Smart Biomass Control Saves Energy While Maintaining Treatment Objectives

ABSTRACT

Automatic control of biomass inventory is seldom used in wastewater treatment plants today, despite the high impact on treatment capacity. In this study, a smart biomass control system was used to find the required sludge age of a continuous feed sequencing batch reactor (SBR) based on real-time measured process parameters. The control system further adjusted the amount of biomass wasted to maintain this sludge age. It was found that the system was capable of controlling the process to the sludge age required to reach the desired level of nitrification. The test period was compared to a subsequent test period operating at a sludge age two-folded the required as calculated by the control system. The comparison showed no impact on the treatment performance from increasing the sludge age further. However, the higher endogenous respiration of the older sludge increased the energy consumption with 12 %. The results show that the use of a smart biomass control system has potential to automatically recognize and maintain the sludge age to the current process conditions while providing significant energy savings.

INTRODUCTION

With rising energy costs and sustainability directives setting new demands on carbon footprint reduction, the incitement for energy efficiency and process stability of the biological treatment step in a wastewater treatment plant is growing. Greater efficiency can be reached by optimizing both the biomass sludge age and the amount of oxygen added to address process needs. While most wastewater treatment plants today use aeration control, typically based on dissolved oxygen feedback, to regulate the amount of oxygen added, automatic control of the biomass inventory is still seldom used. Typically, the biomass is only controlled manually by an operator targeting a desired mixed liquor suspended solids (MLSS) concentration. In a survey of the status of control and automation within wastewater treatment in Europe in 2002, dissolved oxygen control is found to be used as standard while sludge inventory control targeting a sludge age only is used seldom, and if so normally trough manual adjustments (Jeppsson et. al, 2002). This is common practice despite the fact that the biomass sludge age generally is considered one of the most critical parameters affecting the treatment performance.

The sludge age required to achieve a desired level of nitrification is dependent on the nitrifier growth rate, which in term is affected by the effluent nitrogen requirement, the dissolved oxygen concentration and the water temperature (Metcalf & Eddy, 2003). This causes the required sludge age to vary both between plants and over time. Continuous optimization and control of the biomass sludge age has the potential to both stabilize the treatment process and save energy by avoiding operation at a higher sludge age than optimal.

METHODOLOGY

Test site and setup

A collaborative research study was conducted by Xylem and IVL Swedish Environmental Research Institute at a pilot plant in Hammarby Sjöstadsverk (Nacka, Sweden). The biological treatment system of the pilot plant consisted of a continuous feed sequencing batch reactor (SBR) of type ICEAS^{TM} from Sanitaire, Xylem. The influent wastewater to the pilot plant was a flow paced portion of the total influent municipal wastewater treated by the Henriksdal wastewater treatment plant (WWTP) located in the city of Stockholm. The dry weather average flow to the pilot plant was 17 m^3/day (4500 gpd) and the peak dry weather flow was 38 m^3/day (10000 gpd).

The study was conducted from February to May 2014 and consisted of two separate test periods. During a stable period of five weeks (Period 1), the plant was controlled with a biomass control system of type OSCAR™ Solids Inventory Management System, which adjusted the Sludge Retention Time (SRT) to the current process conditions. As a second step (Period 2), the SRT was increased twofold during an acclimation period of three weeks and was then maintained for an additional stable period of three weeks. The second period represents a scenario when the sludge age is not optimized for the process but is excessively high for safety, which is the case in many plants today.

During the study, the influent and effluent streams to the continuous flow SBR were monitored with 24 hour composite samplers. Influent and effluent samples were analyzed for total suspended solids (TSS), chemical oxygen demand (COD), carbonaceous biochemical oxygen demand (cBOD), ammonium (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N) and total nitrogen (TN). The samples were taken two to three times per week. The SRT and MLSS of the SBR reactor was continuously monitored online through TSS measurements in the SBR reactor and the waste activated sludge (WAS) stream, as well as by a flow meter in the WAS stream and a level indicator in the SBR reactor. Reference samples of the reactor and WAS stream MLSS and mixed liquor volatile suspended solids (MLVSS) were also analyzed in a laboratory on a routine basis. To evaluate the energy consumed, the airflow, blower current and voltage as well as the number of blowers running was continuously monitored and recorded.

Biomass control system

In the biomass control system used during test period 1, the SRT required for the process could continuously be defined based on a combination of online measurements and operator inputs, including temperature, aeration time per day, dissolved oxygen level and the required effluent ammonia concentration. Through the use of the online TSS and flow measurements in the SBR reactor and WAS stream, the control system further adjusted the mass of sludge wasted to maintain the required SRT in a stable manner without disturbing the process though fast process changes. The effluent ammonia requirement was set to 1 mg/l.

