Pergamon

Wat. Sci. Tech. Vol. 40, No. 6, pp. 39–44, 1999

0273–1223/99 $20.00 + 0.00

PII: S0273-1223(99)00535-1

BENCH-SCALE EVALUATION OF ADSORPTIVE PROCESSES FOR TASTE AND ODORS CONTROL USING RAPID SMALL-SCALE COLUMN TESTS AND FLAVOR PROFILE ANALYSIS

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ABSTRACT

The City of Appleton, Wisconsin operates an 800 l/s Drinking Water Treatment Plant (WTP). Lake Winnebago serves as the source water which experiences algae blooms that are typically accompanied by severe taste and odor (T&O) episodes. Historically, raw water quality in the summer months prevents the full capacity from being achieved despite the use of potassium permanganate, powdered activated carbon (PAC) and granular activated carbon (GAC) filters. Thus, the City proceeded with a study of various treatment processes to mitigate the T&O problems experienced during the summer months. The relatively short duration of T&O episodes and extensive experimental plan necessitated a bench-scale testing for rapid evaluation of various oxidation and adsorptive processes.

This paper presents a review of the effect of carbon type, dosage, contact time, and application point on the performance of PAC in controlling odors. In addition, the effect of GAC type and empty bed contact time (EBCT) on removal of T&O compounds were evaluated using a rapid small scale column test (RSSCT).

KEYWORDS

Activated carbon; flavor profile analysis; cyclocitral; geosmin.

INTRODUCTION

The Appleton WTP has a capacity of 800 l/s and uses a lime softening process for hardness removal and clarification. The water supply for the Appleton WTP is Lake Winnebago which has a length of approximately 48 km and a maximum width of approximately 17 km. The average depth of the lake is 4.7 m with a maximum depth of 6.4 m. The average theoretical detention time in the lake is estimated to be approximately 9 months. The water supply has been characterized as moderately hard with a pH ranging from 7.8 to a maximum of 9.3 during the algae blooms. Algae counts are typically greater than 10,000 area standard units during the algae bloom. The total organic carbon (TOC) concentration of the raw water ranged from 5.5 mg/l to 15. 7 mg/l during the course of the study.

One of the most troublesome seasonal treatment issues at the Appleton WTP is control of algae and related tastes and odors (T&O). The typical raw water Threshold Odor Number (TON) levels in Lake Winnebago range from 12-15 TON in the winter to 30 TON in the summer. With late summer algae blooms the raw water odor level can rise to 100-250 TON within a short period of time. The Appleton WTP uses potassium permanganate, powdered activated carbon, and granular activated carbon (GAC) filters for the control of T&O. Despite these efforts, periods of poor water quality in the summer often limit the treatment capacity of the WTP, due to odors in the finished water.

Within the context of planning for a new WTP, alternative treatment processes were evaluated during the worst case water quality conditions in the fall. Both adsorptive treatment technologies and oxidation were tested for the control of T&O compounds. This paper focuses on the use of adsorptive treatment technologies including an investigation on the effect of carbon material, contact time, and application point in the treatment process on the performance of PAC. In addition, the effect of carbon type and empty bed contact time (EBCT) on the performance of the GAC filtration process was evaluated.

METHODS

The investigation of PAC and GAC was performed at the bench-scale level because of the relatively short duration of the T&O episode and extensive experimental plan of the study. Evaluation of PAC application at various locations in the treatment process was performed using a standard jar test unit in accordance with Kawamura (1991). Three types of commercially available PAC were used for this testing including a lignite, bituminous, and wood based carbon.

Evaluation of three types of GAC at two EBCT were performed using a rapid small scale column test (RSSCT) in accordance with Summers *et al.* (1992). The carbon types used in this testing included bituminous, lignite, and wood based granular carbons. The RSSCT tests experimental design used proportional diffusivity and a 9.42-scaling factor. RSSCT testing was performed for a total of 70 days corresponding to a full-scale operation of 21 months. Softened and recarbonated water from the Appleton WTP was used as feed water for the RSSCT testing.

