Effects of Nitrification and Chlorine Disinfection on BOD of Effluent from Johkasou Systems

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Abstract

A nitrification reaction by nitrifying bacteria has remarkably exerted the influence in the measurement method of present BOD according to the design and the operation condition of facilities though the quality of effluent in domestic wastewater treatment facilities has been evaluated by before disinfection in johkasou and after disinfection in public sewerage systems. Moreover, the examination of the influence evaluation of the chlorine disinfection is not necessarily done enough. In this study, we examined the quality of effluent in operating johkasous before and after disinfection for the appropriate and efficient promotion of domestic wastewater measures to protect regional aquatic environments. The investigation was executed for 85 small johkasous which had been installed in the separate houses in prefecture of KANTO area. As a result, the rate of BOD fitting to an expected performance reached 92% after disinfecting 79% whole before disinfected, and the effect of the BOD removal in the disinfection tank was admitted. In the evaluation of the effect of the environmental load-reducing the final effluent on the destination from this, it was showed that it was appropriate intended for the quality of effluent after disinfected, and there were few significant differences concerning the treatment performance with public sewerage systems.

Key words: Johkasou system, chlorine disinfection, nitrification, ATU-BOD, public sewerage system

INTRODUCTION

Domestic wastewater treatment facilities in Japan are classified into collective systems and individual systems³. Collective systems, individual systems, or combinations of both have been established with consideration of economics and the characteristics of the regions where they are installed. Treatment is required by law to yield a BOD of no greater than 10–15 mg/l in public sewage treatment facilities (Sewerage Service Act) and no greater than 20 mg/l in johkasous (Johkasou Law). This performance level is an extremely important factor for the appropriate and efficient promotion of domestic wastewater measures to protect regional aquatic environments.

In the past, the quality of effluent in domestic wastewater treatment facilities has been evaluated by sampling and measuring final effluent after disinfection in the case of public sewage treatment facilities, and by sampling and measuring effluent before disinfection in the case of johkasous. The main reason for this difference in evaluation methods is that public sewage treatment facilities are ranked as specified facilities, and are thus subject to the Water Pollution Control Law, which requires testing of effluent (that is, final effluent) after it has been disinfected, whereas in johkasous it is
the biological treatment function that is evaluated, and therefore effluent before disinfection is measured in legal inspections according to the Johkasou Law.

In this study, we examined the quality of effluent in operating johkasous before and after disinfection, and propose a method for evaluating the quality of effluent from the perspective of water quality management that aims to make johkasous consistent with public sewage treatment facilities.

**MATERIALS AND METHODS**

**Surveyed Facilities** We randomly selected and studied 85 small johkasous, which were installed in separate houses in prefecture of KANTO area and which were designed to treat waste from 5 to 10 people: 10 were standard-structure johkasous (BOD-removal types), 39 were compact type johkasous (BOD removal-types), and 36 were johkasous with advanced treatment processes (BOD/Total nitrogen (T-N) removal johkasous, hereafter called N-removal types, and BOD/T-N/Total phosphorus (T-P) removal johkasous, hereafter called NP-removal types). As shown in Figure 1, the treatment system for the standard-structure model is an anaerobic filter–contact aeration system, and the treatment system for the compact type model uses an anaerobic tank in its primary treatment stage followed by a biofilm filtration or moving-bed biofilm process. In the N-removal johkasou, a flow adjustment function is added to the same system as used in the compact type model, and the NP-removal johkasou has iron electrolysis–type phosphorus removal equipment built into the secondary treatment apparatus of the N-removal johkasou.

**Methods** In all of the facilities, we conducted the study during testing carried
Effects of Nitrification and Chlorine Disinfection on BOD

out as required under the Johkasou Law. We collected 2 l each of effluent before and after it flowed into the disinfection tank. We preserved the samples by refrigeration, and we analyzed them for BOD, Suspended solid (SS), T-N, and T-P according to the Sewage Testing Method. We measured the BOD in the disinfected effluent after we reduced its residual chlorine by adding an amount of Na₂SO₃ that was equivalent to the amount of residual chlorine. We also measured BOD of adding Allylthiourea (ATU-BOD) in the same sample at the same time.

Test of the Effects of Adding Chlorine

We collected effluent from a part of surveyed facilities before it was disinfected, and used it to perform laboratory tests on the effects of chlorine addition on BOD.

