Effects of ozone in treating drinking water by DAF system
Byoung-Ho Lee, Won-Chul Song, Jong-Gyu Ha, Hyeon-Ju Yang and Young-Suk Kim

ABSTRACT

The Dissolved Air Flotation (DAF) process is very effective in removing low density floc particles for drinking water treatment. It is especially well known in removing turbidity and algae by flotation process. The micro-bubbles in the DAF process pick up small flocs, thereby turbidity materials and floated algae are removed efficiently. When air is substituted by ozone in the DAF process, the removal rates of water quality parameters are highly enhanced including turbidity and algae. The turbidity removal rate is enhanced by 1.1% while the removal rate of THMFP is increased by 11.7%. Other parameters such as TOC, and microbial agents are also removed greatly by using ozone instead of air in DAF system.

Key words | DAF, DOF, drinking water treatment, flotation, ozone

INTRODUCTION

The DAF system is widely used in drinking water treatment all over the world (Veenstra & Schnoord 1980). In Korea, DAF technology has also been applied in two large drinking water treatment plants located in Wonju & Jeonnam. There are some limitations in adopting the DAF system for drinking water treatment especially in Korea. The main problem is high concentration of SS in drinking water sources, which have high specific gravity in rainy season. If a drinking water source is pretreated to remove the high turbidity in rainy season, the DAF system may be an excellent option in drinking water treatment providing better performance than the sedimentation process.

When ozone is used instead of air in the DAF system, removal performance of the water quality parameters is greatly enhanced because ozone provides high oxidation potential in addition to the floating force of the DAF system.

EXPERIMENTAL METHODS

Batch tests

A batch test has been performed to decide the proper concentration of ozone, which will be used in the pilot tests of the DAF system. Removal efficiencies of water quality parameters were measured in various ozone concentrations, so that the optimal ozone concentration was chosen. Ozone was dissolved in a stainless steel tank with about 5.0 kg/cm² of pressure. Pressurized water containing ozone gas is applied in a column to treat raw water just like a batch DAF test. A schematic diagram of the DAF system using ozone is shown in Figure 1.

Ozone generator was manufactured by the Ozone Engineering LTD., Co. which is in Korea. The capacity of the ozone generator is maximum 20 g/hr (50 g-ozone/m³, 4.24 LPM), which requiring 330 watts of electric power. Ozone is generated by high voltage of electric discharge while oxygen passes between two highly charged positive and negative electric field.

Pilot tests

A pilot plant was built with a capacity of 20 m³/day. The pilot plant was operated at the site of H dam which is a source of drinking water of U city, Korea. Recycle rate was about 20%, and pressure of the air dissolving tank was 5–6 kg/cm². Even though ozone was used instead of air in

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the DAF system, air can also be used alternatively. Ozone was applied by about 1.1–4.3 mg/l. A schematic diagram of the DAF system is shown in Figure 2. The pilot system consists of several parts. The first part may be a coagulation and flocculation chamber, and a flotation chamber with a skimmer for removing floated sludge. The remaining part may be an ozone (air) compressing system with an ozone generator.

This system was manufactured by Michigan Technology, which is located in Korea, and has partial patents. The company has supplied the technology in domestic wastewater, and in non-biodegradable wastewater like the treatment plants for livestock wastewater, and leachate.

RESULTS AND DISCUSSION

Batch tests

Batch tests have been performed to decide the proper concentration of ozone which will be used in the pilot test.
Ozone was applied from 1.1 mg/l to 4.3 mg/l. Results are presented in Table 1 and Table 2.

Some of the results are presented in Figures 3–5. Removal efficiency of turbidity is the highest when 2.4 mg/l of ozone was applied. At lower concentration of ozone, amount of gas bubble may not be enough. At higher concentration range of ozone, floc may be dissociated by oxidation resulting in lower turbidity removal efficiency (Becher & O’Melia 1995).

Results of other parameters such as KMnO₄ consumption, TOC, UV₂₅₄ absorption, and Chlorophyll-a are presented in Figure 4. Overall removal efficiencies of the parameters are good in the concentration 2.4 mg/l and 2.7 mg/l of ozone. The reason of the results may be the same as that of the turbidity. In high concentration range of ozone, organics flocculated in flocs are dissociated by ozone oxidation (Petrusevski et al. 1993; Chung 1994).

