Hampden Township's Roth Lane Wastewater Treatment Plant in Mechanicsburg, Pa., installed a continuously sequencing reactor to enable intermittent aeration and achieve biological nutrient removal. Gannet Fleming

Dynamic modeling of cyclic aeration process for biological nutrient removal

An innovative activated sludge process, coupled with an advanced control system, helped the Hampden Township (Pa.) Roth Lane facility meet strict nitrogen and phosphorus effluent limits

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The Hampden Township Roth Lane Wastewater Treatment Plant in Mechanicsburg, Pa., developed and calibrated a dynamic model to predict the performance of a cyclic or intermittent aeration process for its extended aeration activated sludge process. The water resource recovery facility automatically cycled aeration on and off to create oxic, anoxic, and anaerobic conditions within the reactor's biomass.

Sequencing these conditions in the same order enabled nitrification, denitrification, and biological phosphorus removal in a single reactor. Several variants of the intermittent aeration process exist for biological nutrient removal applications, including the continuously sequencing reactor (CSR), which the Roth facility used. The facility used its model to predict the performance of the CSR process at different flows and loadings conditions.

Hampden Township Roth Lane Facility

The Hampden Township Sewer Authority owns and operates the Roth Lane facility, which has an average design flow of 18,244 m^3/d (4.82 mgd) and a maximum month flow capacity of 25,662

m^3/d (6.78 mgd). The facility was constructed in 1982 and upgraded in 2010. It consists of five influent wastewater screens, a spiral-flow aerated grit and grease removal system, two CSR basins, three final clarifiers, and ultraviolet disinfection.

Waste secondary sludge generated by the biological treatment process is thickened using a gravity belt thickener and then pumped to a two-stage mesophilic aerobic digestion process. Thickened sludge is dewatered, lime-stabilized, and eventually land-applied. Sidestreams from the gravity belt thickener and the sludge dewatering process are recycled back to the head of the facility. An alum feed system also can be used to chemically precipitate phosphorus.

Roth Lane has to comply with strict nitrogen and phosphorus removal requirements associated with Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy. Roth Lane's current National Pollutant Discharge Elimination System permit includes total nitrogen (TN) and total phosphorus (TP) effluent mass load limits, which are enforced on a 12-month "compliance year" basis from Oct. 1 through Sept. 30 of the following year (see Table 1, p. 32). The annual mass load limits are 46,266 kg (101,997 lb) TN and 5606 kg (12,359) lb TP.

However, with the help of the CSR process, Roth Lane is capable of producing much lower TN and TP annual mass loadings than required.

Continuously sequencing reactor

CSR is a cyclic aeration process that uses fine-bubble membrane diffusers suspended from a peripherally driven rotating bridge. As the bridge rotates, it moves the submerged diffuser assemblies, stirring the reactor contents without the necessity of using air.

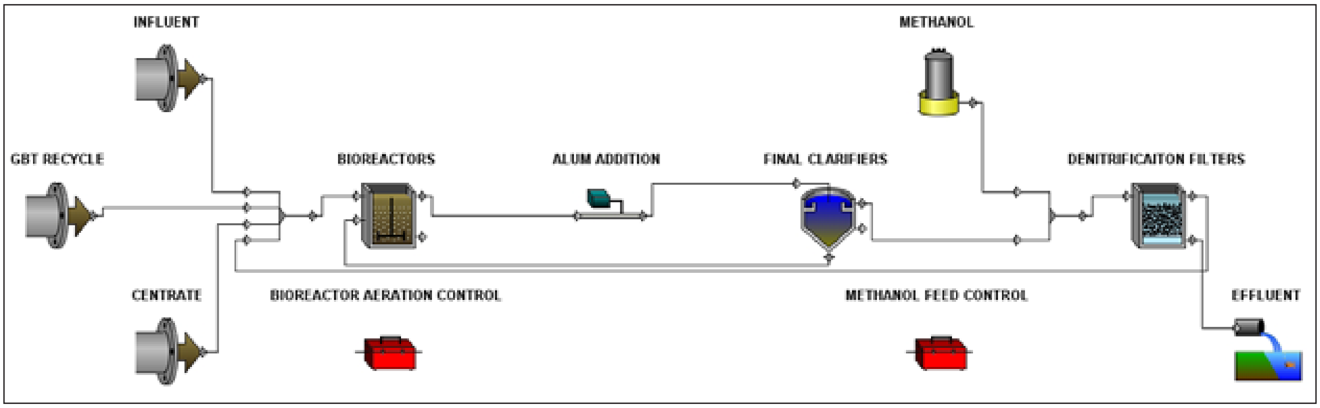
Roth Lane has two CSR reactors; each has a diameter of 34 m (111.5 ft) and side water depth of 5 m (16.4 ft). The CSR process was designed based on a solids retention time of 16 days. Each reactor is equipped with 562 tube diffusers, which are mounted on retrievable rack assemblies and suspended from the rotating bridge. These diffusers are termed "rotating diffusers," since they rotate with the bridge.

