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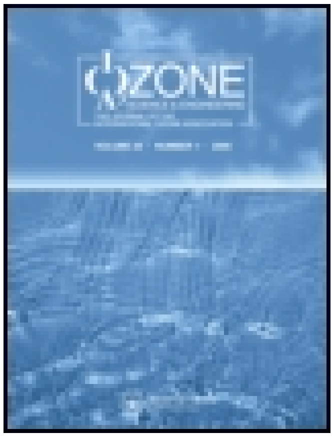

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Use of Ozone for Disinfection and Taste and Odor Control at Proposed Membrane Facility

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Use of Ozone for Disinfection and Taste and Odor Control at Proposed Membrane Facility

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Zone 7 of Alameda County Flood Control and Water Conservation District, in coordination with Black & Veatch, conducted a 9-month pilot study to determine preliminary design parameters for a new water treatment plant (WTP). The pilot study was performed to verify the performance of membrane filters and to establish preliminary design parameters for the submerged membrane process, followed by ozonation and biological granular activated carbon filtration. The pilot testing was conducted using water from the Patterson Pass WTP reservoir. The process included coagulation with either ferric chloride or polyaluminum chloride, flocculation, sedimentation, membrane filtration, ozonation, and filtration using biological granular activated carbon (BAC). The goals of the study were as follows:

1. *Determine the potential effectiveness of ozone and BAC for removing geosmin and MIB.*
2. *Determine the impacts of different levels of pathogen inactivation, i.e., 0.5-log Giardia and 2-log virus inactivation.*
3. *Monitor the formation of bromate under various conditions of ozone oxidation for different levels of pathogen inactivation as well as for taste and odor control, and evaluate bromate mitigation strategies, if necessary.*

The results of the study showed that the use of ozone achieved 2.0-log virus inactivation and 0.5-log Giardia inactivation. It also decreased the disinfection by-product formation and effectively controlled geosmin and removed a significant fraction of the MIB during a taste and odor event. Because the raw water bromide concentrations were low, bromate formation remained below the regulated level of 0.010 mg/L. However, in one instance, bromate mitigation was utilized by applying sulfuric acid to lower the pH to less than 7.1, which reduced bromate formation to less than 0.010 mg/L.

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INTRODUCTION

Zone 7 of Alameda County Flood Control and Water Conservation District plans to build a 24 mgd water treatment plant, to be named the Altamont WTP, which will treat water conveyed through the South Bay Aqueduct (SBA) from the Delta in northern California and from the future Dyer Reservoir (which will be supplied through the SBA).

After evaluation of treatment alternatives, an advanced strategy consisting of coagulation, direct low-pressure membrane filtration, and ozonation followed by biologically active carbon filters was selected. Although this treatment strategy consisted of proven technologies, it required pilot testing to develop a reliable basis of design.

The pilot study included evaluation of the reliability and feasibility of using low-pressure membranes as a filtration barrier for the AWTP, and determination of the need for pre- and post-treatment to meet the District's water quality goals. One treatment scheme included ozonation followed by filtration through biologically active filters (BAC). The purpose of the study was to evaluate the effectiveness of the combination of ozone and BAC in removing geosmin and MIB and the impacts of different levels of pathogen inactivation on bromate formation.

PILOT PLANT DESCRIPTION

The pilot-plant process includes direct filtration through the submerged ultrafiltration membrane units operated at

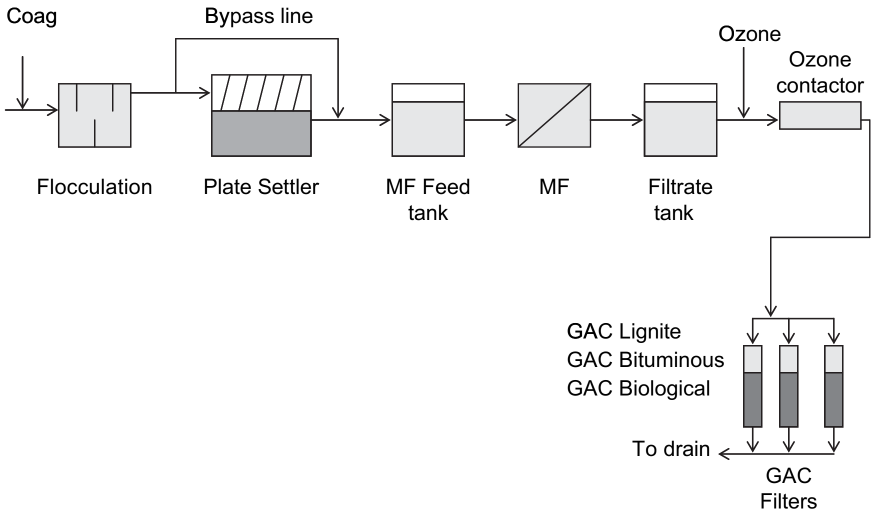

FIGURE 1. Pilot-plant flow diagram.

