Treatment of taste and odor material by oxidation and adsorption

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Abstract Massive blooms of blue–green algae in reservoirs produce the musty-earthy taste and odor, which are caused by compounds such as 2-MIB and geosmin. 2-MIB and geosmin are rarely removed by conventional water treatment. Their presence in the drinking water, even at low levels (ng/L), can be detected and it creates consumer complaints. So those concentrations have to be controlled as low as possible in the drinking water. The removals by oxidation (O₃, Cl₂, ClO₂) and adsorption (PAC, filter/adsorber) were studied at laboratory and pilot plant (50 m³/d) to select suitable 2-MIB and geosmin treatment processes. The following conclusions were derived from the study. Both of the threshold odor levels for 2-MIB and geosmin appeared to be 30 ng/L as a consequence of a lab test. For any given PAC dosage in a jar-test, removal efficiencies of 2-MIB and geosmin were increased in proportion to PAC dosage and were independent of their initial concentration in raw water for the tested PAC dosages. In comparison of geosmin with 2-MIB, the adsorption efficiency of geosmin by PAC was superior to that of 2-MIB. The required PAC dosages to control below the threshold odor level were 30 mg/L for geosmin and 50 mg/L for 2-MIB at 100 ng/L of initial concentration. Removal efficiencies of odor materials by Cl₂, ClO₂, and O₃ were very weak under the limited dosage (1.5 mg/L), however increased ozone dosage (3.8 mg O₃/L) showed high removal efficiency (84.8% for 2-MIB) at contact time 6.4 minutes. According to the initial concentrations of 2-MIB and geosmin, their removal efficiencies by filter/adsorber differed from 25.7% to 88.4%. For all those, however, remaining concentrations of target materials in finished waters were maintained below 30 ng/L. The longer run-time given for the filter/adsorber, the higher the effluent concentration generated. So it is necessary that the run-time of the filter/adsorber be decreased, when 2-MIB or geosmin occurs in raw water.

Keywords Adsorption; filter/adsorber; GAC; geosmin; ozone; PAC; taste and odor; 2-MIB

Introduction

Eutrophication has already accelerated for years in reservoirs used for sources of water supply in Korea and has often caused water blooms of blue–green algae. Especially massive blooms of blue–green algae in reservoirs produce taste and odor problems during the summer and fall. Taste and odor are the main basis by which most consumers judge the safety of their tap water, therefore, inadequate taste and odor control can create perceived health problems (McGuire, 1995).

One of the most common and problematic types of taste and odor is the musty-earthy type caused by 2-MIB (2-methylisoborneol) and geosmin (trans-1,10-dimethyl-trans-9-decalol) (Robert et al., 2000). 2-MIB and geosmin are rarely removed by conventional water treatment. Their presence in the drinking water, even at low level (ng/L), can be detected and creates consumer complaints (Ho et al., 2002). So water treatment facilities need suitable treatment processes of 2-MIB and geosmin to control aesthetic problems. And they have to control concentrations of 2-MIB and geosmin in the drinking water as low as possible.

Oxidation and adsorption are generally the suggested methods to mitigate taste and odor problems. The methods most commonly used to combat taste and odor are oxidation by
oxidants such as chlorine (Cl$_2$), chlorine dioxide (ClO$_2$), potassium permanganate (KMnO$_4$), ozone (O$_3$), and adsorption by powdered and granular activated carbon. Oxidation processes by chlorine and chlorine dioxide are effective for removing some types of taste and odor but are not effective for removing 2-MIB and geosmin (Lalezary et al., 1986; Glaze et al., 1990).

Ozonation is less commonly used but can be an effective method for removing 2-MIB and geosmin. O$_3$ used to disinfect surface water is a strong oxidant, removes tastes and odors, enhances coagulation, and provides other benefits. O$_3$ destroys 2-MIB and geosmin if the dose is high enough (Lundgren, 1988; Ferguson et al., 1990; Koch et al., 1992).

