

COMPUTER MODELING AND FIELD-TESTING OF AN INTELLIGENT SEQUENCING BATCH REACTOR (iSBR) CONTROL SYSTEM

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ABSTRACT

The Sequencing Batch Reactors (SBR) at Daniel Island WWTP are rapidly approaching design capacity. The Charleston Water System (CWS) commissioned Black & Veatch to investigate options to optimize the treatment capacity of the SBRs beyond their existing design capacity.

The plant optimization used – for the first time in a full-scale application - an intelligent control approach termed the “intelligent” SBR or “iSBR”. The iSBR control approach uses a measurement of oxygen uptake rate (OUR) to determine when the SBR has completed treatment, indicated by a sudden decrease in the OUR as the activated sludge reaches an endogenous state. Testing the iSBR control was carried out in two steps. Firstly a dynamic process model of the plant was used to prove iSBR control approaches based on OUR, dissolved oxygen (DO) and rate of change of DO (“dO/dt”). Secondly, a 5-day full-scale trial was carried out on one of the SBRs at Daniel Island. The full-scale trial was successful and so the control was left in operation after the trial period was over.

Implementation of the iSBR control system in conjunction with the addition of extra aeration capacity enabled the plant to increase its design rating by 50%. Addition of an influent equalization tank will enable the plant to increase its design still further to effectively double the plant capacity.

BACKGROUND

The Daniel Island WWTP consists of two Aqua-Aerobic SBRs designed to treat a combined average day flow up to 0.5 mgd. The SBRs are followed by a small post equalization basin, cloth-media Aqua-Disk filters and Trojan UV disinfection. The operation of the SBRs is controlled by a dedicated PLC unit linked to a fully-functional SCADA system that was developed and is maintained by CWS personnel.

Daniel Island is an area undergoing rapid development, which is causing the plant influent flows to increase dramatically. As a result, the plant is rapidly approaching its design capacity. In order to accommodate these increasing flows in the near-term, CWS (formerly CPW: Charleston Commissioners of Public Works) engaged Black & Veatch to investigate options to optimize and maximize the treatment capacity of the SBRs beyond their existing design capacity.

THE iSBR CONTROL APPROACH

In order to optimize the plant performance, it was proposed that the plant should use an advanced control approach termed the “intelligent” SBR or “iSBR”, which is a concept first proposed by

Shaw *et al* (2002), that had yet to be tested on a full-scale plant. The iSBR control approach uses a measurement of oxygen uptake rate (OUR) to determine when the SBR has completed treatment, indicated by a sudden drop in the OUR at the point where all the ammonia has been oxidized and the biomass becomes endogenous. Figure 1 shows the output from a process model of the Daniel Island SBR showing how the OUR changes (in red) as it goes through its treatment cycle. On the same graph, the predicted dissolved oxygen (DO) is also shown (in blue). It can be seen that there is a sudden increase in the SBR DO at the same point that the OUR drops. This is because the SBRs have fixed-speed blowers and no DO control so that they do not adjust their output as the OUR varies.