a flux rate of 38 to 55 gpd. A 20 to 30 mg/L dose of polyaluminum chloride was added to the raw water before three stage flocculation. Following filtration, the water was ozonated by sidestream injection using a Pacific Ozone generator on a GDT Technologies ozone skid and a Mazzei injector (Mazzei Injector Corporation/GDT). The ozone contactor provided approximately 15 minutes of residence time. The ozonated water was split among three biologically active filters containing lignite carbon, bituminous carbon, and an exhausted but biologically active bituminous GAC from a full-scale facility treating Delta water in northern California. Figure 1 is a schematic of the pilot plant system.

OZONE STUDIES

Several testing strategies were applied to identify the most appropriate ozone doses to achieve disinfection, to control taste and odor, and to minimize disinfection by-product formation while maintaining low bromate formation during both summer and winter operation. This paper discusses the results of the following evaluations:

- Ozonation studies
- Disinfection
- Taste and odor control
- Bromate mitigation

Ozonation

The residual ozone concentration was measured using the indigo bleaching technique (HACH Ultra Analytics, Geneva, Switzerland). To accomplish disinfection, it was necessary to achieve either 2-log virus inactivation or 0.5-log *Giardia* inactivation. Ozone demand was calculated by operating the ozonation system at different transferred ozone dosages and identifying the maximum ozone dosage that did not produce an ozone residual. Figure 2 is a graphical representation of the ozone demand during summer and winter of 2005. As indicated, the ozone demand was less in the winter than in the summer.

Ozone decay curves for August and December are shown on Figure 3. The decay rate was much faster in August when the temperature was higher, resulting in an ozone half-life of 30 seconds. In the winter, the ozone half-life was 1.7 minutes, and the residual persisted longer in the contactor.

Disinfection

The ozone decay rates, dosages, and demand from the experiments to achieve 2.0-log virus inactivation are listed in Table 1. As the season changed from summer to winter and the temperature dropped, the ozone demand decreased, which resulted in a lower transferred ozone

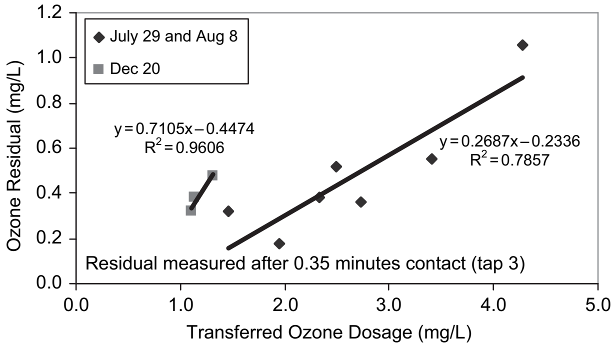

FIGURE 2. Ozone residual as a function of transferred ozone dose (mg/L).

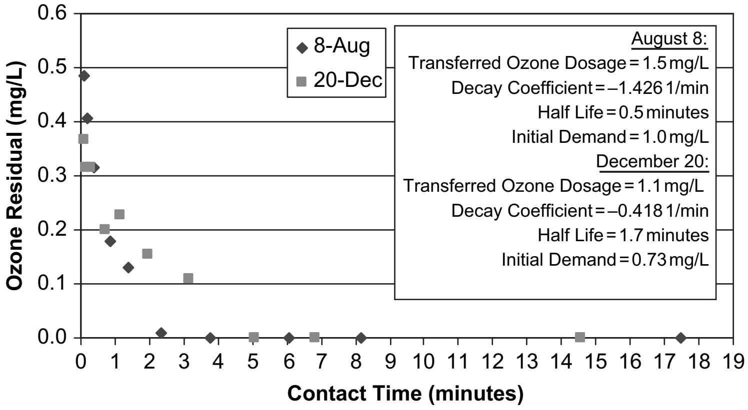

FIGURE 3. Ozone decay curves for August and December.