There also are 480 tube diffusers mounted 203 mm (8 in.) above the floor on retrievable rack assemblies attached to the tank's wall. These diffusers are termed "stationary diffusers," which have a clearance of 0.5 m (1.7 ft) with the rotating diffusers.

Aeration in each CSR basin is supplied by three positive-displacement blowers, each equipped with variable-frequency drives. The operating airflow for each blower ranges from 15.3 to 49.3 m^3/min (540 to 1740 ft^3/min). For each bioreactor, one of the blowers is dedicated to the stationary diffusers, and the second blower is dedicated to the rotating diffusers. The third blower serves as a redundant standby blower for either set of diffusers.

The process control system at the Roth Lane facility is capable of continuously monitoring dissolved oxygen (DO) and nitrate. The 4- to 20-mA output signals from each probe in each reactor

Figure 1. Model layout for the continuously sequencing reactor process at the Roth Lane Wastewater Treatment Plant



are sent to a programmable logic controller (PLC) to establish process phasing through oxic, anoxic, and anaerobic cycles. A proportional-integral-derivative (PID) control loop is used to modulate the blower speed in each reactor to maintain the DO setpoint. To allow operational flexibility, the PLC enables the user to adjust the DO setpoint and stage timers for each phase.

Simulation model development and calibration

The Roth Lane facility currently is expanding to accommodate additional flows and loadings from a nearby municipality. As part of the expansion project, denitrification filters with methanol addition will be installed to enhance nitrogen removal at the projected design flows and loadings. To predict performance and meet the low TN and TP effluent limits, a process simulation model was required.

Mechanistic models have become a popular design tool for evaluating and sizing biological nutrient removal processes. Designers can use model simulations to quickly test many different process configurations and design parameters in a fraction of the time and cost it would take to perform traditional design calculations and laboratory or pilot tests. Process simulators are computer programs that enable users to specify all of a facility's processes, select a mathematical model (such as an activated sludge model), and solve the model to predict plant performance.

Gannett Fleming (Camp Hill, Pa.) developed a comprehensive simulation model for Roth Lane. The model was developed using the carbon, nitrogen, and phosphorus library based on the activated sludge model version 3 (ASM3). The software used has an improved user interface, compared to previous versions, and enables easier generation of output graphs and reports. It also has useful features, such as a methanol feed module and denitrification filters.

The model included three influent sources: wastewater influent, recycle flows from the gravity belt thickener, and recycle flows from the solids dewatering process. A detailed speciation of the CSR influent was carried out by defining the composite variables and their various constituents (state variables) for each parameter. For example, the composite variables for chemical oxygen demand (COD) are soluble COD and particulate COD, and the state variables are soluble inert COD, soluble substrate COD, particulate substrate COD, and particulate inert COD. With the CSR influent adequately characterized, a modeling layout to simulate the existing operation of the Roth Lane facility was constructed (see Figure 1, above). The treatment processes were modeled with respect to the existing operation of the CSR, chemical precipitation of phosphorus, and the final clarifiers. The ASM3 model was employed to model carbonaceous oxidation, nitrification, and denitrification.

The two CSR reactors were modeled as a single complete-mix reactor. Operating one or two reactors in the model was accomplished by increasing or decreasing the total volume. The complete-mix reactor was set up to aerate using fine-bubble diffusers operating with the native DO controller (a PID controller based on effluent DO). Cyclic aeration mode was simulated and controlled using the software's Modeling Toolbox running as a timer. The timer was used to cycle the aeration on and off by varying the DO setpoint.

