Advanced treatment for taste and odour control in drinking water: case study of a pilot scale plant in Seoul, Korea

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Abstract Taste and odour problems of tap water in Seoul are attributed to 2-methylisoborneol (2-MIB) and *trans*-1,10-dimethyl-*trans*-9-decalol (geosmin), which are the result of metabolism of algae and chlorine for disinfection. This study was carried out to measure 2-MIB and geosmin in the raw water from the Han River, to investigate removal efficiency of GAC and BAC integrated with post-ozonation, and to minimise and quantify the required chlorine concentration as a final disinfectant through the candidate process.

Keywords BAC; chlorine; GAC; geosmin; 2-methylisoborneol; ozonation

Introduction

According to the results of a public opinion survey about citizen's satisfaction of the drinking water quality, most complained about taste and odour of the drinking water served. Although these problems are not hazardous to human health, it makes aesthetic discomfort. The most common taste and odour (T&O) problem (musty and earthy T&O) was caused by microbial metabolites such as 2-methylisoborneol (2-MIB) and geosmin. They are major concerns of the water treatment utilities because they can be detected by the human nose, even at extremely low concentrations, i.e. as low as 4.0 ng/L for geosmin and 8.5 ng/L for 2-MIB (Pirbazari *et al.*, 1993; Ho *et al.*, 2004).

The standards for drinking water quality of Japan for 2-MIB and geosmin were revised in 2003, and enforced to the level of 10 ng/L in 2004. Individual T&O compounds have not yet been regulated in Korea. The Korean government started to make water quality standards for 2-MIB and geosmin quite recently. The waterworks office of Seoul's metropolitan government is planning to start to construct highly advanced water treatment plants. This plan will be carried out step-by-step from 2006 to 2011.

This research focusses on introducing advanced water treatment technologies to provide drinking water with higher quality for the citizens of Seoul. The objectives of this research are: (1) to report 2-MIB and geosmin in the raw water from the Han River; (2) to investigate removal efficiency of the candidate processes; (3) to minimise and quantify chlorine dose and final disinfectant with the candidate processes.

Methods

Pilot plant

The pilot plant for this study was constructed at Guwi water plant in October 2002. The pilot plant consisted of granular activated carbon (GAC) process and biological activated carbon (BAC) process integrated with post-ozonation. These two types of advanced unit processes were evaluated as advanced unit processes to be introduced to Seoul

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metropolitan in a previous study. Figure 1 shows the schematic diagram of the pilot plant used in the study.

It was expected that the efficiency of the candidate processes could be evaluated under the same conditions despite fluctuation of field conditions, as the feed water was filtered through a sand filter at the Guwi water treatment plant (Figure 1). The operating conditions for the GAC and BAC processes were as follows: 15 min of empty bed contact time (based on 3 m of total bed height), 7 day backwash interval by free chlorine water, and coal-based GAC media (Calgon F-400, 12 × 40 mesh, USA). Ozone was generated by an ozone generator (OZONIA, CFS-1, Swiss) which had a capacity of 40 g/hr. The total contact time was 30 min (bubble diffuser contact time: 10 min + reaction time: 20 min). The ozone dosage was regulated at 0.5 mg/L, but increased by 1.0 mg/L in such a case when the concentration of T&O compounds in the influent increased. Sampling points for this study were: (1) raw water; (2) sand filter; (3) GAC; (4) ozone; and (5) BAC from each process of conventional and advanced treatments.

Analytical methods

TOC was measured using Sievers 820 Total Organic Carbon Analyser.

2-MIB and geosmin analyses were conducted based on the method of *Standard Methods 6040D* (2005). Gas chromatography-mass spectrometry (GC: Varian CP-3800, MS: Varian Saturn 2200) was used in combination with solid phase microextraction (SPME fibre: polydimethylsiloxane/divinylbenzene) (Watson *et al.*, 2000). The detection limit was l.0 ng/L for both 2-MIB and geosmin.

Chlorine demand was made using amber glass bottles filled with the sample water and sufficient stock chorine to make the concentration of residual chlorine over 0.2 mg/L after 48 h. The solution was stored in the incubator at constant temperature of 25 °C for 2 days. Residual chlorine was measured on the first and the second day. Residual chlorine concentrations were measured by a colorimeter (Hach Co.).