To 1 l of treated water with a BOD of 10−30 mg/l we added a predetermined amount of 3000−mg/l NaClO standard solution to yield a residual chlorine concentration of 0−5 mg/l for each type of johkasou. After the addition, we mixed the solution for 15 min. at room temperature and immediately measured the residual chlorine and BOD. Before measuring the BOD, the residual chlorine was removed as described above.

RESULTS AND DISCUSSION

Quality of Effluent before Disinfection (1)

Distribution of BOD Values and Rate of BOD fitting

We measured the BOD in treated water collected from each of the 85 facilities at the time of sewage inflow and before it was disinfected (Fig. 2).

The mean BOD in all of the facilities was 17.1 mg/l (3≤BOD≤60 mg/l), and when a BOD of no greater than 20 mg/l was set as the total treatment performance criterion, this criterion was satisfied by 67 facilities, giving a rate of BOD fitting of 79%. These results are similar to those of past reports²10 and are judged to indicate the mainly favorable quality of effluent. The scattering of data may have been caused by factors such as effluence of SS due to fluctuations in flows, faulty setting of the volume of recirculation water, increases in users to a number exceeding the Number of Users for Design (NUD), and problems with johkasou maintenance.

(2) Evaluation by ATU-BOD

The quality of effluent collected from johkasous before it was disinfected was tested to evaluate the biological processing function of the johkasous. However, since BOD is affected by nitrification reactions while it is being measured, Kitao¹¹ has asserted that the BOD measurement method should be improved so that it can exclude the effects of nitrification, and that the measurement should be made using a method that is appropriate for the original purpose of BOD. In this study, we added a sufficient amount of Allylthiourea to diluted test water to yield an ATU concentration of 2 mg/l, and we measured the BOD values of the same samples as in (1).

As shown in Figure 3, there was some scattering of data in the samples with BOD values of 40−60 mg/l, but in all samples, the ATU−BOD values were lower than the BOD values, and the ATU−BOD/BOD ratio was 0.46. We discovered that 92% of the
ATU-BOD values were below 20 mg/l, and this percentage was higher than past conformance rates based on BOD. This result is consistent with the result of a study by Nakamura et al., and since this result is caused by the effect of nitrifying bacteria contained in SS in effluent before disinfection, ATU-BOD is a more valid criterion than BOD for evaluation of biological processing. Johkasous use biofilm systems such as contact aeration tanks, biofiltration tanks, and moving-bed biofilm tanks; they therefore have long sludge retention times (SRT), making it easy for nitrifying bacteria to multiply. This may be one reason that johkasous are easily affected by nitrification reactions.

(3) SS, T-N, and T-P of Effluent According to Treatment Process The SS, T-N, and T-P of effluent before disinfection in the facilities studied are shown in Table 1.

In the standard-structure and compact type johkasous, the SS values were 6.4 and 14.3 mg/l, the T-N values were 27.3 and 18.4 mg/l, and the T-P values were 3.3 and 2.8 mg/l, respectively. The compact type johkasous showed better nitrogen removal performance than the standard-structure johkasous. This may be because compact type johkasous use a biofiltration process or a moving-bed biofilm process, and nitrogen is removed in the primary treatment apparatus (anaerobic tank) because part of the treated water is continuously recirculated to the anaerobic tank at a rate of 2.0 or more.

In the N-removal johkasous, mean SS was 9.0 mg/l, mean T-N was 20.0 mg/l, and mean T-P was 3.1 mg/l; in the NP-removal johkasous, mean SS was 8.8 mg/l, mean T-N was 7.7 mg/l, and mean T-P was 1.0 mg/l. T-N and T-P removal performance was demonstrated, and all of the facilities showed effluent of favorable quality.

Quality of Treated Water after Disinfection

The BOD values before and after disinfection in the 85 facilities studied are shown in Figure 4. The percentage of facilities with a BOD exceeding 20 mg/l was 21% before disinfection and 12% after disinfection, and the BOD in all of the facilities was lower after disinfection than before disinfection.

Next, as shown in Table 2, a comparison of johkasou types reveals that the rate of

![Figure 4](image-url)
effects of nitrification and chlorine disinfection on BOD

conformance to a BOD value of 20 mg/l or less after disinfection was 80% in the standard-structure johkasous, 87% in the compact type johkasous, and 100% in the N-removal and NP-removal johkasous, and that the conformance rate of the total number of facilities studied was as high as 92%. This high conformance rate may have occurred because nitrification reactions were suppressed by reaction with chlorine, causing the BOD to decrease. Comparing ATU-BOD in effluent before disinfection and BOD after disinfection (Fig. 5) reveals that the BOD after disinfection is lower than the ATU-BOD, suggesting that the chlorine may also have oxidized organic substances.