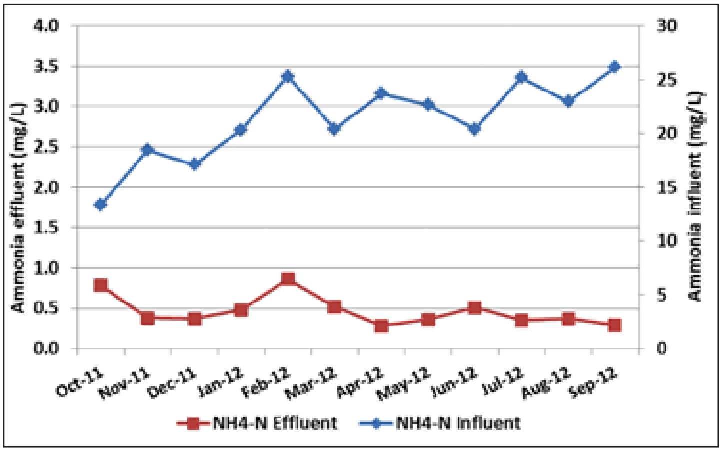
Proper construction and calibration of the model layout was completed in steps that allowed for calibration of each modeling object within the layout. Hampden Township personnel performed a comprehensive sampling program for model calibration. Steady-state and dynamic simulation confirmed the overall modeling layout calibration. For steady-state calibration, the average CSR influent characterizations and the average operational parameters that were experienced during the sampling period were employed in the layout. A steady-state simulation was run to make model predictions relative to effluent, mixed liquor, and the clarifier's underflow sludge criteria. The steady-state model predictions agreed well

Table 1. NDPES permit discharge limits for the Roth Lane Wastewater Treatment Plant

Parameter	Average monthly concentration (mg/L)	Mass load (lb/yr)*
Total suspended solids	30	-
Carbonaceous biochemical oxygen demand	15	-
Ammonia (5/1 to 10/31)	1.8	-
Ammonia (11/1 to 4/30)	5.4	-
Total phosphorus	2.0	12,359
Total nitrogen	-	101,997

* Mass load enforced on 12-month compliance year basis from Oct. 1 to Sept. 30.
NPDES = National Pollutant Discharge Elimination System.

Figure 2. Ammonia influent and effluent concentrations at the Roth Lane Wastewater Treatment Plant



NH4-N = ammonium.

with the average measured parameters during the sampling program, indicating that the model was calibrated.

The dynamic calibration incorporated temporal variations in influent characteristics, operational parameters, and process performance. It was carried out by creating a database that is dynamically read into the model. The database inputs the parameters that govern the performance of the facility – mixed liquor volatile suspended solids, return activated sludge, total suspended solids, etc. – that occurred during the sampling program. Overall, the dynamic model predictions agreed well with the daily measured parameters, highlighting the powerful performance-predicting capability of the model under a variety of operating conditions.

The calibrated model was used to run simulations under a variety of influent scenarios and operating conditions. In total, eight scenarios were simulated to predict Roth Lane's performance to accommodate additional flows and loadings from a nearby municipality.

Four scenarios were simulated during the startup year of the new upgrades, with annual average daily flow (AADF) and maximum month average daily flow (MMADF) for summer and winter conditions. The other four scenarios were simulated at the design year with AADF and MMADF for summer and winter conditions.

