Demonstration of new sensory methods for drinking water taste-and-odor control

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Abstract In order to demonstrate the practicality of two newly developed taste-and-odor methods, raw and filtered water samples from the Songchon water treatment plant, and tap water samples from houses were analyzed from July to October 2000 using three sensory methods (TON, 2-out-of-5 odor test and attribute difference test for the presence or absence of geosmin) and one instrumental method (closed-loop stripping analysis, CLSA, followed by gas chromatography, GC). Comparison of TON values with CLSA indicated a discernible relationship only when the odorant level was relatively high. The two newly developed methods, however, were more sensitive than TON when the odor intensity of samples was low. The attribute rating test for geosmin is more sensitive than the 2-out-of-5 odor test when the TON value is less than 10. These new methods seem better than current methods for identifying the occurrence of odor compounds in raw and filtered waters. They also have practical use in tracking the efficiency of treatment methods, such as adsorption and oxidation, used for controlling taste-and-odor episodes.

Keywords 2-methylisoborneol (2-MIB); 2-out-of-5 odor test; attribute rating test for geosmin ($ART_{geosmin}$); closed-loop stripping analysis (CLSA); geosmin; threshold odor number (TON)

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Introduction

Taste-and-odor (T&O) problems in water can be caused by naturally occurring algal and bacterial metabolites or by the introduction of chemicals through human intervention (Suffet *et al*., 1995). For many decades, one focus of the water industry has been the identification and control of unwanted T&O in drinking water. The number one reason for customer complaints about water quality has been unpleasant sensory characteristics of the water. Although the water industry currently has two standardized T&O methods: threshold odor number (TON) and flavor profile analysis (FPA) (*Standard Methods for Water and Wastewater*, 1998), neither of these methods completely fulfils the needs of the industry (Mallevialle and Suffet, 1987). For years, the TON evaluation has been the industry standard although it measures odor without requiring that the odor be qualitatively described. Also, TON does not provide sufficient useful information. On the other hand, while FPA provides extensive information about the sensory aspects of a sample of water it is too time-consuming and complicated to be readily implemented by many smaller utilities (Krasner *et al*., 1985). The water utility industry has been slow to accept the FPA procedure, and despite its shortcomings, the TON evaluation or some variant thereof, continues to be used by operators at many treatment plants.

Researchers funded by the American Water Works Association Research Foundation (AWWARF) is completing a three-year project to develop more practical methods for the odor evaluation of drinking water, and to create a step-by-step program of T&O identification to guide water utility personnel (Dietrich *et al*., 2001). These methods were adapted from well used methods in sensory science and food quality control. In this context, three sensory methods and one instrumental method were used at a water treatment plant (WTP) in Korea to demonstrate two of the new odor methods proposed by the AWWARF research team.

Materials and methods

The Songchon WTP (capacity of 300,000 m^3/d) takes raw water from the Daechung Reservoir, and was used as the target facility for the odor study. The Daechung Reservoir is the largest one in its watershed with a storage capacity of 1.49×10^9 m^3 and a maximum depth of 55 m. Since the 1990s the reservoir has been the source of seasonal algae-related odor problems due to eutrophication. In order to cope with its T&O problem, the Songchon WTP has been adding powdered activated carbon (PAC) intermittently into the rapid mixing basin.

From July to October 2000, raw and filtered water samples from the Songchon WTP, and tap water samples from houses were analyzed using three sensory methods – TON, 2-out-of-5 odor test, and attribute rating test for geosmin ($ART_{geosmin}$) – and one instrumental method – closed-loop stripping analysis (CLSA) followed by gas chromatography (GC) (*Standard Methods for Water and Wastewater*, 1998). The TON method was performed in accordance with proposed Method 2150B (*Standard Methods for Water and Wastewater*, 1998). The two newly developed T&O methods were performed in accordance with their standard operation procedure (SOP) developed by the AWWARF research team (Dietrich *et al.*, 2001). CLSA (BrechbÜhler AG) followed by GC (M600D, Younglin) were performed in accordance with Method 6040B (*Standard Methods for Water and Wastewater*, 1998). The new T&O methods were compared with the more traditional TON method. During the sampling period, raw and filtered water samples from the Songchon WTP were also sent to the Philadelphia Suburban Water Company (PSWC), USA, for quality control feedback on CLSA instrumental analysis.