Results and discussion

Taste and odour in the Han River

The most common T&O problem (musty and earthy T&O) was caused by the microbial metabolites such as 2-MIB and geosmin in the Han River. Figure 2 shows the changes in 2-MIB and geosmin concentrations in the raw water with changing temperature for a year (from August 2003 to May 2005). The concentration of 2-MIB was relatively high

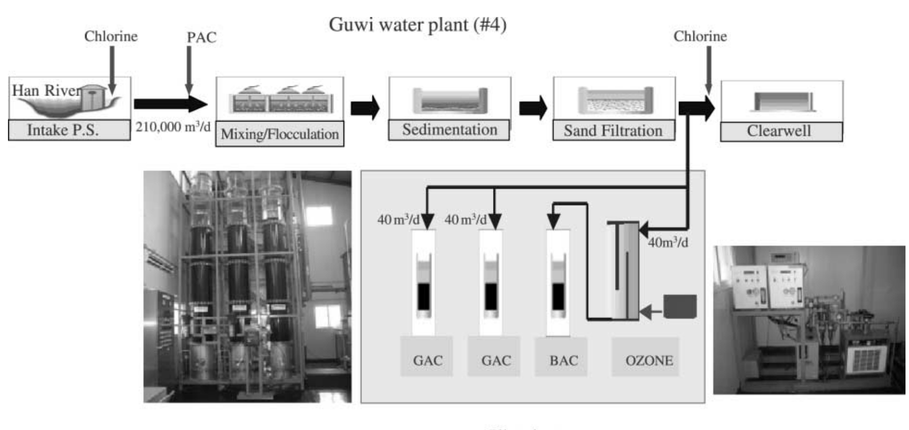

Figure 1 Schematic of pilot plant

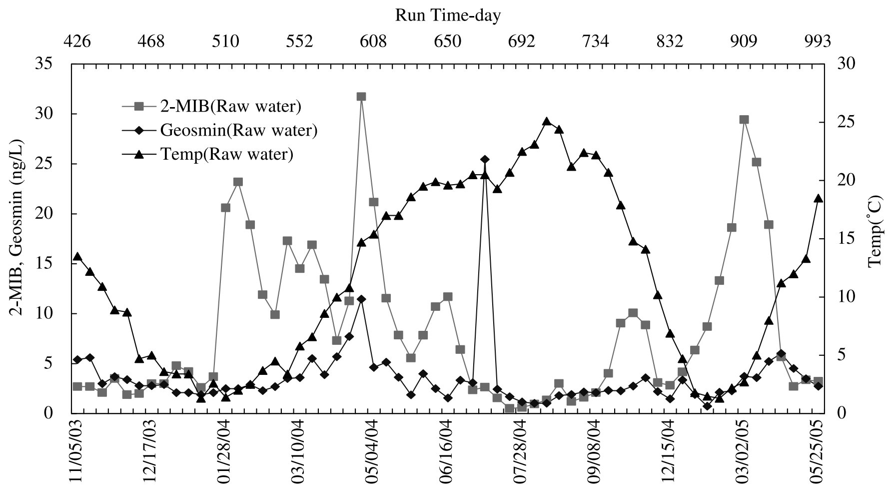

Figure 2 2-MIB and geosmin concentrations in the raw water with water temperature

between February and June while that of geosmin peaked in July for a relatively short period. The peak concentration of 2-MIB in the raw water was 32 ng/L and that of geosmin was 27 ng/L. Even with a PAC dosage of 3–8 mg/L, removal efficiency was very low (10–15%). The concentrations of T&O compounds in the finished water were over their sensory threshold concentration of 10 ng/L for over 200 days.

Although the peak concentration was low, the period of T&O outbreak in the Han River was relatively long. Hence, it is recommended to use GAC or ozone to treat long-term T&O episodes than to use PAC, although PAC is more economical for treatments of brief episodes. The standard in Japan for drinking water quality for 2-MIB and geosmin was revised in 2003, and enforced to the level of 10 ng/L in 2004. Individual T&O compounds have not yet been regulated in Korea. The Korean government has only started to make water quality standards for 2-MIB and geosmin recently.