Actual performance versus model predictions

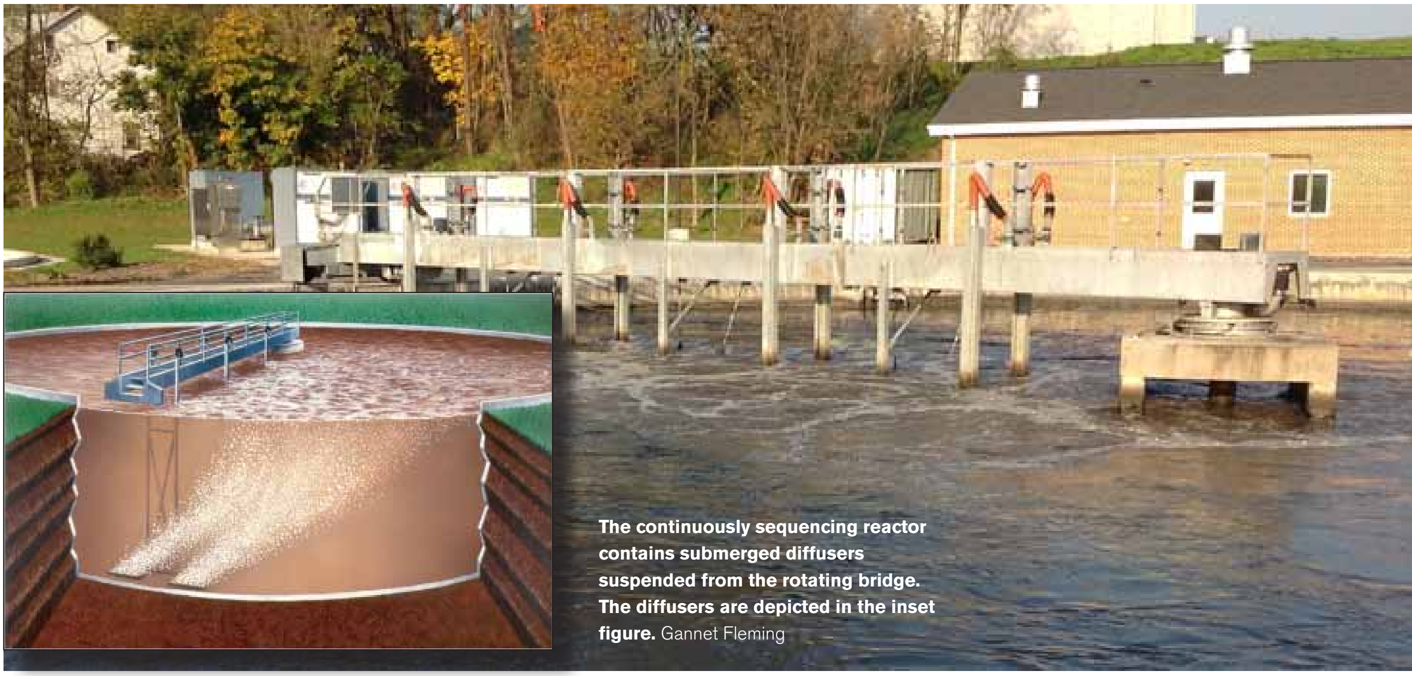
Model predictions at startup conditions were compared to the performance of Roth Lane for compliance year 2012 (see Table 2, p. 34). The model simulations showed that the CSR process met discharge limits with respect to biochemical oxygen demand, total suspended solids, ammonia, and TP at AADF and MMADF in summer and winter conditions. Effluent data from Oct. 1, 2011, to Sept. 30, 2012, showed that Roth Lane performed exceptionally well.

Influent ammonia averaged 21.3 mg/L, and final effluent ammonia averaged 0.46 mg/L – a removal efficiency of 97.8%. The highest monthly average effluent ammonia concentration in the summer was 0.78 mg/L (see Figure 2, above).

In addition, the facility produced final effluent with low TN concentrations, averaging 4.1 mg/L for the same time period. This is well below the target effluent TN concentration of 7 mg/L based on an annual mass load allocation limit of 46,266 kg (101,997 lb) of TN and design average flow of 18,244 m^3/d (4.82 mgd; see Figure 3, p. 34).

The capability of the CSR process in achieving low TN and TP in the final effluent also was evident in the annual nutrient mass load limits. A TN loading of 19,923 kg/yr (43,921 lb/yr) was reported for the same compliance period; that's just 43% of the discharge permit's TN limit. Likewise, a TP loading of 3641 kg/yr (8026 lb/yr) was reported for the same time period, just 65% of the annual mass loading limit.

Overall, the model predictions agreed with respect to the annual average parameters measured in the final clarifier effluent and the annual average mixed liquor suspended solids and waste



The continuously sequencing reactor contains submerged diffusers suspended from the rotating bridge. The diffusers are depicted in the inset figure. Gannet Fleming

Table 2. Model predictions at startup conditions versus actual performance at Roth Lane Wastewater Treatment Plant

Parameter	Scenario 1 AADF (summer)		Scenario 2 MMADF (summer)		Scenario 3 AADF (winter)		Scenario 4 MMADF (winter)	
	Model	Actual[1]	Model	Actual	Model	Actual	Model	**Actual**
Average flow (mgd)	4.56	3.59	6.47	5.03	4.56	3.50	6.47	4.59
Carbonaceous biochemical oxygen demand (mg/L)	1.6	2.6	2.1	3.1	2.4	2.8	3.3	3.5
Total suspended solids (mg/L)	6.4	3.3	9.4	4.7	7.0	3.8	9.6	5.8
Ammonia (mg/L)	0.9	0.4	0.8	0.8	2.2	0.5	2.1	0.9
Nitrate (mg/L)	6.9	2.3	8.3	2.7	8.8	2.6	7.5	3.3
Total nitrogen (mg/L)	8.9	3.8	9.9	4.5	10.4	4.3	10.4	5.5
Total phosphorus (mg/L)	1.1	0.8	1.2	1.1	1.1	0.7	1.2	0.8
Waste activated sludge flow rate (mgd)	0.061	0.051	0.084	0.086	0.070	0.045	0.092	0.079
Mixed liquor suspended solids (mg/L)	2634	2895	3452	3024	3349	2924	3602	3130

