THE EFFECT OF REDUCTION OF AERATION PERIOD ON ORGANIC POLLUTANTS REMOVAL IN SEQUENCING BATCH ACTIVATED SLUDGE REACTORS

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The authors investigated the possibility to reduce aeration time in one of the cycles of sequencing batch activated sludge reactors. It is known that there are microorganisms in activated sludge which can store organic materials temporarily in such forms as polyhydroxyalkanoate (PHA). It was expected that removal of organic materials in the cycle with reduced aeration was supplemented by the microbial activities to store organic materials temporarily. The authors operated sequencing batch reactors with 6 cycles/day with synthetic wastewater, and reduced aeration in one of the cycles. Short-term experiments were conducted to see the effects of aeration reduction for one time, and long-term experiments were conducted to see the effect of long term implementation of operation with aeration reduction. In both experiments, removal of DOC was greater than 92%, and no significant adverse effect was observed. The more aeration was reduced, the more PHA was carried over to the following cycles. It was estimated that about 17% to 50% of PHA was carried over to the cycles following the cycles in which aeration was reduced. The operation with one-cycle reduced aeration was successfully implemented in the experiments. There is a big room to explore wastewater treatment technologies in the direction to flexibly control energy consumption.

Key Words: reduced aeration, power consumption, temporary carbon storage capability

1. INTRODUCTION

The amount of energy used in water and wastewater treatment corresponds to roughly 1% of the total electricity consumption\(^1\). Wastewater treatment represents 0.1 to 0.3% of total energy consumption in the United States\(^2\). In Japan, about 0.3% of total electrical power is consumed for wastewater treatment. With the worldwide resource limitation and increase of energy price, the operation and maintenance cost in wastewater treatment plants (WWTPs) tend to increase as well. Therefore, energy and cost reduction of wastewater treatment should be of serious interest. Aeration in biological treatment accounts for 50 ~ 80% of the total electrical energy consumption in WWTPs\(^3\). Due to this situation, there is also much potential to reduce energy and cost for electrical power\(^4\).

While reduction of total energy consumption is of importance, it is also valuable to reduce peak energy usage in certain situations. The Great East Japan Earthquake on March 11, 2011, and the accident of the Fukushima Daiichi Nuclear Power Plant after the quake caused serious shortage of energy supply capacity in Japan. In disasters such as these, not only reducing total power consumption but also minimizing power consumption during peak time are important concerns.

Apart from emergency situations caused by disasters, even under normal situations, electrical power consumption shift may be beneficial. For example, in Japan, electricity prices are cheaper at nighttime, because demand is less at night. Therefore ability to shift aeration from day to night, would be beneficial in reducing costs.

Furthermore, in a society which depends more on natural power such as wind and solar, the electrical supply will be more unstable. Development of
technologies which can flexibly consume energy to compensate for the instability of the energy supply should be of importance.

On the other hand, it is known that some of microorganisms in activated sludge have the ability to remove organic matter anoxically; the organic matter removed anoxically is accumulated in microbial cells as temporary carbon storage materials such as polyhydroxyalkanoates (PHA)\(^{18,9}\). There are several studies on PHA in activated sludge: some of them focused on the metabolism in enhanced biological phosphorus removal processes\(^{10}\), and others were conducted in a direction to produce PHA as a biodegradable plastic material. Recently, a new research direction has been proposed by Oshiki et al.\(^{11}\) and Huda et al.\(^{12}\). They proposed the ‘Final Aeration of Excess sludge With Excess Loading’ (FAREWEL) process, in which organic matter in wastewater is fixed to activated sludge as PHA and then further converted to methane gas.

Here, the authors propose another approach to use PHA to improve energy efficiency in wastewater treatment: aeration during daytime is reduced and removal of organic pollutants is achieved by the capability of microorganisms to accumulate temporary carbon storage materials such as polyhydroxyalkanoate (PHA). The temporary carbon storage materials accumulated in daytime are oxidized later.

In the present study, the authors conducted preliminary experiments to see the feasibility of operation with one-cycle reduced aeration. Sequencing batch activated sludge reactors were operated with 6 cycles a day using synthetic wastewater. In the short-term experiments, aeration was reduced in one of the 6 cycles, and the behaviour of effluent quality and temporary carbon storage material PHA were monitored in the cycle in which aeration was reduced and the following cycle. In the long-term experiments, reactors were operated with one-cycle reduced aeration per day for about a month to evaluate the effect of long term implementation.