The same control system was used to increase the SRT to the desired higher level of the second test period and maintain this SRT during the period 2. During this period, an operator selected constant SRT was used for control and the SRT required for the process was only calculated as a reference.

Calculations

Based on the measurements, the removed mass of nitrogen and BOD as well as the actual average SRT was calculated for both test periods. Based on the treated mass of nitrogen and BOD, an actual oxygen demand (AOR) required for the treatment process for each period was calculated as shown in equation 1.

$$\mathrm{AOR} = X_{\mathrm{NH4-N}} * \mathrm{NH4-N}_{\mathrm{removed}} + X_{\mathrm{BOD5}} * \mathrm{BOD}_{5,\mathrm{removed}} \quad (1)$$

Where

- AOR = Actual oxygen demand, kg/day
- $X_{NH4\text{-}N}$ = Oxygen required for nitrification, kg O_2/kg NH_4-N
- NH4-$N_{removed}$ = Treated mass of ammonia nitrogen, kg/day
- X_{BOD5} = Oxygen required for BOD removal, kg O_2/kg BOD_5
- $BOD_{5,removed}$ = Treated mass of BOD_5, kg/day

Values used for $X_{NH4\text{-}N}$ and X_{BOD5} were set to 4.6 and 1.2, respectively. Based on the AOR and energy consumption of each period, the aeration efficiency (AE) in kg per kWh was further calculated as shown in equation 2.

$$AE = \frac{AOR}{Energy} \qquad (2)$$

Where

- AE = Aeration efficiency, kg/kWh
- Energy = Blower consumed energy per day, kWh/day

RESULTS

The actual SRT of the reactor and the SRT set points during the test periods are illustrated in Figure 1. The process optimized SRT used as a set point during period 1 varies since it was calculated based on real-time process parameters to account for the process needs. The actual SRT was controlled within on average 0.5 days of the process optimized SRT during period 1. Subsequently, during the acclimation period, the sludge age of the system was gradually increased by the control system until it was stabilized at a fixed higher set point of 25 days. This SRT was purposefully set significantly higher than the process optimized SRT calculated by the control system.

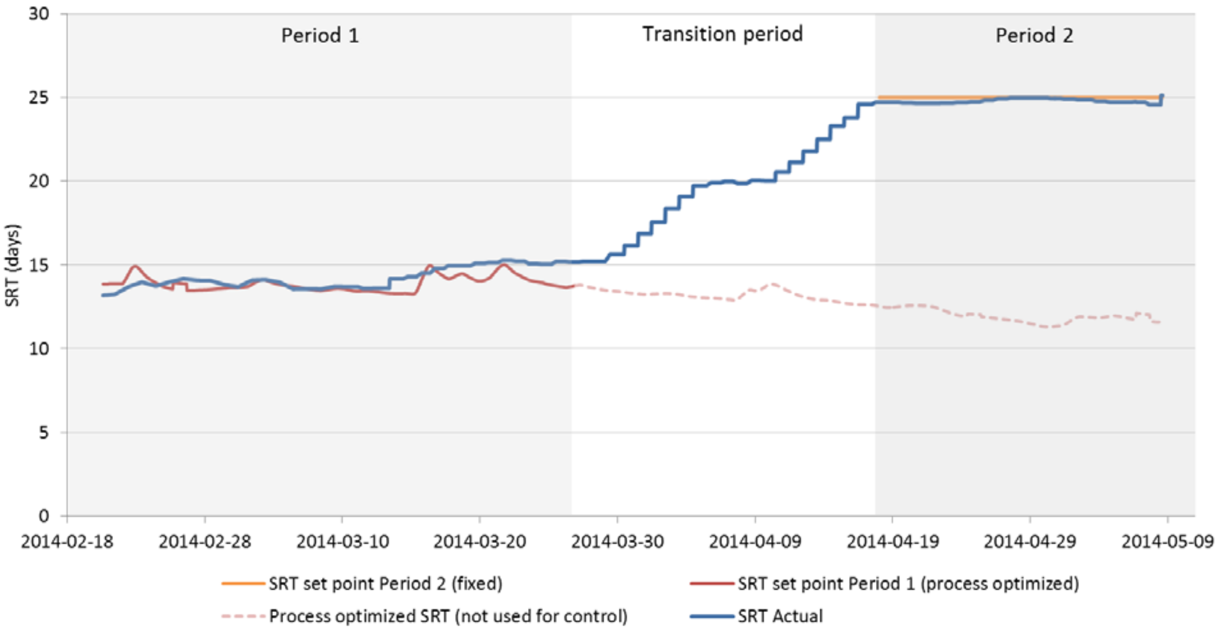

Figure 1 - SRT set points and actual SRT measured at the pilot plant during the whole test period.