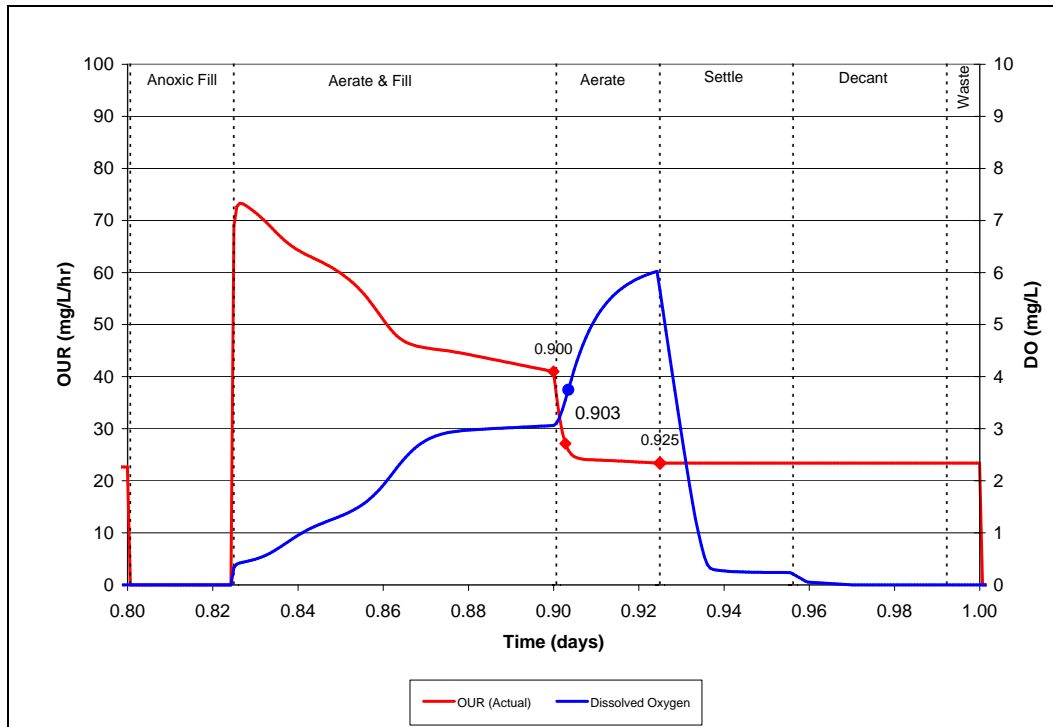


Figure 1: Example SBR Respiriogram for Daniel Island

The iSBR control works by detecting the shoulder in the OUR curve and ceasing aeration at this point. The SBR can then go into an extended settle period or the settle and decant phases advanced to allow the total cycle time to be shortened and more cycles to be completed in a day.

Several potential benefits of the iSBR control can be identified, including:

1. Energy savings by stopping treatment at the endogenous point. All useful aerobic treatment is complete at this stage and continued aeration is a waste of aeration energy.
2. Increased viability of the nitrifying biomass by reducing aerobic endogenous treatment. Continuing to aerate nitrifying bacteria with no ammonia present will cause them to die off. It is postulated that ceasing aeration and allowing the mixed liquor to become anoxic or anaerobic allows the nitrifying population to become dormant and not die off as rapidly as is the case under aerobic conditions.
3. Shorter aerate times, facilitating more cycles per day (increased hydraulic capacity), or longer settle times.

4. Reduced potential for filament growth and potentially better settling sludge. Aerating sludge under low food to micro-organism (F/M) ratios has been suggested to promote the growth of filamentous organisms.
5. Reduced nitrate concentrations as biomass is aerated for a shorter proportion of the treatment time, facilitating more anoxic time.

The main benefit of interest for Daniel Island is number 3 – reducing the aerate time. This could be used to increase the hydraulic capacity of the SBRs, but more usefully it allows for longer settle times. The plant SVI is variable and can reach as high as 200 mL/g. An analysis of the plant capacity indicated that the SBRs could just about cope with SVIs this high but a marginal deterioration in settling characteristics could cause the settling to become critical. The iSBR control could be used to extend the settle time slightly to ensure that it is not critical. An extra 10 or 20 minutes in the settling time is of more benefit than decreasing the overall cycle time by the same amount. In addition to this, benefit number 4 – reduced filament growth - should help prevent the SVIs from rising to historic highs.

PROCESS MODELING – CAPACITY ASSESSMENT

A dynamic process model of one of the SBRs was developed as part of the plant capacity evaluation using the Hydromantis GPS-X simulator (Figure 2). The SBR model in GPS-X is capable of simulating the hydraulic, biological and settling mechanisms of the SBR process.