The flavor profile analysis (FPA) was performed by a trained panel that described each odor as a specific flavor with a numeric value for intensity. The scale and odor intensity used is as follows: (1) Threshold; (2) Very Weak; (6) Moderate Weak; (10) Moderate Strong; (12) Strong. FPA was used in this study as a method to describe the overall odor qualities of a sample. FPA analysis was performed in accordance with proposed Method 2170, Standard Methods for Water and Wastewater, 19th Edition.

Closed loop stripping analysis (CLSA) was used for isolating volatile compounds of intermediate molecular weight from a sample. CLSA was always accompanied by FPA to provide correlation between odor descriptors and specific compounds concentration. CLSA was performed in accordance with Method 6040, Standard Methods for Water and Wastewater, 19th Edition. Steam distillation extraction (SDE) was selected to complement the CLSA technique by extracting organoleptic compounds of greater polarity and higher molecular weight than those extracted by CLSA. SDE was performed as described by Suffet *et al.* (1995).

RESULTS AND DISCUSSION

The raw water supply odor was characterized by several prominent categories of odor descriptors including: earth/musty, algae/pondy, and swampy/decaying vegetation. Individually, the odor descriptors were not reported at strong intensities, however, the combinations of multiple objectionable odor descriptors resulted in a very complex and highly objectionable odor. Results from CLSA and SDE analysis are presented in Table 1 along with a tentative association with an odor description.

Raw water data indicate that the predominant odor characteristic in the raw water was earth/musty. Surprisingly, methylisoborneol (MIB), the compound most often associated with earth/musty odors, as never identified during the study. Cyclocitral was the predominant organic compound identified using both CLSA and SDE with concentrations exceeding 300 mg/l in some raw water samples.

Table 1. Prominent odor compounds common to Lake Winnebago raw water samples[a]

Extracted From CLSA and SDE	Tentative Odor
Benzaldehyde	Sweet
Benzeneacetaldehyde	Flowery
3,5-Dimethyl cyclohexanol	Algae/Pondy
Cyclocitral	Hay/Woody
Geosmin	Earthly
1,1-Dimethoxy trans-9-octadecene	Decaying Vegetation
2-Methyl-8-propyl dodecane	Medicinal

[a] Sampling period: 9/95 to 11/95.

The effect of dose on the predominant odor descriptor, earthy/musty, for the three PAC types was tested using raw water at a contact time of 60 minutes. This contact time represents the Hydraulic Residence Time (HRT) of the raw water main between the intake and the new WTP site at design capacity. As illustrated in Figure 1, a PAC dose of 25 mg/l was effective at removing earthy/musty odors below the threshold level regardless of the carbon type. Bituminous based PAC appeared to outperform the other two carbons at lower dosages. Figure 2 presents the effect of the three carbon types in removing several odor descriptors. Data indicate that the wood based PAC achieved an equal removal of all the descriptors at 25 mg/l. A dose of 50 mg/l of the lignite based PAC was required to remove all of odor descriptors below threshold levels. The application of bituminous PAC removed all of the odor descriptors only at dosages as high as 100 mg/l.

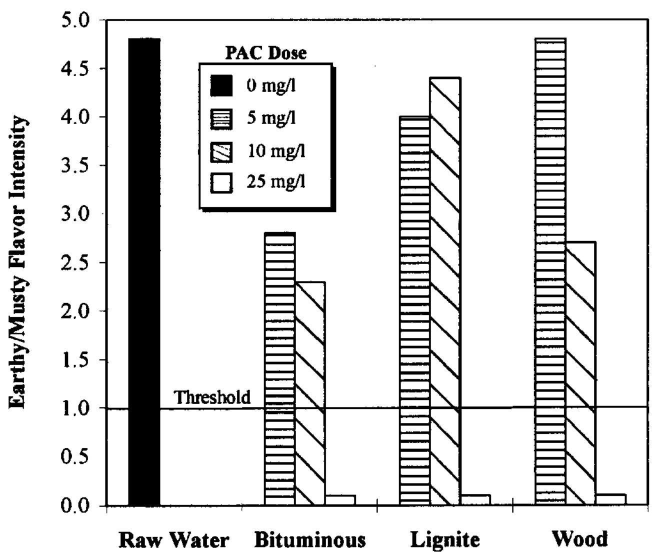

Figure 1. Effect of carbon type and dose on controlling earth/musty odors.