The 2-out-of-5 odor test is a two-step method designed to determine if the odors of any two water samples are noticeably different. Two flasks containing the test water and three flasks containing the control water are labeled by placing stickers face down on the outside bottom. A volume of 200 mL is placed in a 500 mL container with a top, and then the samples are heated to 45°C. After heating, the five flasks are placed on a Lazy Susan in a random order and given a whirl. In the first step, the analyst then is required to sort the five flasks into two groups in 5 minutes or less; this is a "forced-choice" method. If the flasks are sorted correctly, it is likely that the two water samples are different because the chance of guessing the correct grouping is only 1 in 10. When the sample odor qualities differ, the differences can be described as much weaker, slightly weaker, same, slightly stronger, or much stronger. The sample odor is rated as "1" (the test water has a much weaker odor than the control water), "1.5" (the test water has a slightly weaker odor than the control water), "2" (the test water has the same level of odor as the control water), "2.5" (the test water has a slightly stronger odor than the control water), or "3" (the test water has a much stronger odor than the control water). However, in tests of this work where sample water was compared to distilled water, odor differences could only be described as "3" (the test water has a much stronger odor than the distilled water), "2" (the test water has a slightly higher level of odor than the distilled water), and "1" (the test water has the same odor as the distilled water).

The $ART_{geosmin}$ is a method for rating the intensity of geosmin by using a "paired-comparison" format to compare the odors of a test sample and a standard solution containing 15 ng/L geosmin. The odor is evaluated at 45°C; a 200 mL sample volume is placed in a 500 mL container with a top. The sample is sniffed and its odor is rated as "0" (odor not detected), "1" (less than the odor of the 15 ng/L geosmin standard), "2" (equal to the standard), or "3" (greater than the odor of the 15 ng/L geosmin standard). This test can be adapted for use with other odorants like 2-MIB, nonadienal, etc.

Raw water spiked with geosmin was used in a PAC adsorption test to evaluate the usefulness of the new sensory methods for setting the PAC dosage during T&O treatment. The PAC adsorption test was conducted using five 2 L bottles. The bottles were filled with 2 L of spiked water having a geosmin concentration of about 190 ng/L. Next, PAC was added to each bottle to produce a carbon dose of 10 or 20 mg/l. The bottles were placed in a shaking chamber at 20°C and 100 rpm. Samples were collected after 5, 10, 20, and 30 minutes of contact time. PAC was removed from the sample using 0.45 μm membrane filters prior to analysis of geosmin. The removal efficiency of geosmin was measured using the three sensory methods and one instrumental method. Finally the results from each method were compared to evaluate the practicality of the two odor methods.

Algal enumeration and identification was performed according to the Sedgwick–Rafter Counting Chamber Method after preservation in Lugol's solution, as described in Section 10200F (*Standard Methods for Water and Wastewater*, 1998).

Results and discussion

From July to October 2000, the regional Korean Environmental Protection Agency laboratory monitored algae in the surface water at several locations in the Daechung Reservoir. Table 1 shows population densities of algae in surface water at the water intake tower of the Songchon WTP. The population density of algae peaked in early August to about 914,000 cell/mL. A second peak (230,000 cell/mL) occurred in early October. TON alone did not detect a T&O problem but CLSA tests showed that geosmin and 2-MIB were present. During both T&O episodes, the dominant genera of blue-green algae were *Microcystis spp.*, *Anabaena spp.*, *Oscillatoria spp.*, and *Aphanizomenon spp.*

Figure 1 shows the variation in TON of raw and filtered water at the Songchon WTP. TON increased sharply after 1 July, but dropped below 10 in early August, probably due to a long heavy rain. The maximum TON value was about 40, which is a little less than the average calculated from past records. TON values of filtered water were less than five, because the Songchon WTP added PAC up to 10 mg/L on a daily basis. During October, the

Table 1 Population densities of algae in surface water at the water intake tower of the Songchon WTP (cells/mL)