Removal of 2-MIB and geosmin by GAC and BAC

When the concentrations of 2-MIB and geosmin were over 10 ng/L in the raw water, the removal efficiency and concentrations of 2-MIB and geosmin with the conventional unit processes and GAC, and post-ozone/BAC are listed in Table 1. Even with PAC dosage of 3–8 mg/L, removal efficiency was very low. As the GAC column has been operated for 3 years, GAC media was exhausted and could not remove total organic carbon (TOC) efficiently. Adsorption and desorption occur at the same time in order to reach an equilibrium state in GAC media. When GAC was exposed to a higher 2-MIB concentration, 2-MIB at the subsequent lower concentration was not removed with the same efficiency because 2-MIB adsorbed is then desorbed and redistributed in the water (Thomas *et al.*, 1999). Due to the chemical structures of 2-MIB and geosmin, they are biodegradable (Robert *et al.*, 2000). As 2-MIB appears in low temperature water in the Han River, the condition does not seem to be favourable for removal of the T&O compounds.

As listed in Table 1, GAC was barely adequate for <10 ng/L at bed volume (total flow amount/GAC volume) of 50,000–60,000 m^3/m^3. After more than 80,000 m^3/m^3 of bed volume, long-term adsorption resulted in desorption of 2-MIB which was not decomposed biologically. After 3 years of operation, there was breakthrough over 10 ng/L (Figure 3).

Although the concentration of the influent 2-MIB decreased, that of the effluent 2-MIB through GAC did not decrease. This phenomenon was attributed to desorption of 2-MIB that was adsorbed on the GAC, when the influent concentration of 2-MIB was

Table 1 2-MIB concentration and percent removal by the process during the pilot plant operation

Date	Operating condition	GAC Bed Volume (m^3/m^3)	2-MIB, ng/L (% removal)				
			Raw water	Sand filter	GAC	Ozone	BAC
2/9/04	PAC 5 mg/L O_3 0.5 mg/L	49,728	19.0	16.6 (12.6)	8.5 (55.3)	8.7 (54.2)	3.3 (82.6)
2/13/04	PAC 7 mg/L O_3 1 mg/L	50,112	25.2	25.0 (0.8)	9.9 (60.7)	0.0 (100.0)	0.0 (100.0)
2/20/04	PAC 8 mg/L O_3 1 mg/L	50,784	19.1	11.6 (39.3)	7.8 (59.2)	0.0 (100.0)	1.7 (91.1)
2/26/04	PAC 8 mg/L O_3 0.5 mg/L	51,360	16.7	9.4 (43.7)	3.2 (80.8)	2.7 (83.8)	1.2 (92.8)
3/16/04	PAC 8 mg/L O_3 0.5 mg/L	53,280	17.3	11.4 (34.1)	3.1 (82.1)	3.3 (80.9)	1.4 (91.9)
4/21/04	PAC 8 mg/L O_3 0.5 mg/L	56,640	31.6	22.8 (27.8)	8.5 (73.1)	5.7 (82.0)	4.9 (84.5)
5/14/04	PAC 8 mg/L O_3 0.5 mg/L	58,848	7.2	6.4 (11.1)	4.1 (43.1)	2.2 (69.4)	1.9 (73.6)
5/25/04	PAC 5 mg/L O_3 1 mg/L	59,904	5.7	3.8 (33.3)	3.7 (35.1)	0.0 (100.0)	1.2 (78.9)
6/17/04	PAC 5 mg/L O_3 1 mg/L	62,016	12.0	10.0 (16.7)	2.4 (80.0)	0.0 (100.0)	0.0 (100.0)
1/26/05	PAC 5 mg/L O_3 1 mg/L	83,040	12.4	12.0 (3.2)	5.8 (53.2)	1.6 (87.1)	1.9 (84.7)
2/17/05	PAC 5 mg/L O_3 1 mg/L	85,056	23.5	23.0 (2.1)	15.4 (34.5)	4.7 (80.0)	9.7 (58.7)
3/3/05	PAC 8 mg/L O_3 1 mg/L	86,592	31.5	26.8 (14.9)	20.0 (36.5)	5.7 (81.9)	10.4 (67.0)
3/10/05	PAC 8 mg/L O_3 1 mg/L	87,264	30.3	27.5 (9.2)	19.4 (36.0)	5.1 (83.2)	10.1 (66.7)
3/17/05	PAC 8 mg/L O_3 1 mg/L	87,936	26.0	21.5 (17.3)	14.5 (44.2)	4.1 (84.2)	9.3 (64.2)
4/18/05	PAC 5 mg/L O_3 2 mg/L	90,912	19.4	15.1 (22.2)	11.2 (42.3)	0.0 (100.0)	3.6 (81.4)
4/28/05	PAC 5 mg/L O_3 2 mg/L	91,872	5.6	5.2 (7.1)	7.9 (−41.1)	0.0 (100.0)	2.9 (48.2)
5/13/05	PAC 5 mg/L O_3 1 mg/L	93,312	3.8	3.0 (21.1)	5.3 (−39.5)	1.0 (73.7)	2.2 (42.1)

