Increasing Denitrification in Sequencing Batch Reactors with Continuous Influent Feed

ABSTRACT

In this study, the denitrification capacity of a continuous influent feed sequencing batch reactor (SBR) was measured and evaluated trough tests at a pilot plant situated in Nacka, Sweden. The reactor's capacity for total nitrogen removal was determined for three cycle structures with allocated anoxic treatment time during the react phase of 0, 2 and 4 hours per day. In the study, the batch reactor showed a significant capacity for denitrification even with no anoxic phases added into the react phase. Without anoxic treatment phases, an average of 53 % of the influent nitrogen was denitrified. When adding 2 and 4 hours of anoxic treatment time per day, this number was increased to 65 % and 66 %, respectively. Denitrification was found to occur during the settling phase of the treatment cycle. This was possible thanks to the continuous influent feed, which ensured that sufficient carbon for denitrification was available in the settled sludge, as well as the use of proper DO control, which enabled anoxic conditions during the settling phase. Under these conditions, the denitrification capacity offers the potential to reduce the length of allocated anoxic periods in continuous feed SBRs while still meeting required total nitrogen permits. Standard design procedures indicate that the reduction in required anoxic periods can decrease the total life cycle cost of a continuous feed SBR system with up to 15 % and the required footprint per treatment capacity with 15 %.

INTRODUCTION

A sequencing batch reactor (SBR) is a time based biological treatment system typically consisting of a react phase, a settling phase and a decanting phase. When a SBR is required to meet an effluent nitrate limit, one or more anoxic periods are typically incorporated into the react phase to facilitate denitrification of nitrates produced by ammonium oxidation. Anoxic periods imply certain capital and operating cost for a wastewater plant. The capital costs are caused by the larger basin volume required to maintain the aerobic sludge age needed for nitrification, the larger blowers to compensate for shorter aeration periods and mixers to keep mixed liquor solids in suspension during anoxic periods. Operating cost of the system increase by the higher instantaneous power demand of the blowers as well as the power demand of the mixers. The aim of this project was to reduce these capital and operating costs through a better understanding and utilization of the denitrification capacity of a SBR.

When designing an activated sludge process, denitrification is assumed to occur within anoxic treatment reactors kept in suspension by a mixer. However, denitrification has been found to occur also during sludge settling (Chavan et al., 2007; Morlin, 2009). Measurements in full-scale conventional activated sludge plants have not only confirmed that denitrification takes place in secondary clarifiers, but also that these reactors significantly contribute to the overall nitrogen removal (Koch et al., 1999). The capacity to denitrify during settling is dependent on the available carbon source. In traditional SBR reactors, carbon is only supplied through influent water at the start of the treatment cycle resulting in limited carbon available during the settling phase. However, SBRs with a continuous inflow obtains a continuous addition of carbon. This implies that the settling phase has a potential to contribute to the total nitrogen removal.

MATERIAL AND METHOD

Test Site

A collaborative research study was conducted by Xylem and IVL Swedish Environmental Research Institute during a 24-month period at a pilot plant in Hammarby Sjöstadsverk (Nacka, Sweden). The biological treatment system of the pilot plant was a continuous feed SBR of type ICEAS™ from Sanitaire, Xylem. The influent water to the pilot plant consisted of municipal wastewater from Stockholm, which normally is treated in the Henriksdal wastewater treatment plant (WWTP) close by. The pilot plant dry weather average flow was 4500 gpd (17 m^3/day) and the peak dry weather flow was 10000 gpd (38 m^3/day). During the study, the plant operated at temperatures between 10 and 22 °C.

The continuous feed SBR tank is divided into two reaction zones. The influent water enters the basin in a pre-reaction zone (PRZ), covering 15 % of the total basin area. The PRZ ensures complete separation between the influent water and the treated water during decanting and works as a selector to discourage filamentous growth and propagate floc formers due to the high food to mass ratio. The water then enters the main-reaction zone (MRZ), where the majority of the treatment occurs. The treatment cycles are 4 to 4.8 hours long, out of which two hours are allocated for settling and decanting.

As the goal of the research study was to quantify the denitrification capacity of the continuous feed SBR, the reactor was operated both with and without anoxic periods during the react phase and the resulting denitrification capacity was monitored and evaluated.