Date	Blue-greens	Diatoms	Green Algae	Others	Total
3 July	2,947	0	0	0	2,947
10 July	119	0	0	0	119
18 July	22,631	31	187	65	22,914
24 July	49,713	359	128	391	50,591
31 July	776,563	33	78	1	776,675
8th August	913,737	0	634	6	914,377
14 August	8,750	0	410	219	9,379
17 August	10,011	187	419	165	10,782
21 August	14,021	76	591	215	14,903
28 August	26,782	173	1,132	278	28,365
4 Sept.	24,419	437	1,173	1,133	27,116
9 Sept.	463	0	0	0	463
18 Sept.	496	3,553	591	309	4,949
25 Sept.	37,063	615	266	144	38,088
2 Oct.	1,295	2,854	188	144	4,700
9 Oct.	230,440	714	225	47	231,426
16 Oct.	98,312	475	85	44	98,916
23 Oct.	74,970	209	53	22	75,254

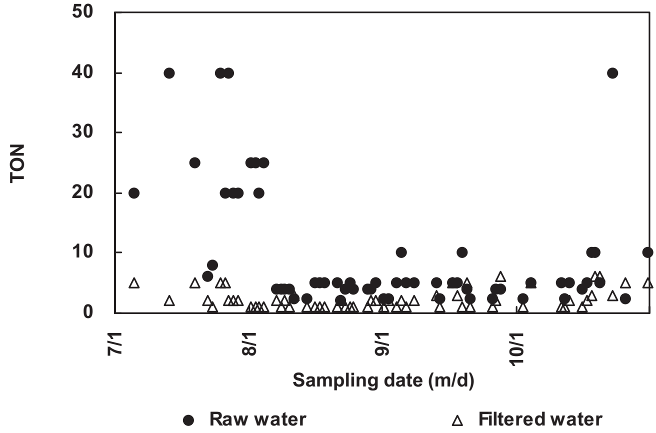

Figure 1 Variation of TON in raw and filtered water of the Songchon WTP

raw water had a relatively high TON, but the odor problem during this period seemed different from that in July.

Figure 2 shows the concentrations of geosmin and 2-methylisoborneol 2-MIB). Analysis of raw water using CLSA+GC showed that geosmin, at a maximum above 40 ng/L, was the dominant of these two odor compounds before the rainy season (from July to early August). Later, 2-MIB became dominant with a maximum concentration of 30 ng/L. Comparison of the TON values in Figure 1 with data from the CLSA analysis (Figure 2) indicates a discernible relationship when the odor intensity was relatively high. Low odorant concentrations were not well correlated with TON.

The data obtained from the 2-out-of-5 odor test for raw and filtered water, are depicted in Figure 3, together with the TON value of each sample. In each 2-out-of-5 odor test, the raw and filtered water samples were compared to distilled water. Results were then converted to average intensities. When the TON value was higher than 10, the result of the 2-out-of-5 odor test was intensity 3. It was found that such samples had a much stronger earthy odor than the distilled water. When the TON value was about 5, the 2-out-of-5 odor test result was intensity 2 or 1. These results were more sensitive and appropriate for the presence of earthy odor than TON when the odor intensity of samples was low.

Figure 4 depicts the results of the $ART_{geosmin}$ in raw and filtered water, together with the TON value of each sample. Each sample of raw or filtered water was compared to a 15 ng/L geosmin standard. The results of the $ART_{geosmin}$ were converted to average intensity. When the TON value was higher than 10, the result of the $ART_{geosmin}$ was intensity 3. It seems that the new method was not sensitive enough when the TON value was higher than 10, but the new T&O method was more sensitive than TON when the odor intensity of samples was low.

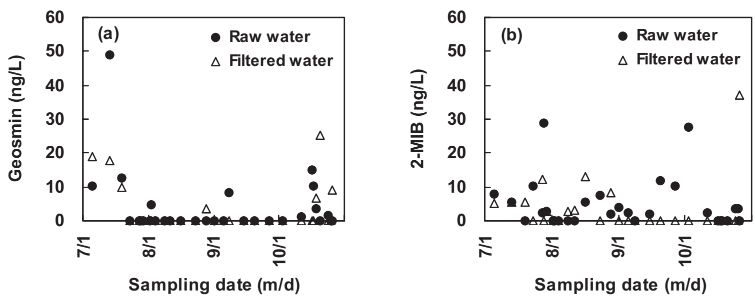

Figure 2 Variations of: (a) geosmin and (b) 2-MIB in raw and filtered water of the Songchon WTP