TABLE 1. Summary of Ozone Demand Data

Date	Transferred Ozone Dosage (mg/L)	Decay Rate, k (1/min)	Ozone Demand (mg/L)	CT* (mg-min/L)	Transfer Efficiency (%)
8/8	1.5	−1.43	1.0	0.23	75
8/15	1.6	−1.06	1.3	0.2	84
8/22	1.3	−1.30	1.0	0.17	93
11/26	1.3	−0.77	0.8	0.45	92
11/28	1.4	−0.84	0.9	0.43	93
12/20	1.1	−0.42	0.7	0.62	97

*A baffling factor of 0.7 was applied to the CT calculations.

dosage needed to meet CT, even though the CT requirement for ozone increases at lower temperatures.

For reference, the CT requirements for ozone as a function of temperature are shown in Table 2. For the pilot study, CT values from 0.15 to 0.55 mg-min/L were used.

UV absorbance (UVA) data were collected two to three times per week. The results are summarized in Table 3. The data show that coagulation using 20 mg/L PACl achieved 39 percent removal of UVA. Using bituminous and lignite BAC, at an empty bed contact time (eBCT) of 3 minutes produced a finished water with UVA of less than 0.012 cm^{-1}.

TABLE 2. CT Requirements For Virus Inactivation By Ozone

	CT Required (mg-min/L)	
Temperature (°C)	2-log Inactivation	3-log Inactivation
< 1	0.9	1.4
5	0.6	0.9
10	0.5	0.8
15	0.3	0.5
20	0.25	0.4
25	0.15	0.25

Ozonation met primary disinfection requirements of 2.0 log inactivation of virus, and 0.5 log inactivation of *Giardia*. Chloramines were selected as the secondary disinfectant for the distribution system, with the following formation potential parameters:

- Holding time – 24 hours.
- Total chloramines after hold time – 2 to 3 mg/L.
- pH – 9.0.
- Temperature – equivalent to raw water temperature.

Data from the DBP tests are listed in Table 4

Samples collected in August, October, and November were chloraminated and had very low TTHM concentrations; therefore, the concentrations of HAA were not measured. The samples collected in December, however, were chlorinated for 3 minutes (to represent 2.0-log virus inactivation) at pH 9.0, followed by ammonia addition and a contact time of 24 hours. The

TABLE 3. UVA Removal Through The Pilot Plant

Process Location	Average UVA (1/cm)	UVA Removal (%)
Raw	0.064	–
Settled	0.039	39 (relative to raw water)
Ozonated	0.019	
Lignite BAC		
–3 minutes EBCT	0.012	37 (relative to ozonated water)
–9 minutes EBCT	0.011	42 (relative to ozonated water)
–15 minutes EBCT	0.008	58 (relative to ozonated water)
Bituminous BAC		
–3 minutes EBCT	0.008	58 (relative to ozonated water)
–9 minutes EBCT	0.007	63 (relative to ozonated water)
–15 minutes EBCT	0.005	74 (relative to ozonated water)
Biological GAC		
–3 minutes EBCT	0.020	0 (relative to ozonated water)
–9 minutes EBCT	0.019	0 (relative to ozonated water)
–15 minutes EBCT	0.018	5 (relative to ozonated water)

TABLE 4. Disinfection By-Product Formation

			DBP (ug/L)					
			BAC - Lignite		BAC- Bituminous		BAC - Biological	
Date	Total Chlorine Residual (mg/L)	pH	TTHM	HAA5	TTHM	HAA	TTHM	HAA
8/15	3.5	9.4	< 1	–	–	–	–	–
8/15	3.5	9.4	–	–	< 1	–	–	–
10/19	2.3	8.9	2.2	–	–	–	–	–
10/19	3.4	9.0	–	–	0.6	–	–	–
10/19	1.0	8.8	–	–	–	–	4.9	–
11/9	2.9	–	< 0.5	NA	–	–	–	–
11/9	2.9	–	–	–	0.6	NA	–	–
11/9	2.7	–	–	–	–	–	3.1	NA
12/12*	2.7	9.4	60	15	–	–	–	–
12/12*	3.3	9.4			64	15	–	–
12/12*	2.5	9.3					70	18

*Included 3 minutes of free chlorine contact at pH 9, followed by ammonia addition and 24 hours contact time.

experiments using free chlorine resulted in TTHM concentrations not much lower than the Stage 1 Disinfectants/Disinfection By-Products Rule MCL of 0.080 mg/L. The HAA5 concentrations were much lower than the MCL of 0.060 mg/L.