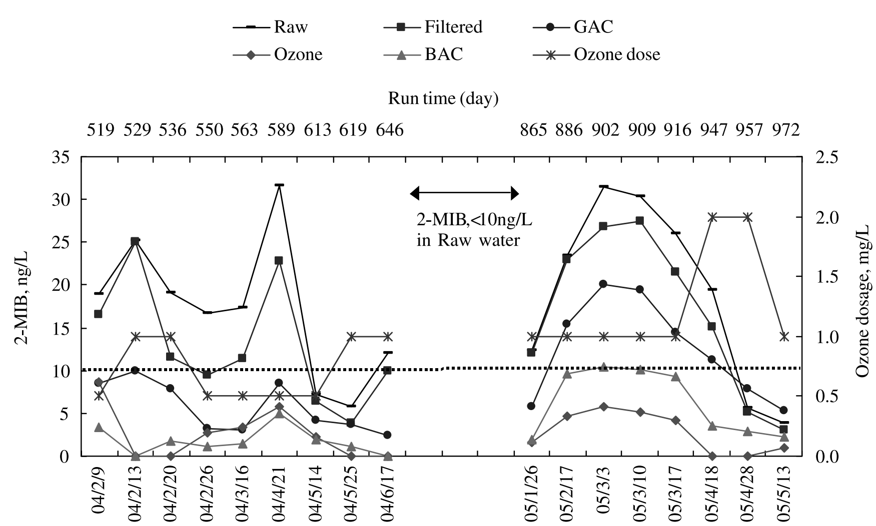

Figure 3 2-MIB concentration in each process during low temperature period

low. Ozonation could remove 2-MIB effectively rather than GAC alone during a low temperature period. It can be found that the removal efficiency of 2-MIB was increased when ozone dosage was increased. 2-MIB decreased in BAC during this period, attributed to oxidation by ozone rather than degradation by microbes in biofiltration process. Thus, in order to remove T&O compounds effectively with GAC, 2-MIB concentration of the influent should be lowered below 10 ng/L. The results emphasised the significance of ozonation in controlling T&O causing compounds.

Reduction of post-chlorine dosage

Ozone and GAC would be innovative processes to control residual chlorine concentration in a distribution system. Because NOM is effectively removed in the water treatment process with ozone and GAC, chlorine concentrations for disinfection can be lowered. Moreover, it can reduce chlorinous tastes and formation of DBPs in the tap water. According to the case of Osaka, Japan, chlorine consumption rates could be reduced by one half of conventional treatment processes by using an ozone/GAC process, and lower the residual free chlorine concentration to 0.21 mg/L (Fuchigami and Terashima, 2003).

The seasonal variation of chlorine demand (reaction time of 24 h) of the water from the pilot plant is illustrated in Figure 4. Average chlorine demands of sand filtrate, GAC effluent and BAC effluent were 0.7, 0.46 and 0.38 mg/L, respectively. Compared to the conventional treatment process, chlorine dosages of GAC and BAC processes were reduced by 34 and 46%, respectively. Chlorine decay rates are illustrated in Figure 5.