2. MATERIALS AND METHODS

(1) Activated sludge reactor

Two sequencing-batch activated sludge reactors (SBR-A and SBR-B) were operated in parallel. Each SBR had a working volume of 10L and was fed with synthetic wastewater containing: CH\(_3\)COONa·3H\(_2\)O 135.6 mg/L, CH\(_3\)CH\(_2\)COONa 64.4 mg/L, peptone 120 mg/L, yeast extract 24 mg/L, KCl 50.4 mg/L, CaCl\(_2·2H_2O\) 15.8 mg/L, MgSO\(_4·7H_2O\) 132 mg/L, K\(_2\)HPO\(_4\) 43.2 mg/L and trace element solution containing B, Fe, Mn, Mo, Co and Cu. The influent dissolved organic carbon (DOC) concentration was around 120 mgC/L and chemical oxygen demand (COD\(_{cr}\)) was around 300mg/L. Each cycle was 4hr in total with following phases under normal operation: inflow and anaerobic reaction for 60min, settling for 53min, and effluent discharge for 7min. In each cycle, 240mL of mixed liquor was discharged to maintain the sludge retention time (SRT) to be around 7 days. In each cycle, 5 L of influent was fed and 5 L of treated water was discharged to maintain the hydraulic retention time (HRT) at 8 hr.

Dissolved oxygen (DO) concentrations were monitored and controlled with DO meters (DO-21P, DKK-TOA, Japan) in combination with a program developed on LabView (National Instruments, USA). The DO concentrations were kept between 2.3mg/L and 2.5mg/L during aerobic reaction phases. For the monitoring of pH, pH meters (WM-22EP, DKK-TOA, Japan) were used. The reactors were installed in an air-conditioned room with an ambient temperature at around 26°C.

The experiments conducted with the SBRs are tabulated in Table 1. The reactors were operated for 170 days in parallel. Runs A-1 and B-1 were seeded with the same activated sludge from a laboratory reactor which had been acclimatized in the laboratory of the authors for longer than half a year. At the end of Runs A-1 and B-1, the settleability was deteriorated, and the sludge was discarded. Runs A-2 and B-2 were started with stored excess sludge from Runs A-1 and B-1 which had been collected before the deterioration of settleability. Activated sludge in the two reactors were mixed, divided into two, and then used as the seed for Runs A-2 and B-2. Similarly, Runs A-3 and B-3 were started with the mixture of activated sludge collected from Runs A-2 and B-2 as excess sludge.

Short-term experiments were conducted in Runs A-1 and B-1 to examine the effect of aeration reduction in one of the six cycles for one day only. The extents of aeration reduction were by 50% (day 12), 70% (day 20), 90% (day 25), or 100% (day 30), and the same aeration reduction conditions were applied to both SBRs in parallel. In the cycle with reduced aeration, the anaerobic period was extended to maintain the cycle time at 4 hours. Operation of the reactors under normal conditions and when aeration was reduced are illustrated in Fig. 1. Aeration was reduced in aerobic phase. It is called 50% reduced aeration if the aeration period is shortened from 2hr to 1hr. Similarly, 70%, 90%, 100% reduced aeration means the aeration period was shortened to 36min, 12min and 0min,
respectively. These percentage values ‘50%, 70%, 90%, 100%’ are defined as ‘reduced aeration levels’ (RA Levels). In the cycles with aeration reduction, anaerobic reaction time was extended to maintain the duration of the cycle at 4 hours.

<table>
<thead>
<tr>
<th>Period</th>
<th>Run Numbers</th>
<th>Outline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBR A</td>
<td>SBR B</td>
</tr>
<tr>
<td>day 1-47</td>
<td>Run A-1 Run B-1</td>
<td>day 12: 50% aeration reduction with Run A and B day 20: 70% aeration reduction with Run A and B day 25: 90% aeration reduction with Run A and B day 30: 100% aeration reduction with Run A and B</td>
</tr>
<tr>
<td>day 48-109</td>
<td>Run A-2 Run B-2</td>
<td>[Long-term experiment] Run A-2: control Run B-2: day 48-70 normal operation day 71-96 50% aeration reduction in one of the 6 cycles per day day 97-109 normal operation</td>
</tr>
<tr>
<td>day 110-170</td>
<td>Run A-3 Run B-3</td>
<td>[Long-term experiment] Run A-3: day 110-140 normal operation day 141-170 50% aeration reduction in one of the 6 cycles per day Run B-3: day 110-140 normal operation day 141-170 70% aeration reduction in one of the 6 cycles per day</td>
</tr>
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Samples were taken at different timings in the cycles with reduced aeration (RA cycles) and in the cycles following them (PostRA cycles). Following them (PostRA cycles).