PAC (powdered activated carbon) is the most commonly used method for removal of 2-MIB and geosmin as it is relatively inexpensive and can be applied only when required. However the presence of NOM (natural organic material) and oxidants like chlorine or chloramines can significantly reduce the effectiveness of PAC (Gillogly, 1999).

The purpose of this study is to verify removal efficiency of taste and odor compounds by the suggested methods to select suitable treatment processes for 2-MIB and geosmin.

**Methods**

**Material and analysis**

2-MIB and geosmin supplied by Waco Pure Chemical Industries Ltd was used for the purpose of spiking since their concentrations were not continuous and mostly trace. Each reagent (20 mg) was dissolved into 100 mL of methanol to make stock solution and stored at 4°C. Raw water was prepared by spiking this 2-MIB or geosmin solution. They were analyzed by using solid-phase microextraction gas chromatography/mass spectrometry (SPME-GC/MS). This method was chosen because it is less expensive and easier to perform than other methods, such as closed-loop stripping, liquid–liquid extraction, steam distillation, and purge and trap.

**PAC adsorption**

The device used to evaluate PAC adsorption capacity was a jar test apparatus. The jar test was performed with influent water of Suji water treatment plant, which was spiked with 2-MIB or geosmin. The conditions for the jar-test were explained in the following procedure; 2-litre samples were prepared in square jars. They were stirred at 60 rpm for 1 minute to determine initial concentration before PAC addition. 3 to 50 mg/L of PAC were added to the samples. Then they were stirred at 300 rpm for 1 minute followed by 40 rpm for 15 minutes. After 10 mg/L of PACS (coagulant) were added to the samples, they were mixed rapidly for 1 minute and then slowly mixed for 15 minutes and settled for 30 minutes. The initial concentrations of 2-MIB and geosmin were varied between 43 and 220 ng/L.

**Oxidation experiment**

This experiment was carried out by adding three kinds of oxidants; 1.5, 3.0, 5.0 mg/L of Cl$_2$, 1.5 mg/L of ClO$_2$ and 1.5 mg/L of O$_3$. Oxidant was added to samples followed by a flash mix of 1 minute. Then they were kept in the incubator, and analyzed at fixed times over the reaction period.

**Pilot plant**

This consists of ozonation (pre and post), rapid mixing, flocculation, sedimentation, filtration and GAC (granular activated carbon) filtration. The capacity of the plant is 50 m$^3$/d. One of the sand filters was replaced by a filter/adsorber (EBCT: 4.14 minutes). Figure 1 provides a schematic of the pilot plant.
Raw water

Influent water of Suji water treatment plant was used for batch experiments and the pilot plant test. It was taken from Lake Paldang by pumping. Water quality parameters during the test period are shown in Table 1.

Results and discussion

Threshold odor level test

Threshold odor level tests were performed for the treated water of the pilot plant in the lab. Threshold odor levels of 2-MIB and geosmin showed the same value of 30 ng/L, which was higher than 20 ng/L and 15 ng/L for each obtained from the solution made of distilled water. Such a difference is supposed to be due to the water quality characteristics of samples and may need more experiments for the range of threshold odor levels for different water characteristics.

Adsorption by PAC

Figure 2 shows the adsorption of geosmin by plotting the remaining percentage vs. PAC dosage. Removal efficiency of geosmin was increased in proportion to PAC dosage. The remaining percentage of geosmin for initial concentration of 106 to 220 ng/L were 12.7 to 29.6% by PAC dose of 30 mg/L. Remaining concentrations were between 16.9 and 41.8 ng/L. The required PAC dosage to control below the threshold odor level was about 30 mg/L at 100 ng/L of initial geosmin concentration, while only PAC 5 mg/L kept it below 15 ng/L at initial concentration of 44 ng/L.

Figure 3 shows the remaining percentage of 2-MIB vs. PAC dosage. Residual percentages of 2-MIB for initial concentration 112 to 158 ng/L were 38.5–51.2% for PAC dose of 30 mg/L. Moreover the remaining percentage was over 30% at PAC dose 50 mg/L. Required PAC dosage to control below threshold odor level was over 50 mg/L at 2-MIB initial concentration 100 ng/L.