Test Setup

During the whole period of operation, the influent and effluent streams to the batch reactor were monitored using 24-hour composite samples. Influent and effluent samples were analyzed for total suspended solids (TSS), chemical oxygen demand (COD), carbonaceous biological oxygen demand (cBOD), ammonium (NH4-N), nitrate (NO3-N), nitrite (NO2-N) and total nitrogen (TN) using Clean Water Act (CWA) analytical methods 304(h). The samples were taken two to three times per week. The SBR reactor mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were also measured trough grab samples in the basin on a routine basis. In addition to the lab analysis, nitrate concentration and dissolved oxygen in the batch reactor were monitored online by ion-selective electrodes (ISE) and optical probes, respectively, connected to an IQ-XT2020 sensor net (WTW, Xylem). The sludge level of the basin was monitored online during settling.

The denitrification capacity of the SBR was evaluated for three different treatment cycle configurations as shown in Figure 1. In one cycle setup, the whole react period of the cycle was aerated resulting in zero anoxic hours per day. In the two other cycle structures aeration was turned off and a mixer was turned on in the basin for some periods of the react phase, leaving a total of 4 and 6 hours per day respectively as anoxic during the react phase.

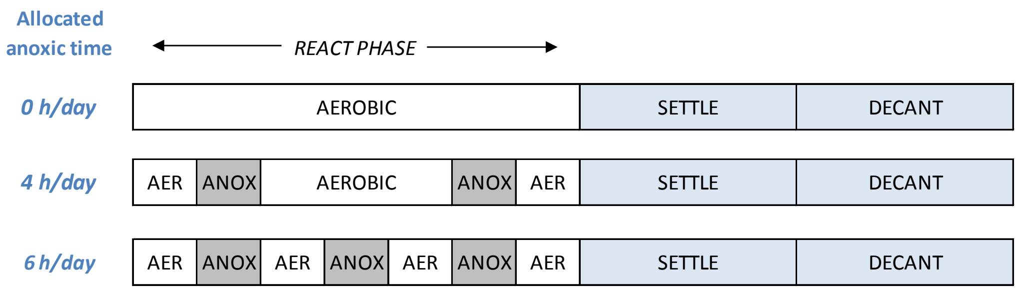

Figure 1- Treatment cycle configurations tested in the continuous feed SBR

Calculations

Based on the influent and effluent samples, mass balances of nitrogen were calculated for the batch reactor. The influent and effluent nitrogen mass were based on the analysis done on the collected composite samples. The emission of nitrogen gas from the basin was estimated as the difference between the influent total nitrogen and the total nitrogen summed in the wasted sludge and in the decanted effluent. The mass of nitrogen in the wasted sludge was estimated from the BOD mass removed by the treatment considering a nitrogen content of 12 % in the sludge volatile suspended solids (VSS) (EPA, 2010) and a sludge yield of 0.6 VSS/BOD (WEF & ASCE, 1998).

RESULTS

Denitrification capacity of the continuous feed SBR

Average measured influent and effluent concentrations from the SBR while operating with different allocated anoxic time during the react phase for a total of 26 weeks are listed in Table 1. When no anoxic period was included in the react phase, the batch reactor had an average effluent total nitrogen concentration of 9.5 mg/L with an influent concentration of 56 mg/L. The average effluent nitrate and nitrite concentrations during the same period were 5.3 and 0.2 mg/L, respectively. When adding anoxic periods lasting a total of 2 and 4 hours per day to the react phase, the average effluent concentration of total nitrogen was reduced to 5.2 and 3.0 mg/L, respectively, at similar influent concentrations. The results indicate that while adding anoxic time to the react phase increases the denitrification capability of the reactor, significant denitrification is still observed when operating with an aerobic react phase only.

Table 1 Average measured influent and effluent concentrations for different treatment cycle configurations operated at Hammarby Sjöstadsverk

Parameter		Unit	Measured data		
Anoxic time during react phase		hours/day	**0**	**4**	**6**
Influent flow		gpd (m3/day)	4500 (17)	5500 (21)	5000 (19)
Water temperature		°C	17	19	17
Influent	cBOD	mg/L	347	312	-
	TN	mg/L	**56**	**60**	**55**
	TSS	mg/L	305	329	334
Effluent	BOD	mg/L	6.7	4.4	-
	TN	mg/L	**9.5**	**5.2**	**3.0**
	NH_4-N	mg/L	1.1	0.6	0.9
	NO_3-N	mg/L	5.3	2.1	1.1
	NO_2-N	mg/L	0.2	0.6	0.4
	TSS	mg/L	6.6	5.6	5

Further, the nitrogen mass balance provides information about what happens with the nitrogen coming into the SBR. The percentage of the influent total nitrogen that either ends up in the decanted effluent water, is assimilated in the sludge or that leaves the basin as nitrogen gas are listed in Table 2. The results suggest that 53 % of the incoming total nitrogen is denitrified when running the batch reactor without anoxic periods during the react phase. When adding anoxic periods, 65-66 % of the influent total nitrogen is denitrified. Independent of the available anoxic period length, around 30 % of the influent nitrogen is assimilated in the sludge because of cell synthesis.