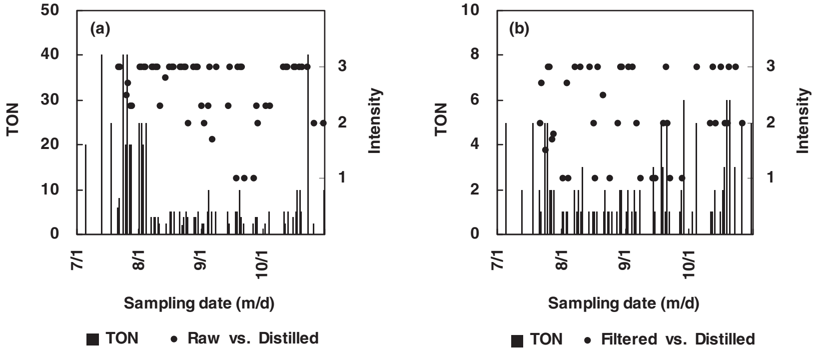

Figure 3 Results of the TON values and intensities of the 2-out-of-5 odor test in: (a) raw water, and (b) filtered water from Songchon WTP (distilled water standard)

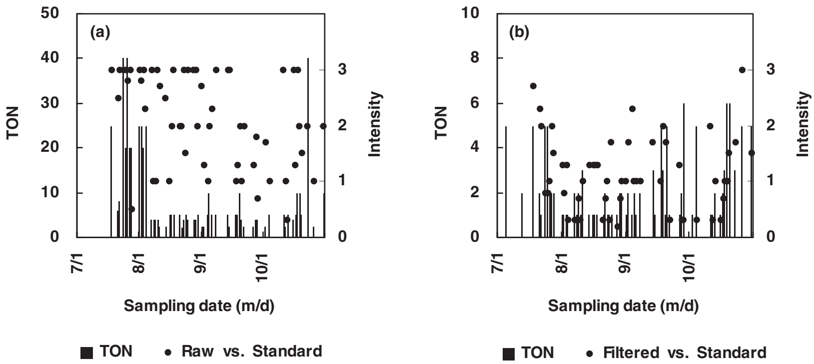

Figure 4 Results of the TON values and intensities of the $ART_{geosmin}$ in: (a) raw water, and (b) filtered water of Songchon WTP (15 ng/L geosmin standard)

The 2-out-of-5 odor test and the $ART_{geosmin}$, both expressed as averaged intensities, were compared with the more traditional TON method in Figure 5. The two newly developed methods seemed to be more sensitive and appropriate than TON when the odor intensity of samples was low. It seemed that the $ART_{geosmin}$ was more sensitive than the 2-out-of-5 odor test when the TON value was less than 10.

Figure 6 shows the results of a PAC adsorption kinetic test for geosmin spiked into raw water from the Songchon WTP. For an initial geosmin concentration of 190 ng/L, 10 or 20 mg/L of PAC was added. Most of the geosmin, which could be removed by PAC at the given dosage, was removed within 5 minutes of contact time. The removal rate of geosmin increased with the dose of PAC and contact time. The extent of adsorption expressed as TON values showed a trend similar to the concentration of geosmin.

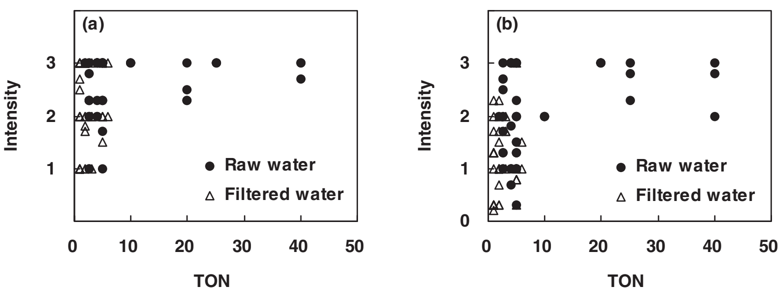

Figure 5 Comparisons of TON values with intensities of: (a) the 2-out-of-5 odor test, and (b) the $ART_{geosmin}$ in raw and filtered water of Songchon WTP