### (2) Analytical methods

The dissolved organic carbon (DOC) concentration in the supernatant was measured with a TOC Analyzer (TOC-Vcsn, Shimadzu, Japan). The concentrations of mixed liquor suspended solids (MLSS) were measured according to the Standard Methods. Analysis of PHA was done by gas chromatography after methanolytic decomposition.

### 3. RESULTS

#### (1) Reactor performance

The concentrations of MLSS in Reactors A and B during the whole experimental period were between 1,000mg/L and 3,000mg/L, as shown in Fig. 2. Settling properties were not very good especially in Reactor B, as can be seen from the SV30 values in Fig. 2. In Runs A-2, B-2, SV30 values were initially at the same level when operation with one-cycle reduced aeration was introduced to Run B-2 on day 71. Then, while SV30 of Run A-2 was improved, that of Run B-2 stayed at the same level. In Run A-3 and Run B-3, SV30 increased after the introduction of operation with one-cycle reduced aeration, but the extent of the increase was higher in Run B-3 than in Run A-3. In Run B-3, biomass was washed out after day 160, and the experiment had to be stopped in the end.

#### (2) Short-term experiments

Figure 3 shows the DOC concentrations during the short-term experiments. Both in Reactors A and B, DOC concentrations reached less than 8mgC/L at the end of the aerobic phase regardless of reduction of aeration. In the cycles following the RA cycles, DOC concentrations at the end of aerobic phase
were less than 5 mgC/L, which were as low as those in normal conditions.

Figure 4 shows the DOC and PHA concentrations in RA cycles and PostRA cycles in the short-term experiments. DOC concentrations decreased rapidly from the beginning both in reactor A and reactor B. As the influent DOC concentration was 120 mgC/L, the initial DOC concentration was 60mgC/L. Removal of DOC remained higher than 92% in all the monitored cycles. When aerations reduction was 50% and 70%, DOC removal was not affected, and even when aerations reduction was 90% or 100%, adverse effects on DOC removal were not very remarkable. In the cycle following the RA cycle, DOC removal remained at the usual level (97%±1%).

As a result of the short-term experiments, effects of aeration reduction up to 100% were examined with synthetic wastewater. Omission of aeration did not badly affect the effluent DOC in the short-term
(3) Long-term experiments

Figure 6 shows the DOC and PHA concentrations at the end of the RA cycles and the PostRA cycles in the long-term experiments. As are shown in Fig. 6 (a, c, e, g), the concentrations of DOC were almost less than 6 mg/L during a one-month-long operation with one-cycle reduced aeration every day. As the influent DOC concentration in the experiment was 120mgC/L, the DOC removal was more than 95% in all monitored cycles.

Figure 6 (b, d, f, h) shows the PHA concentrations during the whole long-term experiments. During the operation with one-cycle reduced aeration, the PHA concentrations at the end of the RA cycles tended to be significantly higher than those at the end of the PostRA cycles. This means that carbon temporarily stored in microbial cells in the RA cycles was carried over and then oxidized in the PostRA cycles.

4. DISCUSSION

In the present study, effects of the introduction of operation with reduced aeration for one cycle only and for a long period of time were investigated. The short-term experiments were to simulate the effects of aeration reduction under accidental shortage of energy supply for a short period of time. The long-term experiments were to simulate shortage of energy supply for a longer period of time and also to take the advantage of cheaper electricity price during night. As far as DOC removal is concerned, operation with one-cycle reduced aeration in the present study was successful. The carbon which could not be oxidized in the cycle with aeration reduction was carried over to the PostRA cycles and then oxidized, as can be seen in Figs. 4 and 6.