Table 2 Calculated nitrogen mass balance for different treatment cycle configurations operated at Hammarby Sjöstadsverk

Parameter	Unit	Measured data		
Anoxic time during react phase	hours/day	**0**	**4**	**6**
Nitrogen in effluent	% of influent TN	17%	8.7%	5.5%
Nitrogen assimilated in sludge		30%	27%	29%
Nitrogen as N_2		**53%**	**65%**	**66%**

The nitrogen mass balance further confirms that a large part of the denitrification occurring in the continuous feed batch reactor takes place outside of the allocated anoxic time during the react phase. This denitrification is occurring in the settling sludge during the two-hour long settling and decanting phase. This is clearly visualized by the online readings of nitrate within the MRZ of the batch reactor. Figure 2 shows a steady decrease of nitrate concentration during the settling and decanting phase. Based on the slope of the nitrate concentration curve, the same denitrification rate is observed during the settling and decanting phase as in the react phase. In the example cycle in Figure 2, the rate corrected to 20 °C was calculated to 0.0018 lb NO_3-N/lb MLVSS*hr.

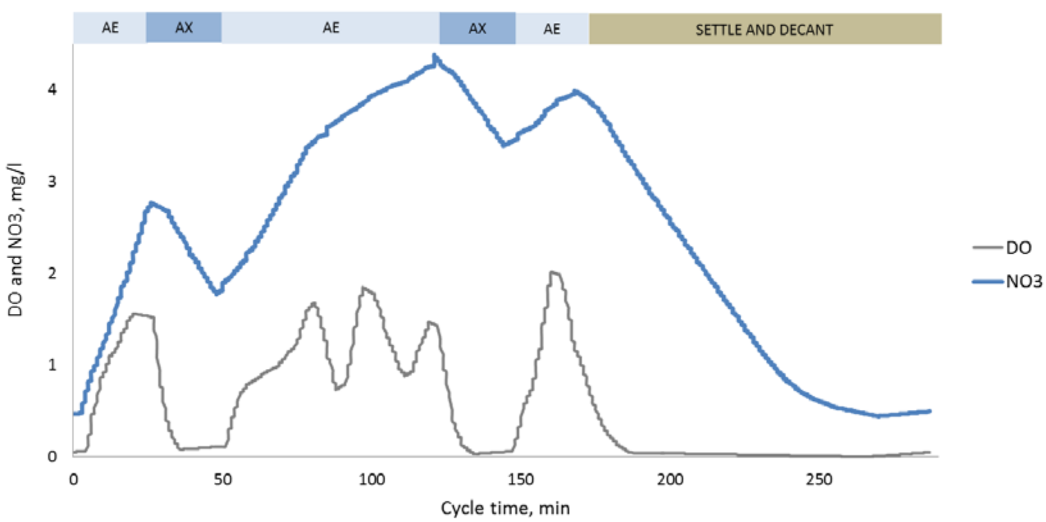

Figure 2 - Online measured values of dissolved oxygen (DO) and NO_3 for the second treatment cycle configuration including two anoxic periods during the react phase. AE = Aerobic period, AX = Anoxic period.

This large capability to denitrify during the settling phase is a result of the continuous carbon supply from the continuous wastewater influent, which enables and accelerates the denitrification process. Another important prerequisite is proper control of dissolved oxygen (DO) during the aerobic section of the react phase. Stable aeration control prevents the DO levels to increase at the end of the reaction phase when the oxygen requirements is low and enables anoxic conditions during the settling phase.

Despite the significant denitrification occurring during settling, no negative effect on the settling characteristics of the sludge was observed. The measured sludge level during the settling and decanting phase, as shown in Figure 3, indicated good settling characteristics of the sludge without disturbance of the sludge blanket caused by denitrification. The measured sludge levels were compared with a theoretical settling curve based on the process measured sludge volume index (Mines et al., 2001) on several occasions. The measured levels were found to either match or indicate better settling than the reference curves.

