reasonable.
- Artificial neural network models can be developed that simulate the nitrification and denitrification processes with adequate accuracy for control purposes.
- Additional experimental field work is required to purposefully vary some controlled parameters so that their effects can be incorporated into new versions of the models.

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