Removal efficiency of THMFP is highest in 2.7 mg/l of ozone concentration in a batch test as shown in Figure 5. In lower concentration of ozone, the amount of micro-bubbles may not be enough, and oxidation potential may also not be high enough for enhancing coagulation. In high concentration range of ozone, flocculated organics such as humic acids are disorganized, and degraded into smaller molecular size by ozone oxidation (Galapate et al. 2001).

The amount of ozone dissolved in the pressure tank of the DOF (DAF) system on a volume basis was more than twice that of air at the same operating pressure of 6 kg/cm², which was considered related gas solubilities. Hence the released amount of micro-bubble volume of ozone in the flotation basin is also more than twice that of air.

Better results of removal rates in DOF than in DAF are not only because of higher released volume of gas, but because of higher oxidation potential of ozone than air.

Ozone (mg) consumed per TOC (mg), and turbidity (NTU) were measured. Results are shown in Figure 6 and Figure 7.

In low concentrations of TOC like 2.0 mg/l or less in influent, consumed ozone per mg-TOC removed was less than 2.0 mg of ozone. However, with increasing TOC concentration, ozone consumption rate also showed rapid increasing such as in Figure 6. Results imply that ozone is efficient in low TOC concentration.

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**Table 1**  Results of organic matters by the batch tests (applied to the same raw water which was used in the pilot test)

<table>
<thead>
<tr>
<th>Ozone dose (mg/l)</th>
<th>KMnO₄ consumption (mg/l)</th>
<th>UV₂₅₄ absorption (cm⁻¹)</th>
<th>Chlorophyll-a (µg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Effluent</td>
<td>Influent</td>
</tr>
<tr>
<td>1.1</td>
<td>7.74</td>
<td>2.90</td>
<td>0.042</td>
</tr>
<tr>
<td>2.4</td>
<td>8.09</td>
<td>1.52</td>
<td>0.041</td>
</tr>
<tr>
<td>2.7</td>
<td>4.87</td>
<td>2.27</td>
<td>0.039</td>
</tr>
<tr>
<td>3.6</td>
<td>5.96</td>
<td>4.10</td>
<td>0.039</td>
</tr>
<tr>
<td>4.3</td>
<td>5.50</td>
<td>1.90</td>
<td>0.043</td>
</tr>
</tbody>
</table>

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**Table 2**  Results of disinfection by the batch tests (applied to the same raw water which was used in the pilot test, continued)

<table>
<thead>
<tr>
<th>Ozone dose (mg/l)</th>
<th>Total colony count (CFU/MI)</th>
<th>Total coliform (MPN/100 ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Effluent</td>
</tr>
<tr>
<td>1.1</td>
<td>1,300</td>
<td>190</td>
</tr>
<tr>
<td>2.4</td>
<td>82,789</td>
<td>15</td>
</tr>
<tr>
<td>2.7</td>
<td>33,100</td>
<td>0</td>
</tr>
<tr>
<td>3.6</td>
<td>7,100</td>
<td>1</td>
</tr>
<tr>
<td>4.3</td>
<td>12,900</td>
<td>0</td>
</tr>
</tbody>
</table>

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**Figure 3**  Removal efficiencies of turbidity in various ozone concentrations.

**Figure 4**  Removal efficiencies of KMnO₄ consumption, TOC, UV₂₅₄ absorption, and Chlorophyll-a in various ozone doses.
Unlike in TOC removal, consumed ozone per removed turbidity was low in high turbidities of influent. Whatever the concentrations of suspended solids causing turbidity in influent are, the effluent turbidities may be lowered down to less than 1 NTU in DOF system. Thus in higher concentrations of suspended solids, the resultant consumption of ozone per removed suspended solids is supposed to be lower.

Pilot plant test

From the batch test results, the proper or optimum concentration of ozone was thought to be 2.4 mg/l to 2.7 mg/l. In this investigation 2.7 mg/l of ozone was chosen for the pilot test to maximize THMFP removal.

The DAF system was operated alternatively with ozone and air. When air is used, the system is the same as the ordinary DAF system. When ozone is used, the system is operated as the DOF (Dissolved Ozone Flotation) system. The results of the pilot test are presented in Figures 8–12.