Domestic wastewater treatment measures today need to be segregated into public sewage treatment facilities and rural sewerage systems as collective systems on the one hand and johkasous as on-site systems on the other hand, based on evaluation of their economy and efficiency. Unified evaluation of effluent based on environmental protection of local areas is necessary.

Table 3 summarizes the BOD values of effluent for each treatment process in 162 public sewage treatment facilities. All samples were collected from treated water after disinfection, and data was obtained from 22 cities in 9 prefectures, including metropolitan Tokyo, and Osaka.

In this study, we were unable to compare the quality of effluent before and after disinfection, but the quality of effluent after disinfection was satisfactory in all public sewage treatment facilities, and the treatment can be judged to have maintained the desired performance level. The quality of effluent from public sewage treatment facilities (Table 3) did not differ substantially from that from on-site johkasou systems after disinfection (Table 2). Johkasous are ranked highly as systems for protection of aquatic environments, and they can also be said to exhibit an environmental load-reducing effect when considered from the perspective of treatment performance.

Reduction of BOD by Chlorine  Baity H.G. et al.\textsuperscript{13,14} and Griffin A.E.\textsuperscript{15} have previously reported that organic substances in influent sewage are oxidized by reaction with chlorine and that BOD after disinfection

\begin{table}[!h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Items} & \textbf{Standard structure} & \textbf{Compact} & \textbf{N removal} & \textbf{N/P removal} & \textbf{Total} \\
\hline
\textbf{Number of facility} & 10 & 39 & 20 & 16 & 85 \\
\hline
\textbf{Before disinfection} & 20.3 \,(8\sim60) & 20.1 \,(3\sim60) & 17.4 \,(10\sim40) & 7.3 \,(3\sim15) & 17.1 \\
\textbf{Rate of BOD fitting (%)} & 80 & 69 & 80 & 100 & 79 \\
\hline
\textbf{After Disinfection} & 11.3 \,(5\sim22) & 12.4 \,(3\sim40) & 10 \,(4\sim15) & 4.5 \,(2\sim10) & 10.2 \\
\textbf{Rate of BOD fitting (%)} & 80 & 87 & 100 & 100 & 92 \\
\hline
\end{tabular}
\caption{BOD of effluent before and after it flowed into the disinfection tank, and the rate of conformance to a BOD value of 20 mg/l or less}
\end{table}

\begin{figure}[!h]
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Relationship between effluent BOD and ATU-BOD concentrations after disinfection}
\end{figure}
decreases to 43–75% if 6–15 mg/l chlorine is added. Peter S.16) has concluded that oxidation of organic substances by chlorine does not progress, because although BOD decreases by 33% over a 5-day period when a sufficient amount of chlorine is added to yield a residual chlorine concentration of 0.7 mg/l, BOD over a 10–day period does not differ from controls. In an experiment using water from treated sewage, Jolly R.L.17) and Michael L.C.18) have shown that the strong oxidizing ability of chlorine decreases the amount of residual organic substances and thus decreases BOD in the effluent. On the other hand, Abdullah M.E.19) has shown that when 2–50 mg/l of chlorine is added to water from treated sewage and allowed to react for 30 min, the BOD decreases when up to 5 mg/l of chlorine is added, but when 30 mg/l or more of chlorine is added, the organic matter is progressively decomposed to low-molecules due to oxidation by the chlorine, causing the BOD and COD to double in the effluent.

Oxidation by chlorine decreases the BOD of influent. Furthermore, reactions between chlorine and secondary treated water, which has a low concentration of residual organic substances, markedly affect the BOD of the effluent depending on the amount of chlorine added. In this study, we mixed a predetermined amount of sodium hypochlorite with secondary treated water of a johkasou, removed the residual chlorine, and measured the BOD.

To secondary treated water with a BOD of 10–30 mg/l, we added sufficient amounts of NaClO to yield 0.5–5.0 mg/l of residual chlorine. Consequently, as shown in Figure 6, the BOD of sample No. 1 decreased with addition of NaClO, and when the amount of residual chlorine was 5.0 mg/l, the BOD for No. 1 decreased to 17 mg/l, which was 60.7% of the initial BOD. There was also a decrease in the BOD of sample No. 2 from 21 mg/l to 13 mg/l, and sample No. 3 hardly changed at all. These results were consistent with the results obtained when the amount of added chlorine was 5 mg/l or less in the experiments conducted by Abdullah M.E.19), and suggested that the decrease in BOD was caused by reactions between residual organic substances and chlorine in the effluent.