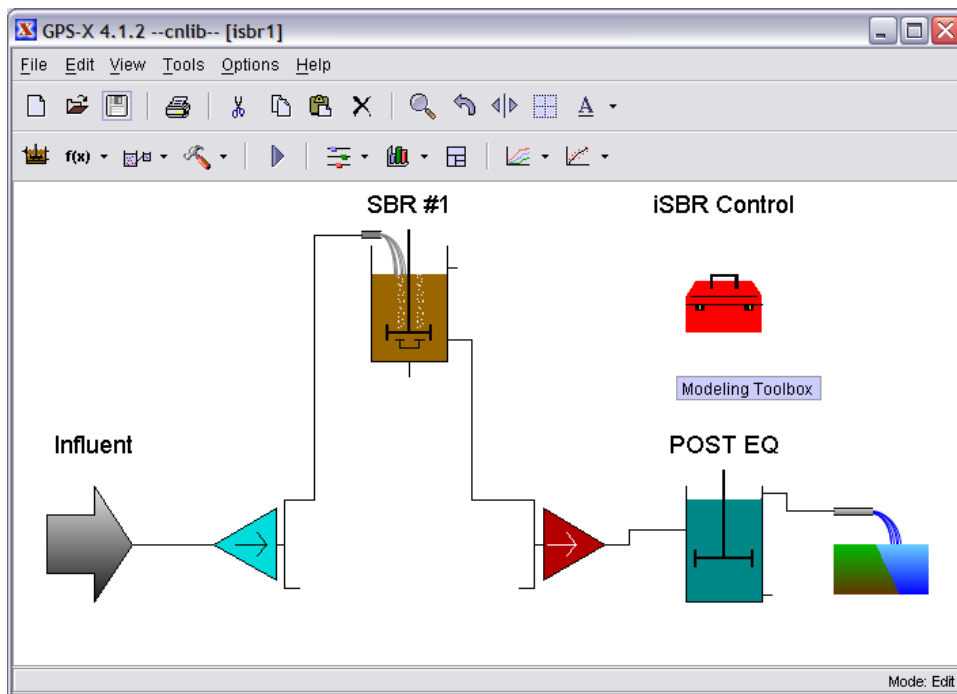


Figure 2: iSBR Model in GPS-X

The most important aspect of modeling any wastewater treatment facility is having an accurate picture of the influent characteristics. For most process simulations, steady-state calculations (i.e. all values fixed over time) are carried out using daily or monthly averaged influent data.

However, because the SBR process is by definition a batch process it cannot be modeled using average daily or monthly values at a steady-state because the process does not operate at a steady state. In order to accurately model the process a dynamic simulation – where all variables change with time - must be carried out. This required extensive diurnal sampling of the influent BOD, TSS and TKN to be carried out by CWS staff. Figure 3 shows the diurnal concentrations expressed as a fraction of the average concentration that were calculated from these samples. In addition to the diurnal sampling, several other samples were taken in order to develop a more detailed influent characterization that was used in the model.