During period 1 and 2, the average sludge age of the system was 14.2 and 24.8 days respectively, as shown in Table 1. The sludge ages used resulted in an MLSS of 2700 mg/l for period 1 and 3600 mg/l for period 2. The sludge volume index (SVI), MLSS to MLVSS ratio as well as the average aerobic dissolved oxygen (DO) level was similar during both periods, while the temperature was slightly higher during period 2.

Table 1 Average process parameters measured during test period 1 and 2

Parameter	Unit	Period 1 (process opt. SRT)	Period 2 (high SRT)
SRT	days	14.2	24.8
MLSS	mg/l	2700	3600
MLSS/MLVSS	-	1.2	1.2
SVI	ml/g	160	170
Aerobic DO, average	mg/l	1.9	1.9
Water temperature	°C	15	18

The measured treatment performance of period 1 showed that the control system managed to control the process to the sludge age required to achieve the desired level of nitrification, as shown in table 1. The average effluent ammonia concentration of the period was 1.0 mg/l. When comparing to the second test period, a similar treatment performance was measured both in terms of BOD and nitrogen removed despite the significantly higher SRT used during period 2.

Table 2 Average influent/effluent flow and concentrations during test period 1 and 2, including average mass treated per day

Parameter	Unit	Period 1 (process opt. SRT)	Period 2 (high SRT)
Influent flow	m^3/day (GPD)	20.1 (5300)	17.0 (4500)
Influent TN	mg/l	49	60
Influent NH4	mg/l	31	38
Influent BOD	mg/l	325	394
Influent TSS	mg/l	278	313
Effluent TN	mg/l	6.6	8.0
Effluent NH4	mg/l	1.0	1.2
Effluent BOD	mg/l	5.3	9.0
Effluent TSS	mg/l	6.6	8.1
TN treated	kg/day (lb/day)	0.9 (1.9)	0.9 (1.9)

BOD treated	kg/day (lb/day)	6.4 (14)	6.5 (14)
TSS treated	kg/day (lb/day)	5.5 (12)	5.2 (11)

The influent and effluent load resulted in an AOR of 12.2 kg/day and 12.5 kg/day for period 1 and 2, respectively, as shown in Table 3. The average energy consumption was 9.3 kWh/day during period 1 and 10.4 kWh/day during period 2. This correlates to a 12 % higher energy requirement for period 2. The ratio between the AOR and energy consumption represents the aeration efficiency of the system. This was calculated to be 1.33 kg/kWh during period 1 and 1.21 kg/kWh during period 2, giving a difference of 9 %. This means that 9 % more energy was consumed to transfer the amount of oxygen required for the treatment processes when running at the higher SRT of period 2 compared to the process optimized SRT of period 1.

Table 3 Average measured airflow, energy consumption, calculated actual oxygen demand and aeration efficiency for test period 1 and 2, with comparison

Parameter	Unit	Period 1 (process opt. SRT)	Period 2 (high SRT)	Difference
Actual Oxygen Demand (AOR)	kg/day (lb/day)	12.2 (27.0)	12.5 (27.7)	2 %
Average airflow	Nm^3/h (scfm)	29.5 (18.7)	21.2 (20.4)	9 %
Energy consumption	kWh/day	9.3	10.4	12 %
Aeration Efficiency (AE)	kg/kWh (lb/kWh)	1.33 (2.92)	1.21 (2.66)	9 %

CONCLUSIONS

This study shows that it is possible to automatically calculate and maintain the required SRT for a process through a smart biomass control system. The automated control system was shown to calculate the SRT required to give the desired level of nitrification and to maintain this SRT in the process in a stable manner.

Many treatment plants today lack automatic control of the biomass and instead rely on manual adjustments of the wasting to maintain a desired MLSS concentration that ensures sufficient treatment. This typically results in the use of higher SRTs than required by the process. In this study, running the process at a sludge age greater than the calculated optimal did not increase the treatment performance. However, the higher SRT induces endogenous respiration, which in addition to the nutrient removal increased the total oxygen demand and therefore also the energy consumption. An energy saving potential of 12 % was observed by avoiding excessive sludge age.

REFERENCES

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