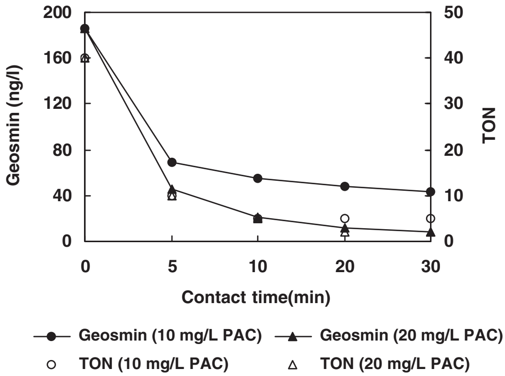

Figure 6 Variation of geosmin and TON with contact time and PAC dosage (10 and 20 mg/L) during the adsorption kinetic test

The results of the kinetic test, measured using the 2-out-of-5 odor test and the $ART_{geosmin}$, are shown in Figure 7, together with the concentration of geosmin. The water treated with PAC was tested against the untreated raw water and a 15 ng/L geosmin standard, respectively. The reason why the untreated raw water was used as a blank in the 2-out-of-5 odor test was to estimate the extent of geosmin removed by PAC. The results of the 2-out-of-5 odor test, expressed as average intensity, were very similar to the concentration of geosmin. The $ART_{geosmin}$ method seems to have decisive limitation when the samples have high odor intensity, that is, more than 15 ng/L as shown in Figure 7b.

Conclusions

Comparison of TON values with CLSA indicated a discernible relationship only when the odorant level was relatively high. Low odorant levels were not well tracked by TON. The two newly developed odor methods, however, were more sensitive and appropriate than TON when the odor intensity of the sample was low. The $ART_{geosmin}$ is more sensitive than 2-out-of-5 odor test when the TON value is less than 10. These new methods seem better than current methods for identifying the behavior of T&O compounds in raw and filtered waters. While FPA can accomplish all of the requirements for these tests, it has a much higher setup and operating costs. They also have practical use in tracking the efficiency of treatment, such as adsorption and oxidation, for controlling T&O episodes. Further development of these methods into standardized methods should facilitate better T&O control among water utilities worldwide.

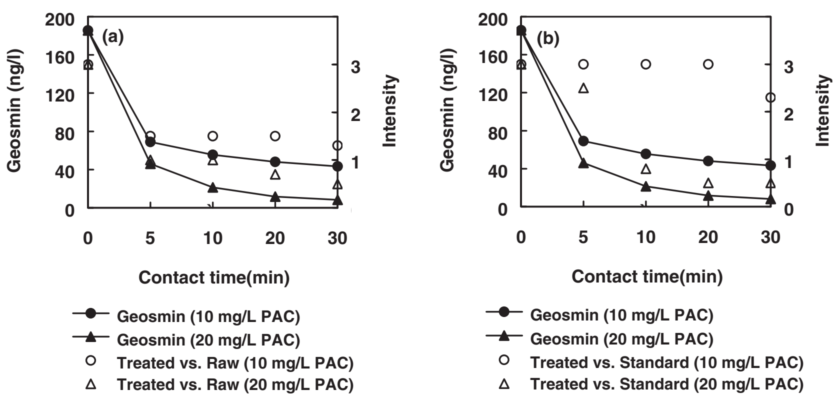

Figure 7 Variation of geosmin concentration by CLSA and the results of: (a) the 2-out-of-5 odor test, and (b) the $ART_{geosmin}$ with contact time and PAC dosages (10 and 20 mg/L) during the adsorption kinetic test. Solid symbols are CLSA data and open symbols are intensity data

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References

Dietrich, A.M., Burlingame, G.A., Hoehn, R.C., Gittelman, T., Hiltebrand, D., Johnson, M., Khiari, D., Waer, M., Whelton, A.J. and Worley, J. (2001). WQTC Sunday Seminar: New practical methods for sensory analysis in drinking water: beyond threshold odor number (TON) and flavor profile analysis (FPA). *American Water Works Association Water Quality Technology Conference*, 11 November, Nashville, TN, USA.

Krasner, S.W., McGuire, M.J. and Ferguson, V.B. (1985). Taste and odors: the flavor profile method. *JAWWA*, **77**(3), 50–55.

Mallevialle, J. and Suffet, I.H. (1987). *Identification and Treatment of Tastes and Odors in Drinking Water*. Report of American Water Works Association Research Foundation.

Standard Methods for the Examination of Water and Wastewater (1998). 20th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Suffet, I.H., Mallevialle, J. and Kawczynski, E. (1995). *Advances in Taste and Odor Treatment and Control*. Report of American Water Works Association Research Foundation.