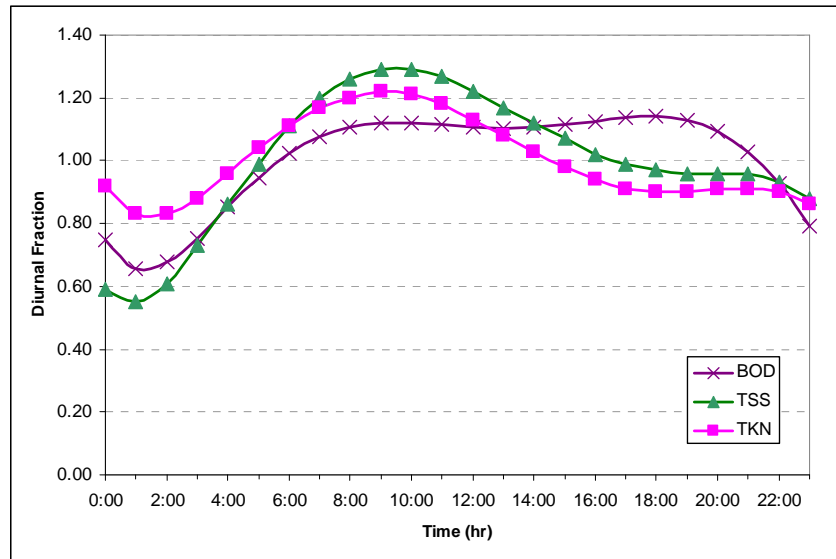


Figure 3: Influent Diurnal Concentrations

In addition to the diurnal concentration profile, the dynamic process model requires a diurnal flow profile. It is especially important to have an accurate diurnal flow profile for an SBR simulation as the model also calculates the variation in the tank liquid volume and predicts when the tank will overflow using hydraulic calculations. Unfortunately the Daniel Island facility does not have an influent flow meter and the effluent flow that is measured does not match the influent flow because the SBRs are filled and emptied at different rates and are followed by an equalization basin. In order to develop an influent flow profile, SCADA data for the tank levels for the two SBRs was analyzed (Figure 4). The rate at which each of the SBRs filled equals the influent flow rate for the measured period and so this was used to calculate the influent flow. In a way, this was like having a giant bucket (the SBRs) and stopwatch. Figure 5 shows the influent flows that were calculated using this data over a period of 4 weeks. On the same figure a polynomial curve was fitted to the data to represent a typical diurnal flow profile for the plant.