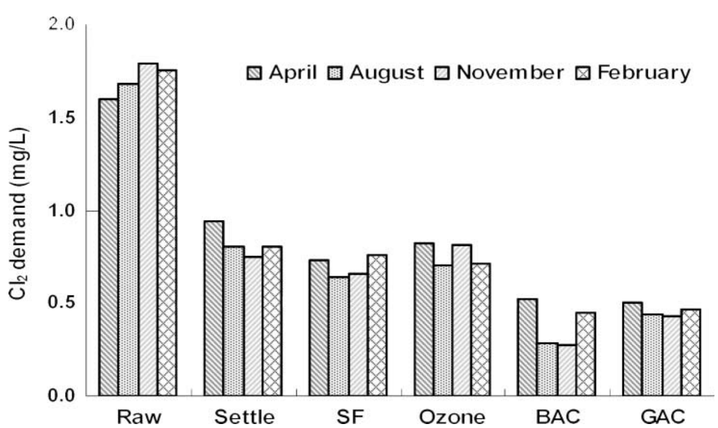

Figure 4 Chlorine demand on each process

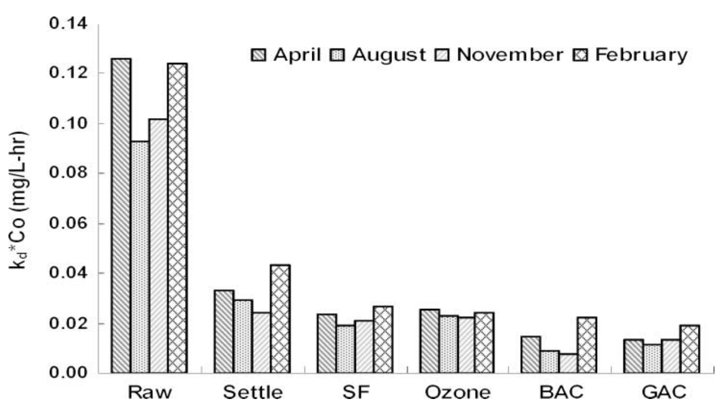

Figure 5 Chlorine decay rates on each process

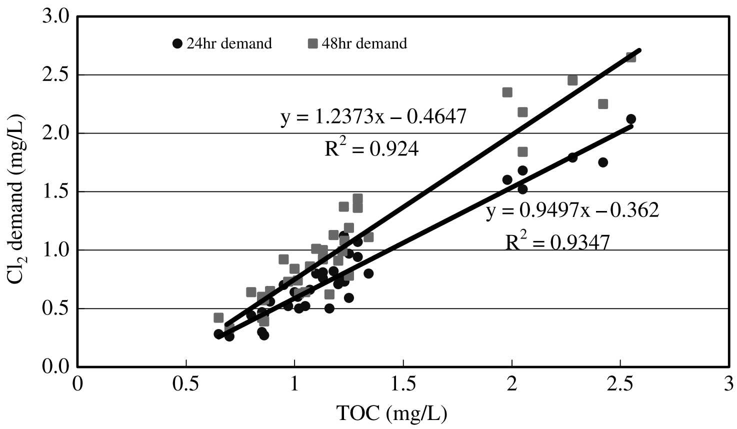

Figure 6 Chlorine demand versus TOC

The conventional treatment followed by GAC or BAC could reduce the chlorine decay rates by 1.6 and 1.7 times. As shown in Figure 6, chlorine demands had an apparently strong relationship with TOC concentration in the treated water. One of the most efficient ways to minimise chlorinous tastes and odours in drinking water would be by removing TOC in the treated water as much as possible prior to disinfection with chlorine.

Conclusions

Although the peak concentration was relatively low (i.e. 32 ng/L for 2-MIB, 27 ng/L for geosmin), the length of a 2-MIB outbreak in the Han River was relatively long. It was not possible to lower the 2-MIB concentration below the threshold value (10 ng/L) by conventional water treatment processes including chlorination and PAC dosing of 3–8 mg/L.

When the concentration of 2-MIB in the influent was high during the low temperature period, it was difficult to maintain the concentration of 2-MIB within the reasonable level (< 10 ng/L) with the GAC process. The BAC process could remove the T&O compounds effectively. However, it was necessary to reduce the influent concentration below 10 ng/L by controlling ozone dosage in the BAC process during the low temperature period.

Compared to the conventional treatment process, chlorine dosage as a final disinfectant could be reduced by 34% after the GAC process and 46% after the BAC process.

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