As shown in Figure 2 and 3, removal efficiencies of geosmin and 2-MIB showed some

Table 1  Raw water characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ave.</th>
<th>Min.</th>
<th>Max.</th>
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<td>7.9</td>
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<td>13.1</td>
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<td>KMnO₄ consumption (mg/L)</td>
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<td>TOC (mg/L)</td>
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<td>0.0474</td>
</tr>
<tr>
<td>THMFP (µg/L)</td>
<td>51</td>
<td>22</td>
<td>77</td>
</tr>
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</table>
difference. However, removal efficiency of each material for a given dosage was almost constant regardless of initial concentration except geosmin of 44 ng/L, which was the lowest beyond the range of most initial concentrations. Therefore the removal efficiency became independent of initial concentration of target material in raw water for a given PAC dosage as reported in previous studies (Knappe et al., 1998; Gillogly et al., 1998).

In comparison of geosmin with 2-MIB, adsorption efficiency of geosmin by PAC was superior to that of 2-MIB. This difference in the adsorption of the two compounds is due to the difference in their structure. Geosmin has a slightly lower solubility and molecular weight and has a flatter structure, which may render it more amenable to adsorption in the slit-shaped pores of the PAC (Cook et al., 2001).

**Pilot plant**

Figure 4 shows the residual concentration of geosmin and 2-MIB for each process. When 1.5 mg/L of ClO2 and O3 were added as pre-oxidation, respectively, removal efficiencies of geosmin and 2-MIB were below 20%. Under the limited dosage, the oxidation process by ClO2 and O3 was not effective for removing 2-MIB and geosmin at the pilot plant test.

**Oxidation by chlorine, chlorine dioxide and ozone**

Figure 6 shows the results of the oxidation experiment by Cl2 and ClO2. Generally, removal efficiencies of 2-MIB by Cl2 and ClO2 were very weak. In the case of increased Cl2 and ClO2 dosage of 5 mg/L, removal efficiencies of 2-MIB were also below 50% in 72 hours.

Figure 7 shows 2-MIB removal percentage for ozone dosage. Removal efficiency of 2-MIB was rapidly increased in proportion to O3 dosage and removal up to 84.8% for 2-MIB.
occurred at 3.8 mg O$_3$/L for 6.4 min contact time. However more tests will be necessary for probable ranges of initial 2-MIB concentration level, as treated 2-MIB hardly attained the threshold concentration level and most experimental initial 2-MIB concentrations were much higher than that occurring in raw water.

Figure 4 Variation of 2-MIB and geosmin at each process

Figure 5 Variation of 2-MIB and geosmin by run-time through filter/adsorber

Figure 6 Variation of 2-MIB by reaction time
Conclusions

Laboratory and pilot tests were conducted to evaluate the removal of taste and odor by oxidation (O3, Cl2, ClO2) and adsorption (PAC, filter/adsorber). The results showed adsorption or oxidation by ozone might be sufficient to control 2-MIB and geosmin below threshold odor level. The conclusions are as follows.

- Both threshold odor levels for 2-MIB and geosmin were 30 ng/L as a consequence of the lab test.
- For any given PAC dosage in the jar-test, removal efficiencies of 2-MIB and geosmin showed some difference. In comparison of geosmin with 2-MIB, adsorption efficiency of geosmin by PAC was superior to that of 2-MIB. The required PAC dosage to control below the threshold odor level was 30 mg/L for geosmin at the initial concentration of 100 ng/L while that for 2-MIB was 50 mg/L.
- Removal efficiencies of 2-MIB by oxidants were very weak except with ozone.
- Removal efficiencies by filter/adsorber differed from 25.7% to 88.4%. When run-time of the filter/adsorber was shorter than 20 hours, remaining concentrations of target materials were maintained below 30 ng/L. However the longer the run-time given, the higher the effluent concentration observed. So it is necessary that the run-time of the filter/adsorber is decreased, when 2-MIB or geosmin occurs in raw water.

References