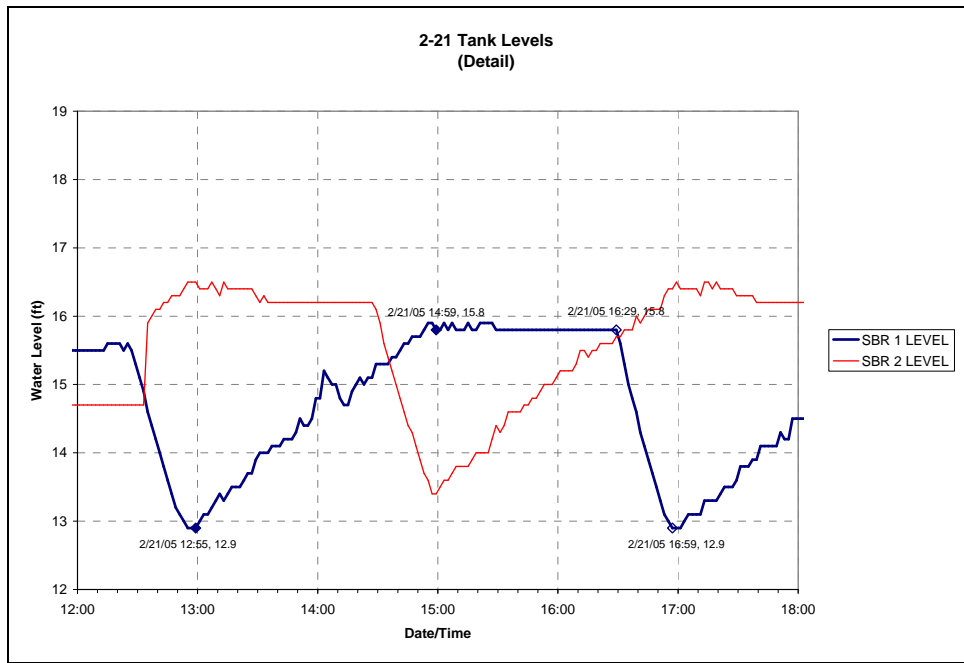


Figure 4: SBR Tank Levels Used to Calculate Influent Flows

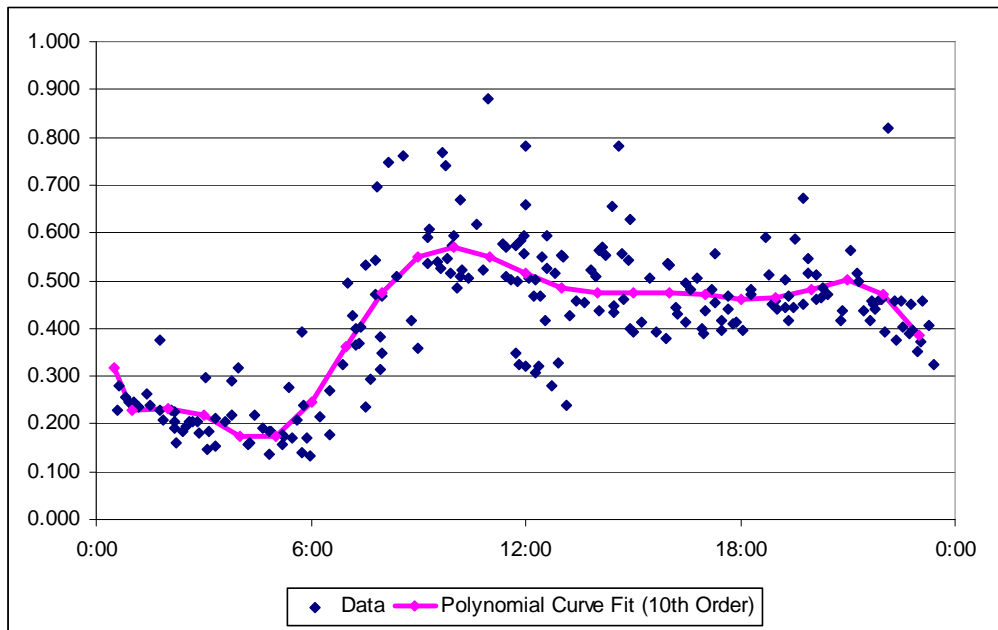


Figure 5: Influent Flows (mgd) Calculated from SBR Fill Rates

Several dynamic model runs were carried out to determine the maximum capacity of the SBR model. In each case, three criteria were used to assess the model performance and adjustments were made to flows and operating times to keep the SBR within these criteria:

1. Hydraulic capacity – the SBR should not overflow (max liquid height = 19.3 ft). Figure 6 shows how the height of liquid varied based on the influent flow to it and the batch operation for one of the model simulations.
2. Biological capacity – the effluent ammonia load must be less than the target load (3.6 ppd)
3. Settling – the SBR effluent should not contain excessive solids. The settling model does not produce a totally accurate prediction of effluent TSS – tending to overestimate effluent solids – but can be used to give an indication of the SBR reaching its limit for handling solids or being in danger of losing its blanket. For this purpose, a target effluent TSS of 20 mg/L was selected as an acceptable maximum (note also that the SBR is followed by a tertiary filter).

In addition to the constraints listed above, the maximum MLSS was maintained between 4000 and 4500 mg/L (design value max is 4500 mg/L) and the phase timings were set up to ensure that filling and aeration were correctly synchronized between the two SBRs.