Since the bases of regulation for public sewage treatment facilities and johkasous differ, samples used to evaluate the quality of effluent have been taken before or after the effluent was disinfected. Until now, treatment performance by johkasous has been evaluated based on the BOD of effluent before disinfection, and it has been pointed out that johkasous are markedly different from public sewage treatment facilities. Based on the results of this study, the conformance rate in terms of BOD is higher after disinfection than before disinfection in johkasous as well, and johkasous are judged to be effective as on-site systems. However, since no decrease in BOD was observed when the residual chlorine was 2 mg/l or more, it might be necessary to add the condition that the concentration of residual chlorine must be 2 mg/l or less.

Predictions about the future based on past progress in domestic wastewater treatment measures and past decreases in population are now being debated in national and local

<table>
<thead>
<tr>
<th>Number of facility</th>
<th>Effluent (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>(1~17)</td>
</tr>
<tr>
<td>11</td>
<td>(1~9)</td>
</tr>
<tr>
<td>10</td>
<td>(1~11)</td>
</tr>
<tr>
<td>34</td>
<td>(1~9)</td>
</tr>
<tr>
<td>16</td>
<td>(N.D.~9)</td>
</tr>
<tr>
<td>2</td>
<td>(1~3)</td>
</tr>
</tbody>
</table>

**Table 3 BOD of effluent for each treatment process in public sewerage facilities**

<table>
<thead>
<tr>
<th>Items</th>
<th>Conventional activated sludge process</th>
<th>Oxidation ditch process</th>
<th>AO process(^1)</th>
<th>A(_2)O process(^2)</th>
<th>Recirculation process(^3)</th>
<th>Others(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of facility</td>
<td>89</td>
<td>11</td>
<td>10</td>
<td>34</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Effluent BOD</td>
<td>4.3 (1~17)</td>
<td>3.3 (1~9)</td>
<td>4.7 (1~11)</td>
<td>2.7 (1~9)</td>
<td>2.3 (N.D.~9)</td>
<td>2.4 (1~3)</td>
</tr>
</tbody>
</table>

1) AO process: anaerobic-oxic activated sludge process
2) A\(_2\)O process: anaerobic-anoxic-oxic process
3) Recirculation process: multi-stage nitrification/denitrification process, denitrification process with nitrified mixed liquor recycle, and nitrification/denitrification process with coagulant etc.
4) Contact aeration process, batch type activated sludge process
Effects of Nitrification and Chlorine Disinfection on BOD

governments. In terms of treatment function, there is no difference between the quality of effluent of public sewage treatment facilities and johkasous when they are viewed objectively, and segregation of the two systems according to economy and efficiency should be considered. When evaluating the effect of the environmental load of the final effluent on its destination, in johkasous too, it is desirable to regulate the effluent based on the BOD of the effluent after disinfection.

Furthermore, nitrogen and phosphorus removal type advanced johkasou system have functioned both efficient nitrification and removal of C-BOD, ATU-BOD. Therefore it is very important to establish measuring BOD of the effluent after disinfection and applying advanced johkasou system.

CONCLUSIONS

Methods for evaluating quality of treated water differ between public sewage treatment facilities and johkasous. An examination of the actual conditions of compact type johkasou and the effects of chlorine on the quality of effluent showed the following results:

1) The conformance rate in terms of BOD of effluent was 79% for effluent before disinfection but was 92% for effluent evaluated after disinfection.

2) Effluent before disinfection was affected by nitrifying bacteria, and ATU-BOD/BOD was 0.46.

3) NP-removal johkasous achieved favorable treatment presumably after disinfection and yielded a BOD of 2–10 mg/l, a T-N value of 5.0–12 mg/l, and a T-P value of 0.1–2.3 mg/l.

4) In the disinfection process, there was a decrease in BOD that was caused by reactions between chlorine and residual organic substances in the secondary treated water.

5) There will continue to be a need for segregation of public sewage treatment facilities and johkasous, and a unified opinion about quality of effluent to be evaluated will be necessary.

ACKNOWLEDGEMENTS

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