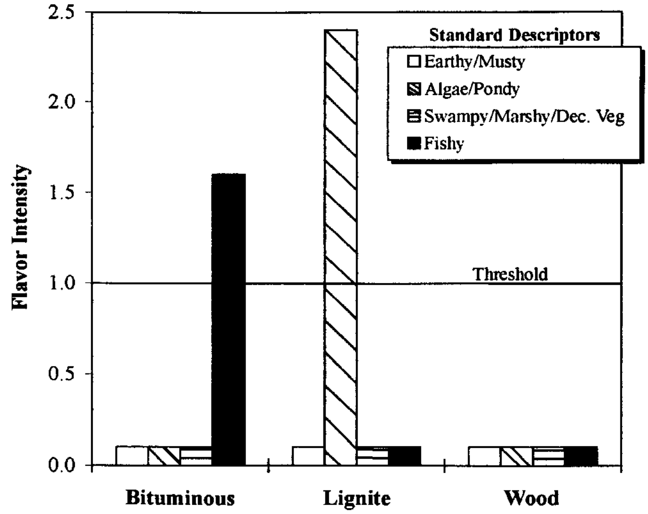

Figure 2. Effect of carbon type on odor control (PAC concentration of 25 mg/l).

In summary, it appeared that the wood based PAC was a more effective tool to address T&O removal in the raw water. Two factors may have promoted this phenomenon. First of all, Lake Winnebago is heavily concentrated in humic and fulvic material that reduces the adsorption capacity of activated carbons (Sontheimer *et al.*, 1988). Thus the carbon exhibiting the most affinity for Natural Organic Matter (NOM) will be first saturated. Second, the testing conditions did not allow adsorption equilibrium to be reached. This approach matching practical operation conditions favored the PAC exhibiting fast kinetics over the PAC exhibiting high adsorption capacity (Lalezary *et al.*, 1988). Wood based PAC mostly differ from fossil carbon based PAC, by pore size distribution (Sontheimer *et al.*, 1988). In addition to better performance observed in this case, wood-based PAC are significantly cheaper than others, thus resulting in the best choice for addressing T&O at Appleton.

The effect of contact time and application point in the treatment process was also evaluated. Data indicate that application of PAC requires a minimum of 30-minute contact time to reduce odor descriptor intensity values below the threshold value. The kinetics of this adsorption process appeared to be independent of application point, either upstream (raw water) or downstream of the softening process. However, the application of PAC to the softened water reduced the required PAC dose from 25 mg/l to 10 mg/l. Sequencing testing with potassium permanganate indicated that the concurrent application of PAC and potassium permanganate with a 60-minute contact prior to the softening process provided the best treatment alternative. The 60-minute contact time represented the theoretical contact time available in the raw water piping at nominal flow. These findings are somewhat surprising because of the potential oxidation by potassium permanganate of the PAC.

As illustrated in Figures 3 and 4, none of the RSSCT conducted with bituminous GAC at a 5-minute or 15 minute EBCT produced odor-free water at any point during the 10 weeks of testing. Because of the fluctuation in softened water odor characteristics during the course of the study, it was difficult to compare column results based on removal of target compounds such as geosmin or cyclocitral. No defined trend was seen for odor breakthrough with the 10-week testing period for all three types of GAC. Instead, a steady odor level was observed in the carbon columns effluent, thus showing that GAC should be only one of several T&O removal processes. Under this operation strategy, this would translate to a bed life in excess of 21 months which is consistent with the Appleton WTP's full-scale bed life of approximately 18 months. It should be noted that the 15-minute EBCT consistently produced better water with less complex odors than the columns operated at a 5-minute EBCT.