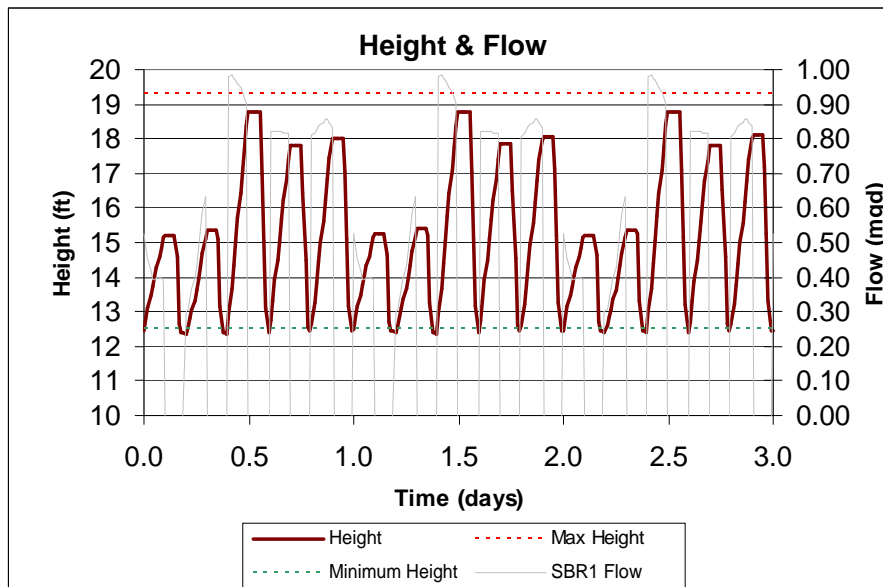


Figure 6: SBR Liquid Height and Flow for a 3-day, 0.7 mgd Simulation

Based on the modeling analysis it was found that the SBRs could adequately treat up to 0.75mgd of flow on an average monthly basis, provided that additional blowers were installed. In addition to this, it was found that if the influent flow was equalized, the plant could be pushed further to treat up to 1.0 mgd of flow.

In order to achieve these maximum capacities it was recognized that the SBR control must be optimized and so the iSBR control was proposed to facilitate this.

PROCESS MODELING – iSBR CONTROL TESTING

Three variations of the iSBR control approach were suggested for testing in the model:

1. Control using a direct measurement of OUR to detect endogenous.

2. Control using a DO setpoint to infer that an endogenous OUR has been reached.
3. Control using the derivative of DO (dO/dt) to detect when this parameter suddenly rises – an indicator that the OUR is heading towards endogenous.

The GPS-X model used to assess the plant capacity was modified to test the effectiveness of the three different control approaches to detect the endogenous point. Figure 2 shows a red toolbox icon in the model layout. This toolbox contains an on/off controller that uses one of the 3 parameters listed above to switch off the blower once a setpoint has been reached. In addition to adding this toolbox icon, some user code was added to the model to carry out the endogenous detection only when the model was in the aerate phase (phase number 4 in the model).

The model was operated using each control parameter for a period of three days and the outputs compared. All three control approaches detected the endogenous point correctly and proved suitable for further investigation. Figure 7 is an example output using a DO setpoint for the control.

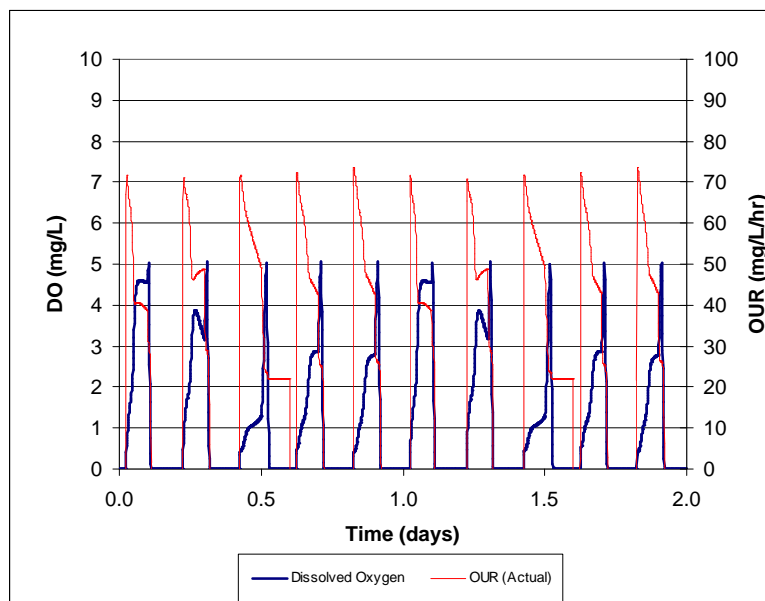


Figure 7: DO and OUR Profile Using DO-based iSBR Control

FULL SCALE TESTING

Having proved the iSBR control approach in the model, it was then successfully field-tested for one week on one of the SBRs at Daniel Island that had an online Hach LDO probe and ORP probe installed in it. Figure 4 shows the results from one cycle in the test period. During the react phase for this cycle, additional measurements were taken, namely, ammonia was measured from filtered grab samples every 10 minutes using the plant's colorimetric test kit and the DO was measured manually using the plant's handheld YSI probe. At the end of the react phase for this cycle it was evident that ammonia concentrations were dropping close to 1 mg/L and a further 35 minutes of aeration would probably enable the SBR to reach endogenous and so the react phase was extended by 35 minutes (labeled "Extended Aerate") in order to test the iSBR control.