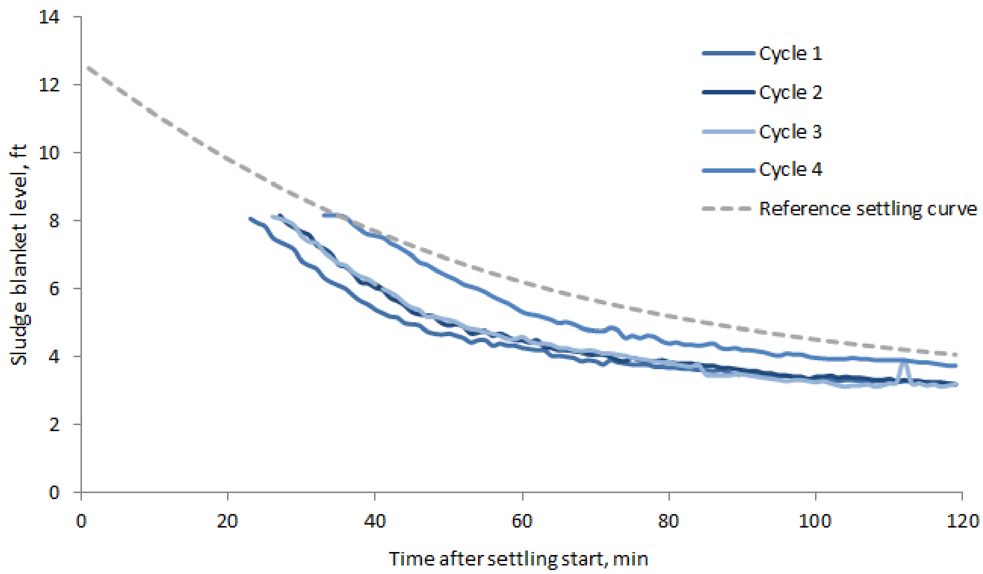

Figure 3 - Example of measured sludge blanket level during four treatment cycles compared to a reference settling curve based on the basin mass and SVI.

Impact on treatment capacity and life style cost

SBRs are typically designed and operated with enough anoxic time during the react phase to ensure the full denitrification capacity required to reach the effluent total nitrogen permit. While this is likely required for true batch SBR systems, it results in overcapacity in continuous feed SBRs due to the denitrification capacity of the settling phase. By taking the settling phase into account during design and operation, the allocated anoxic periods during the react phase can be reduced to increase the treatment capacity and lower the capital and operational cost of the system. For low stringent effluent nitrogen permits, such as 15 mg/l, the settle phase alone can be enough to provide the required denitrification capacity.

The anoxic time of the react phase directly impacts the treatment capacity of an SBR basin. A reduction in anoxic time means an equally large increase in aerobic treatment time, which in term is proportional to the biomass required to reach sufficient nitrification capacity. An increase in the aerobic treatment time per day therefore means an equally large increase in treatment capacity per basin footprint.

The increase in aerobic treatment time per day also impacts the capital and operational cost of the blower, given the lower instantaneous oxygen demand of the treatment system. Additional reduction of the blower cost is gained when taking into account the oxygen credit given from the denitrification occurring during the settling phase. The capital cost is also reduced with the removed need of a mixer for low stringent effluent permits.

Taking the above into consideration while using standard design procedures by Xylem for continuous flow SBRs such as the one used in this study, the footprint required per treatment capacity was calculated to be reduced with an average of 15 % for a range of effluent total nitrogen permits. Using the standard method for calculating investment cost (CAPEX) for wastewater treatment plants (DWA, 2011), total CAPEX cost of the system was calculated to be reduced with between 10 and 15 %.

CONCLUSIONS

The results obtained from the continuous feed SBR at Hammarby Sjöstadsverk indicate that substantial denitrification is occurring even without allocated anoxic periods during the react phase. The result shows that denitrification takes place during the settling and decanting period of the treatment cycle. Taking advantage of this denitrification capacity offers the opportunity to reduce the capital and operating cost of the continuous influent batch reactor system significantly. Standard design procedures indicate that the reduction in required anoxic periods can reduce the total project investment cost of a continuous feed SBR system with up to 15 % and the required footprint per treatment capacity with 15 %.

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