Using a continuous-fill, intermittent-discharge SBR to remove biological nutrients

By K. Khier Chibani

The plant has three continuous - fill, intermittent – discharge sequencing batch reactors.

Five years ago, the Town of Essex, in southwestern Ontario, decided to upgrade its facultative lagoon treatment systems with an alternative wastewater treatment plant — a continuous-fill, intermittent-discharge sequencing batch reactor (CFID-SBR) system, targeting even higher effluent quality.

The CFID SBR process was designed by Premier Tech Aqua, which also provided major process equipment for the high-performance treatment plant. Engineering for the construction was designed and provided by Stantec Consulting Ltd. (Windsor). The plant is being operated by the Ontario Clean Water Agency.

The plant has three CFID-SBR reactors with a total average capacity of 4,590 m^3/d (flow rate estimated for the next 20 years). Provision has been made to expand the plant further, with 33% more capacity, by building a fourth reactor to treat an ultimate design flow of 6,120 m^3/d.

The Essex Sewage Works was commissioned in early January 2006, and since then the CFID-SBR system has consistently met the effluent requirements. Six months after a successful start-up of the first two reactors, process performance testing began. Warm-period testing started in the last week of July and continued through August, September and October. This was followed by cold-period testing for four more months: November, December, January and February.

When the plant had successfully passed the two testing periods with two reactors in operation, testing was continued at higher flow (inflow/infiltration) in March and April 2007, with only one reactor in operation. The CFID SBR demonstrated its ability to efficiently handle a constantly changing flow with high-rate inflow/infiltration.

SBR design approach

The main treatment objectives for the CFID SBR were to achieve reduction of biological oxygen demand (BOD_5), total suspended solids (TSS), ammonia, and total phosphorus (TP). Chemically assisted phosphorus removal was used to ensure that the SBR consistently met effluent requirements for total phosphorus.

Microbial growth kinetic coefficients for heterotrophic bacteria, as well as nitrification kinetic coefficients, were based on the ASM model (Henze et al. 2000). Kinetic coefficients given at 20°C were adjusted to design temperatures using the Arrhenius equation.

Mass balance and prediction of sludge production were based on modeling of the suspended growth treatment process, considering heterotrophic biomass, cell debris, nitrifying biomass, non-biodegradable volatile suspended solids (VSS) in influent and inert TSS in influent (Metcalf & Eddy, 2003).

Each of the three basins has an effective volume of 1,567 m^3, leading to one-day hydraulic retention time at average dry weather flow (design flow).

Biological process simulations using BioWin as a platform were also part of the design. The simulations considered cycle time and the particular hydraulic management of the CFID SBR and tracked the variation of the concentrations of pollutants being treated. Two main scenarios were explored. The first one considered wastewater with cold temperature 8°C. In this case, effluent quality for ammonia and BOD remained below the limits.

The second scenario assumed a 50% higher flow per reactor, lasting a whole week. This would be the case, if one out of the three reactors was suddenly out of service for a week. Simulation results confirmed that the CFID SBR system, as designed, would meet targeted effluent criteria.

Field data and performance results

For March and April 2007, one reactor configuration had to face a continuous, extremely high hydraulic load, most likely due to water infiltration and inflow. Average design flow per reactor was exceeded by more than 70% and maximum treated daily volume was on average 4.6 times the design average daily flow. Hourly peak flow reached 150 L/s, which is 8.5 times the average design flow per reactor.

Influent pumps were equipped with variable frequency drives (VFDs) and indeed the influent intensities were progressively increasing and decreasing. The CFID SBR sequence was not just jumping between two modes (normal mode and storm mode), instead, it was continuously and smoothly adjusting every five minutes to the variation of the inflow. Treatment steps were automatically and progressively shortened, or extended, depending on influent variations.

At all times, the system was able to make best use of the process equipment, thereby extending the cycle of treatment every time it was possible.

SBR mixed-liquor temperature was significantly affected by influent temperature, and both SBR and influent temperatures were affected by ambient temperature. Environment Canada reported that the average monthly ambient temperatures for March and April 2007 for the Windsor area were 4.2ºC and 8.5ºC, respectively.

The SBR was roofless and quite exposed to weather conditions. Consequently, in March and April 2007, both factors (influent and ambient temperatures) contributed to cooling the SBR, which is unhelpful for treatment performance. Although January and February were the coldest months, the impact on the SBR was less visible because of low precipitation and, therefore, low water inflow/infiltration.

It happens that with excessive high incoming flow, the time for the treatment cycle is reduced considerably, meaning the static-fill step is skipped almost regularly and the fill-settle step is reduced progressively to about 45 minutes per cycle. This may well have contributed greatly to gradually diminishing the effectiveness of the biological selector effect and thus raising the SVI number.

Analyses of effluent TSS for March and April 2007 confirm this observation about settling deterioration under stress conditions. TP concentration in the effluent also displayed the same trend as TSS, despite alum dosing. Note that dosing was on average at 49 µL of liquid alum per litre of wastewater. The mole ratio was on average around Al:P 2.2, based on an estimated 2.38% w/w phosphorus assimilation in VSS biomass (Eckenfelder & Grau). Chemical sludge made up about 8% of total sludge, which might have contributed to maintaining relatively good settling.

Organic matter concentrations expressed as COD and BOD showed the plant had no difficulty at all in demonstrating an excellent performance. Even with one reactor in operation, BOD was consistently below 5 mg/L.

Full nitrification was observed. Even at low temperatures, total ammonia in the effluent remained well below the target concentration of 1 mg/L. For the last testing with one reactor in operation for three months, total ammonia did not exceed 0.6 mg/L on average. This means the treatment cycle as engineered provided enough aeration time to complete the nitrification reaction.

Also important was that filling with wastewater during settling and decanting did not affect the quality of the effluent, thanks to the baffle wall.

Nitrate (NO_3) and nitrite (NO_2) concentrations in the influent were monitored on a regular basis, similar to the rest of parameters reported above. On average, total influent concentration (NO_2+ NO_3) was below 0.25 mg/L, so the im-

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pact on total balance is not significant.

The percentage of removal of total nitrogen during the warm period and with both reactors in operation averaged 70%. When shifting to one reactor configuration, the percentage of removal dropped to 60%. Average BOD loading for March and April 2007 was around 200 kg BOD/d, and, based on the synthesis of new biomass and nitrogen assimilation, could not be responsible for more than 25% of removal. Therefore, the excess nitrogen removal can only be attributed to the denitrification process.

Conclusion

Process performance testing started in July 2006 and continued till April 2007. CFID SBR system performances were excellent and consistently in compliance with the design criteria for effluent quality. Analyses of BOD_5, TSS, ammonia and phosphorus concentrations in the effluent were always very low and almost never exceeded discharge limits.

Full nitrification was observed. Even at low temperatures, total ammonia in the effluent remained well below the targeted concentration. Inherently, the CFID SBR system provided partial denitrification, despite the lack of mechanical mixing.

The CFID SBR, with its added flexibility, allowed the treatment process to provide more than satisfactory results in particularly challenging conditions where only one reactor was in operation with a high inflow/infiltration rate.

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