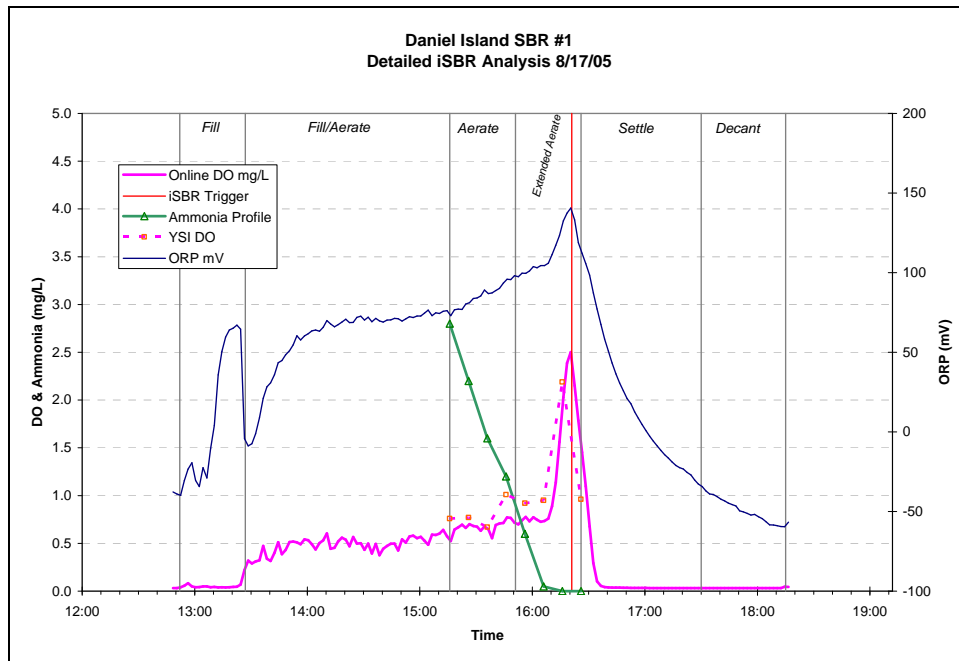


Figure 8: Detail of control cycle including ammonia profile and YSI DO

In Figure 8 it can be seen that the rapid increase in DO occurs when the ammonia concentration reaches zero. This is because the reaction rate for nitrification is zero order (not a function of concentration) except at very low concentrations and nitrification exerts a significant proportion of the oxygen demand observed in the SBR. At the point where all the ammonia is used up, the oxygen demand falls rapidly and so the DO increases. This figure also shows that the ORP curve doesn't respond quite as rapidly as the DO curve at the endogenous point. Finally, from this figure it can be seen that the online DO measurement using the Hach LDO is similar to the readings from the handheld YSI probe, with the YSI reading slightly higher than the Hach LDO.

CONCLUSION

The full-scale test proved very successful using either the DO or the dO/dt approach. iSBR control was continued beyond the initial one week trial and plans are in hand to convert the second SBR to do the same. The study enabled the plant to be rerated to 0.75 mgd with the addition of extra aeration capacity and further to 1.0 mgd using an influent equalization tank.

REFERENCE

Shaw, A. and Watts, J.B. (2002) "The Use of Respirometry for the Control of Sequencing Batch Reactors: Principles and Practical Application", Water Environment Federation 75th Annual Conference, Chicago, Illinois, September 2002.