[1]Actual values are based on annual average effluent conditions for compliance year 2012.

AADF = annual average daily flow.

MMADF = maximum month average daily flow.

activated sludge flow rate. The CSR process was modeled at higher flows and loadings to take into account the additional flows and loadings from the nearby facility. The actual AADF and MMADF for Roth Lane in 2012 were lower than those used for modeling. In addition, the two CSRs at Roth Lane were operated in series during low-flow periods in 2012.

According to Jeff Klahre, operation supervisor at Hampden Township, "The flexibility of operating the CSRs in series provided Hampden Township the opportunity to reduce sludge production and the operational costs associated with polymer addition." The actual annual average waste activated sludge flow rates were generally lower than those predicted by the model.

The model prediction for effluent nitrate was somewhat greater than the actual annual average values, making the predicted effluent TN concentrations greater. It should be noted that the ASM3 model uses the oxygen half-saturation coefficient for heterotrophic bacteria, a kinetic coefficient that governs denitrification in the bioreactor as a function of DO. The ASM3 model default value used for the oxygen half-saturation coefficient is 0.2 mg oxygen per liter. However, several studies argue that the oxygen half-saturation coefficient should be 0.3 mg oxygen per liter, which would reduce the effluent nitrate concentration and reduce the predicted effluent TN values.

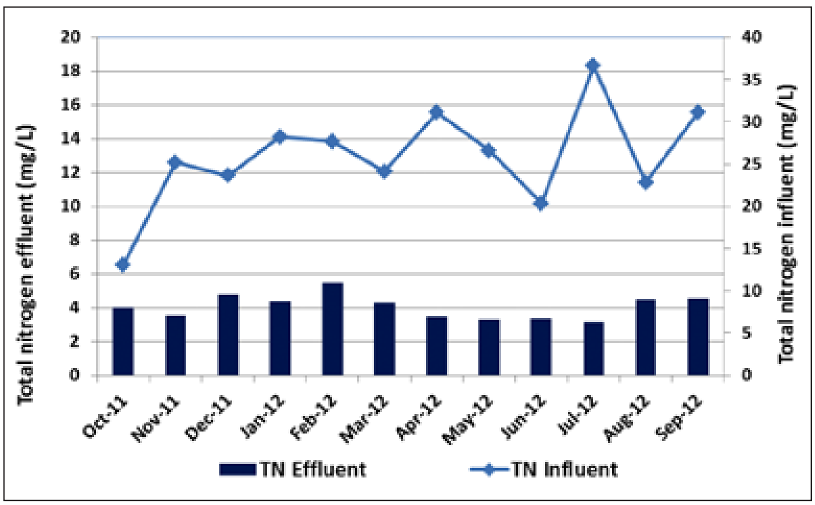
The predicted performance of the Roth Lane facility would more closely approach the actual effluent data values if modeling were performed at the actual flow and loading condition. The slight discrepancy between model predictions and actual effluent data could be attributed to the fact that the two CSRs were being operated in series, not in parallel as intended, during low flows and loadings conditions.

Advantages of cyclic aeration modeling

The validated model developed for Roth Lane is a powerful performance-predicting tool, which has been used to evaluate the capability of the CSR process in meeting strict effluent TN and TP limits under a variety of loadings and operating conditions. Model predictions and actual plant performance data highlight the operational flexibility of the CSR process, which enabled Hampden Township Sewer Authority to generate TN and TP credits that could be sold to other municipal water resource recovery facilities on the nutrient trading market.

According to Klahre, "The results that Hampden Township gets from the CSR process speak for themselves. The CSR system is extremely operator-friendly and low-maintenance."

Figure 3. Total nitrogen influent and effluent concentrations at the Roth Lane Wastewater Treatment Plant



TN = total nitrogen.

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