Based on the results shown in Fig. 6 (d, f and h), the concentrations of PHA at the end of the RA cycles were reduced during the PostRA cycles by 10 to 30 mgC/L. As the concentration of the influent synthetic wastewater was 120mgC/L and was diluted by half as the return sludge ratio was 50% in the present study, it is thought that about 17% to 50% of carbon was carried over from RA cycle to PostRA1 cycle.

In Fig. 5(a), it was shown that higher level of aeration reduction resulted in more accumulation of PHA. This means that PHA play an important role in carbon removal in the operation with aeration reduction. Yet, PHA accumulation was not significant in the experiments with 50% aeration reduction. This may be because most of temporarily accumulated carbon was oxidized within the
shortened aeration time, or may simply mean that temporary storage in other forms than PHA was more important under lower RA levels. Additionally, Fig. 5(b) indicates PHA content in activated sludge increased as RA level was increased, and that increase was less at RA levels higher than 90%.

In the present study, the effect of reduction of aerobic period of anaerobic/aerobic SBRs treating synthetic wastewater on the treatment performance of DOC was investigated. The efficiency of the aeration reduction should be evaluated from the view of the reduction of electrical power consumption.

It should be noted that 50% reduction of aerobic time, for example, does not mean 50% reduction of
aeration energy. Indeed, the amount of carbon carried over to PostRA cycle was less than 50% of carbon from influent, and this mean more than 50% of carbon was oxidized during the RA cycles. It would be necessary to more precisely evaluate the efficiency of energy reduction in the aeration reduced cycles. In addition, it would also be necessary to evaluate the extra amount of energy which is needed to oxidize carbon carried over from the RA cycles to PostRA cycles.

However, the authors would like to discuss about the effect of aeration time on energy consumption under an assumption that energy consumption is proportional to aeration time. For example, in the case of 50% aeration reduction in one of the 6 cycles of a day is assumed to result in reduction of 50% of aeration energy in the RA cycle, and 8.3% within a whole day. Under the above assumption, reduction of energy consumption during peak period was evaluated on a wastewater treatment plant which has four SBRs each operated with 4-hr cycles consisting of 1-hour feeding and anaerobic mixing, 2-hour aeration, and 1-hour settling and discharge. In this simulation as shown in Fig. 7, energy for aeration is thought to be reduced by 50% for 4 hrs in day time. Reduction of electrical consumption by 50% would be a great contribution to reduce the electrical power demand during peak time of urban activities.

On the other hand, the authors observed adverse effect of aeration reduction on the settleability of the sludge. That is, during Runs A-2 and B-2, while settleability of Run A-2 (without aeration delay) was improved, that of Run B-2 (reduced aeration of 50%) maintained high SV30. During Runs A-3 (reduced aeration of 50%) and B-3 (70%), settleability became worse only in Run B-3.

The authors found filamentous microorganisms in the sludge when SV30 became higher. The reduction of settleability was caused by the overgrowth of filamentous microorganisms. The effects of aeration reduction on filamentous microorganisms and bulking requires further study.

There are other concerns. One of them is the removal efficiency of nutrients. Aeration reduction can be first focused on the application of such treatment plants which do not have to remove nutrients. Treatment plants located along open ocean satisfy such condition. Another concern is if results achieved with synthetic wastewater can be applied to real wastewater. To respond to this concern, similar experiments should be done with real wastewater. Further, this study was conducted with sequencing batch reactors. The way to apply the aeration reduction to continuous reactors should be studied.

5. CONCLUSION

The efficiency of operation with reduced aeration was evaluated with short-term experiments and long-term experiments.

In the short-term experiments, DOC removal was maintained above 92% in all monitored cycles and was not badly affected by reduced aeration. PHA concentration variations in RA cycle and PostRA cycle showed a periodic storage-consumption cycle during anaerobic and aerobic phases. The concentrations of PHA in sludge increased as a result of aeration reduction and reduced in the following cycles. The more aeration was reduced, the more PHA was carried over to the following cycles.

In the long-term experiments, DOC removal was higher than 95% in a one-month run with either 50% or 70% reduced aeration. Based on the
differences of PHA concentrations between RA cycles and PostRA cycles, it was estimated that about 17% to 50% of carbon stored in microbial cells in the RA cycle was carried over to PostRA1 cycle.

In this study, the authors successfully demonstrated the concept of operation with one-cycle reduced aeration. There are good opportunities to explore wastewater treatment technologies related to flexible control of energy consumption.

REFERENCES

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