Reduction of Excess Sludge in Sewage Treatment by Ozone Application

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Key words: Wastewater treatment, sludge ozonation, excess sludge reduction, phosphorus recovery

Abstract

A new process which attains both excess sludge reduction and phosphorus recovery has been developed. In this paper, characteristics of sludge solubilization by ozone were investigated in batch experiments with sludge taken from an A/O reactor supplied with synthetic sewage and several real wastewater treatment plants. Then, performance of the new developed process was investigated in a laboratory-scale plant. The process eliminated withdrawn excess sludge by 100% with recovering more than 80% of phosphorus in influent. Water quality (S-BOD, SS and phosphorus) of effluent was maintained at the same level as that from conventional process.

Introduction

Excess sludge is an inevitable product of wastewater treatment process with activated sludge. However, treatment of the excess sludge costs much, requires much energy, and has been a serious issue because of lack in landfill space. Hence, reduction of excess sludge has been gathering attention in wastewater treatment sector in Japan. Therefore, several kinds of technologies for excess sludge reduction were developed so far. One of the methods is sludge ozonation. Some researches showed that ozone can reduce excess sludge [1][2], so that ozone can be a possible alternative. However, there is a drawback of installing the excess sludge reduction technology with ozone in some areas of Japan. The wastewater treatment process with the technology cannot remove phosphorus because phosphorus is to be removed as the content of withdrawn excess sludge. Thus, in the area which has an enclosed water body, the installation of the technology raises the concern of eutrophication in the water body.

In order to attain the both targets, excess sludge reduction and phosphorus removal, a new advanced wastewater treatment process has been developed [3][4]. The new process consists of conventional anaerobic/oxic (A/O) phosphorus removal process, sludge ozonation process for excess sludge reduction and crystallization process for phosphorus removal and recovery. The schematic diagram of the new process is shown in Figure 1. In this process, a part of the returned sludge is treated by ozone in ozonation tank resulting in increase of biodegradable organic substance through sludge solubilization. The solubilized substrate generated in ozonation tank can serve as energy source for phosphorus release when ozonated sludge is returned into the anaerobic tank in A/O process. Phosphorus accumulating organisms (PAOs) in A/O tank releases phosphorus under anaerobic condition and then phosphorus rich condition is made in bulk water. The P-rich liquor is then introduced to crystallization tank, where phosphorus is recovered as a crystalline product with Mg or Ca ion.
As previous study showed important parameters for designing this process were solubilization degree in sludge ozonation, activity change of microbes, and biodegradability of solubilized sludge [3], sludge ozonation experiment was conducted to obtain basic information to determine process operation condition using several kinds of sludge. Based on the result, the process was continuously operated in lab scale plant to investigate the performance.

**Sludge Ozonation Experiment**

1. Materials and method
1.1 Sludge ozonation apparatus

Semi-batch system (liquid; batch, gas; continuous flow), which consisted of an ozone generator, ozone contactor, ozone meter and exhausted ozone decomposer, was utilized to investigate effect of ozone on sludge solubilization, biodegradability and activity. Sludge was ozonated in a cylindrical glass contactor with 2L effective volume (Φ=120 mm, H=200 mm). Ozone gas, generated from pure oxygen with an ozone generator (Mitsubishi OS-1N), was continuously bubbled into the contactor through a diffuser equipped at the bottom of the contactor. The ozone concentrations in the gas phase at inlet and outlet of the reactor were determined by ozone meter. Ozone consumption and solubilization degree of sludge were defined in the following equations:

\[
\text{Ozone consumption} = \frac{[\text{amount of inf. O}_3 - \text{amount of eff. O}_3] (\text{mgO}_3)}{(\text{Initial SS}) (\text{mg/L}) \times \text{Sludge volume (L)}}
\]

\[
\text{Solubilization degree} = \frac{\text{initial (P-COD}_{Cr}) - \text{observed (P-COD}_{Cr})}{\text{initial (P-COD}_{Cr})}
\]

**Sludge source**

Totally six kinds of sludge were used in this experiment. Sludge was taken from a reactor of A/O process supplied with artificial sewage, and five real sewage treatment facilities. The synthetic sewage supplied to A/O tank contained only soluble substances including glucose, acetate, ammonium,
phosphate, and other minerals. The type of the process and other information is summarized in Table 1 along with experimental condition.

Table 1 Experimental condition for sludge ozonation

<table>
<thead>
<tr>
<th>Process type</th>
<th>A/O reactor</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage type</td>
<td>artificial</td>
<td>AS</td>
<td>BPR</td>
<td>AS</td>
<td>BPR</td>
<td>BPR</td>
</tr>
<tr>
<td>Initial MLSS conc. (gSS/L)</td>
<td>1.2, 1.4, 4.0</td>
<td>2.2</td>
<td>1.8</td>
<td>1.6</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>VSS/SS ratio (-)</td>
<td>0.92</td>
<td>0.80</td>
<td>0.82</td>
<td>0.74</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Ozone flow rate, (L/min)</td>
<td>0.20, 0.42</td>
<td>{specific ozone flow rate, (cm³/cm²/min)}</td>
<td>0.40</td>
<td>{3.53}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone concentration (mgO₃/L)</td>
<td>20 ~ 90</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* AS: conventional activated sludge process, BNR/BPR: biological nitrogen/phosphorus removal process

Results and Discussion

Figure 2 shows the relationship between consumed ozone and sludge solubilization degree. As the consumption increased, more sludge was solubilized. However, the figure shows that the sludge from actual sewage treatment plants was relatively less solubilized than that cultivated with synthetic swage. Especially, sludge from Plant D, which contained higher inorganic constituents (0.6 of VSS/SS as shown in Table 1), was least solubilized. Plant D is located near the industrial area and therefore receives large volume of industrial wastewater. The effect of ozone on sludge was then thought to be influenced by many chemicals and pollutants which were largely contained in industrial wastewater than in domestic wastewater. In fact, we analyzed metal content in the sludge and found that the sludge from Plant D contained large amount of iron compared to other sludge.