Removal of turbidity by the DAF and DOF system was excellent, maintaining below 1 NTU in most cases during the test as shown in Figure 8. Removal is little bit better in the DOF system probably because ozone enhanced the coagulation efficiency (Edward et al. 1993), and increased the volume of micro-bubbles.

Removal of KMnO₄ consumption is similar pattern to the turbidity removal. The mechanism and reason of the KMnO₄ consumption removal is the same. Result of the KMnO₄ consumption removal is shown in Figure 9. There is not much difference in effluent concentrations between the DOF system and the DAF system.

Removal of chlorophyll-a is excellent in both DOF and DAF systems. Because density of algae is low, flotation is efficient to remove chlorophyll-a, which is contained in algae. Even though removal is little bit higher in the DOF system, the concentrations of chlorophyll-a is very low in effluent for both systems as shown in Figure 10.

The average concentration of THMFP in the treated water was 55.6 µg/l when ozone was used, while that was 76.4 µg/l when air is used in the DAF system. The difference of removal rates was 11.7% indicating much better removal of THMFP by ozone instead of air. As shown in Figure 11,
Figure 9 | Removal of KMnO₄ consumptions by the DOF and DAF system. (Ozone dose: 2.7 mg/l; Recycle ratio: 20%; Flotation time: 20 min).

Figure 10 | Removal of Chlorophyll-a by the DOF and DAF system. (Ozone dose: 2.7 mg/l; Recycle ratio: 20%; Flotation time: 20 min).

Figure 11 | Removal of THMFP by the DOF and DAF systems. (Ozone dose: 2.7 mg/l; Recycle ratio: 20%; Flotation time: 20 min).

Figure 12 | Removal of total coliform by the DOF and DAF systems (Ozone dose: 2.7 mg/l; Recycle ratio: 20%; Flotation time: 20 min).

Table 3 | Results of the pilot test

<table>
<thead>
<tr>
<th>Water quality parameter</th>
<th>Influent</th>
<th>Effluent</th>
<th>Removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>5.51 (±2.07)</td>
<td>0.58 (±0.16)</td>
<td>91.5 (±3.6)</td>
</tr>
<tr>
<td>KMnO₄ consumption (mg/l)</td>
<td>7.39 (±1.96)</td>
<td>2.73 (±0.98)</td>
<td>62.9 (±10.4)</td>
</tr>
<tr>
<td>Chlorophyll-a (mg/m³)</td>
<td>1639 (±4.657)</td>
<td>739 (±1.96)</td>
<td>56.5 (±6.2)</td>
</tr>
<tr>
<td>Total coliforms (MPN/ml)</td>
<td>5.51 (±2.07)</td>
<td>0.58 (±0.16)</td>
<td>91.5 (±3.6)</td>
</tr>
<tr>
<td>THMFP (µg/L)</td>
<td>262.5 (±63.6)</td>
<td>113.1 (±34.5)</td>
<td>58.1 (±15.9)</td>
</tr>
</tbody>
</table>
the differences of effluent THMFP concentrations are apparent.

Removal of total coliform by the DOF system was 100% during the test period as shown in Figure 12. It was proved that ozone is very effective in disinfection of drinking water treatment (Glaze 1987). Even though it was high in removal rate of coliform by the DAF system, it could not guarantee complete disinfection.

Results of the pilot test are summarized in Table 3. As shown in Table 3, the difference of removal rate between the DOF system and the DAF system is the highest in THMFP even though other parameters including turbidity, KMnO₄ consumption, chlorophyll-a, and total coliform are removed more in the DOF system.

CONCLUSION

Ozone enhanced removal rates of water quality parameters in drinking water treatment in the DAF system. Because turbidity removal was very high in both the DOF system and the DAF system, it seemed that it was not greatly enhanced by ozone. Removal rates of other water quality parameters were also increased by ozone including THMFP. Out of them removal rate of THMFP was the highest, which is one of the most important purposes of applying ozone instead of air. It was supposed that humic acids and fulvic acids were oxidized by ozone.

It was found that the DAF system with ozone (DOF system) was very effective in treating drinking water.

REFERENCES