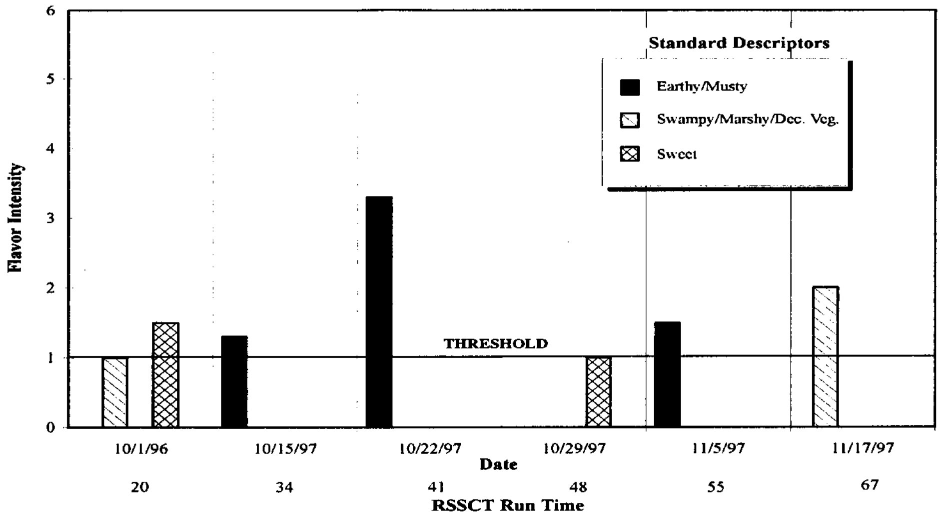

Figure 3. Bituminous GAC at 5 min EBCT RSSCT Column Effluent FPA.

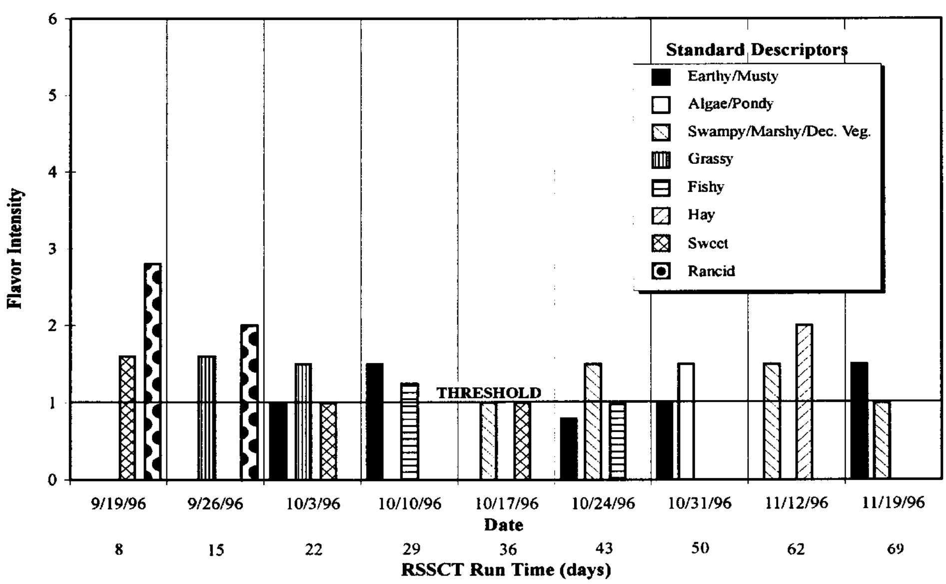

Figure 4. Bituminous GAC at 15 min EBCT RSSCT Column Effluent FPA.

TOC data on RSSCT effluent indicate an almost instantaneous breakthrough of TOC through both the 5 and 15-minute EBCT columns. From this observation it can be concluded that length (or time) of the mass transfer zone was longer than the RSSCT bed depth. This may be due to the relatively high pH of the recarbonated water (pH=9.3). All three of the carbon types yielded equivalent results in TOC removal. After the equivalent of 21 months of full-scale operation the GAC columns were removing less than 20 percent of the feed water TOC. These results are consistent with TOC profiles of the full-scale plant which show a 15 percent TOC removal across the GAC filters.

CONCLUSION

The use of bench-scale testing techniques allowed us to evaluate the performance of various adsorption processes during a short T&O episode. Several of the findings from the bench-scale testing were confirmed by observations of the full-scale facility.

Data indicate that a wood-based carbon provides superior treatment for the removal of several odor descriptors when compared with bituminous and lignite-based carbons. This conclusion applied to both PAC and GAC systems. However, this analysis should be expanded further to include economic factors. The modified or new treatment facility may not rely only on GAC filters for dealing with problems and should include PAC and possibly potassium permanganate addition.

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