Changes in soluble BOD and COD concentrations during ozonation are shown in Figure 3. Unlike Figure 2, the tendency of those increase were almost same between the sludge. Soluble COD increased almost linearly, while BOD saturated at solubilization degree of around 0.4. Then, biodegradability of solubilized sludge was discussed in Figure 4 using the ratio of soluble BOD to soluble COD as the index of biodegradability, where the decomposition ratio of organic substance was assumed to be 70% in BOD measurement. Biodegradability increased once up to around 0.8 (-) at solubilization degree of 0.3, but gradually decreased after that. Ozone may have degraded biodegradable substance generated from sludge.
As it was expected that sludge was damaged by ozone, oxygen/ammonium/nitrate utilization rates (OUR/AUR/NUR) and phosphorus release rate (P-rel) were examined to observe the change in activity of general heterotroph, nitrifier, denitrifier and PAOs. Those rates were measured with sludge taken from ozone contactor after ozonation. The result was indicated in Figure 5, in which the activity was shown as the ratio to the initial value. All of the indices showed similar tendency, and the activity was lost exponentially as the solubilization proceeded.

**Operation of Advanced Wastewater Treatment Process**

Based on the results obtained in sludge ozonation experiment, a steady-state mass balance model was developed to investigate feasibility and operation condition of the process. The model predicted this process was feasible [3]. Then, continuous operation of the process was conducted with a lab scale plant whose capacity was 225 L/d. The operation condition was determined by the model and summarized in Table 2. Operation was separated into four phases. In the first phase, the process was operated without ozonation and phosphorus recovery, while excess sludge amount was reduced to one tenth and zero in phase III and IV, respectively, by introducing sludge ozonation. In those phases, phosphorus recovery by crystallization was also incorporated.

Treatment performance is shown in Figure 6. In all of the indices except soluble COD the advanced process showed same or better performance compared to the conventional A/O process (Phase I). Due to the production of non-biodegradable substance in ozonation process COD was increased but still kept around 30 mg/L.
Table 2  Operation condition of the experimental plant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Phase I</th>
<th>Phase III</th>
<th>Phase IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage flow rate</td>
<td>L/d</td>
<td>225</td>
<td>225</td>
<td>225</td>
</tr>
<tr>
<td>Return sludge ratio</td>
<td>% of sewage inflow</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Ratio of excess sludge wasting</td>
<td>&quot;</td>
<td>1.7</td>
<td>0.17</td>
<td>0</td>
</tr>
<tr>
<td>Ratio of sludge flow to ozonation</td>
<td>&quot;</td>
<td>-</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Sludge ozonation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ozone flow rate</td>
<td>L/min</td>
<td></td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>- Ozone concentration</td>
<td>mgO&lt;sub&gt;3&lt;/sub&gt;/L</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>- Ozone consumption</td>
<td>mgO&lt;sub&gt;3&lt;/sub&gt;/gSS</td>
<td>30~40</td>
<td>30~40</td>
<td></td>
</tr>
</tbody>
</table>

Although excess sludge was not withdrawn at all in Phase IV, certain amount of suspended solid was discharged in effluent. Therefore, reduction in sludge production yield considering SS discharge in effluent was evaluated. The yield was decreased to 0.055 gSS/gBOD in Phase IV from 0.44 gSS/gBOD in Phase I. This means sludge production was reduced by 88%.

Figure 7 shows phosphorus balance in every phase. In the first phase, 81% of phosphorus was disposed in excess sludge, while the amount was reduced to 12% and 0% in Phase III and IV, respectively, due to excess sludge reduction. On the other hand, recovery as crystal was increased to 75% and 83%, respectively. This indicates that the process successfully recovered phosphorus resource from sewage.

Energy consumption of the new process was estimated and compared to that of conventional process whose capacity of 50,000 m<sup>3</sup>/d. As the new process can recover phosphorus, energy for phosphate rock mining and transportation was taken into account in the conventional process instead of phosphorus recovery. In addition, energy for sludge treatment and disposal was also considered to make compensation for excess sludge reduction. The new process was expected to reduce operation energy by about 10%.
Conclusion

Sludge ozonation experiment was conducted with sludge taken in several wastewater treatment plants in Japan to investigate required ozone consumption to solubilize sludge, effect of sludge solubilization on sludge activity and biodegradability of solubilized sludge. The degree of sludge solubilization was different from each other, and the sludge which showed least solubilization contained high concentration of iron.

Based on the experimental result, operation condition of a new advanced wastewater treatment process with sludge ozonation and phosphorus crystallization was designed. The process was operated in lab scale plant, and accomplished 100% excess sludge reduction, 88% reduction in sludge production, and 83% of phosphorus recovery.

Acknowledgement

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References