Taste and Odor Removal

The proposed treatment scheme includes removal of geosmin and MIB from the Delta water using ozone and BAC. These compounds, which impart tastes and odors to the water, generally occur in the SBA in July and August. The data in Table 5 show the results of geosmin and MIB removal during the pilot study. High MIB concentrations (29 ng/L) were detected in the raw water during the first 2 weeks of sampling in August. The concentrations of geosmin in the raw water were low (less than 8 ng/L).

Oxidation using ozone effectively controlled the geosmin and removed a significant fraction of the MIB during the taste and odor event. The applied ozone dosages and MIB removals are listed in Table 5. The ozone dosages were initially higher than required for CT, but over time,

TABLE 5. Geosmin, MIB, and Bromate Concentrations During Pilot Testing

	Raw		Ozonated*				Lignite BAC		Bituminous BAC		Biological GAC	
Date	Geosmin (ng/L)	MIB (ng/L)	BrO_3 (ug/L)	Geosmin (ng/L)	MIB (ng/L)	EBCT for BAC Tap (min)	Geosmin (ng/L)	MIB (ng/L)	Geosmin (ng/L)	MIB (ng/L)	Geosmin (ng/L)	MIB (ng/L)
7/18	< 5	8	–	–	–	15	–	–	–	–	–	–
7/26	6.5	13	–	–	–	15	–	–	–	–	–	–
8/2	5.1	29	< 5	< 5	< 5	15	< 5	< 5	< 5	< 5	–	–
8/8	2.9	21	< 5	< 5	5.3	15	< 5	< 5	< 5	< 5	–	–
			< 5†	< 5†	8.2†							
8/15	6.3	14	< 5	< 5	6.5	15	< 5	< 5	< 5	< 5	–	–
8/22	7.9	13	1.3	< 4	6.6	15	< 4	< 4	< 4	< 4	–	–
9/7	6.2	11	–	–	–	15	< 4	< 4	< 4	< 4	–	–
9/22	< 4	8.3	< 5	< 4	< 4	3	< 4	< 4	< 4	< 4	< 4	< 4
9/28	5.1	4.7	< 5	< 4	< 4	9	< 4	< 4	< 4	< 4	< 4	< 4
10/5	3.3	3.4	< 5	< 4	< 4	9	–	–	–	–	–	–
10/12	4.2	< 5	< 5	–	–	9	–	–	–	–	–	–
			5.6†	–	–							
10/19	–	–	< 5	–	–	9	–	–	–	–	–	–
10/26	4.5	2.2	–	–	–	9	–	–	–	–	–	–
11/7	–	–	< 5	–	–	–	–	–	–	–	–	–
			< 5†									
11/16	–	–	< 5	–	–	–	–	–	–	–	–	–
			5.1†									

*Ozone dose for 2 log virus inactivation, unless noted otherwise.

†Ozone dose for 0.5 log *Giardia* inactivation.

TABLE 6. The Effect of pH on Bromate Formation

pH	Transferred Ozone Dose (mg/L)	CT (mg-min/L)	Decay Coeff., k (1/min)	Bromate (μg/L)	
				Reporting Value	Detected Amount
6.4	1.14	1.25	−0.28	< 0.005	0.003
7.1	1.02	0.80	−0.31	< 0.005	0.003
7.1	1.14	1.29	−0.23	< 0.005	0.003
7.7	1.10	0.62	−0.42	0.010	0.010

they declined to near the CT for 2.0-log virus inactivation.

Bromate Formation

Bromate is a by-product of ozone oxidation and its concentration is limited by the Stage 1 DBP Rule to 0.010 mg/L. It must be monitored monthly in ozonated systems, and compliance is based on the running annual average of the monthly samples. The goal for bromate in the finished water from the pilot plant was < 0.005 mg/L.

For the first several months of pilot testing, bromate formation was minimal due to low bromide concentrations in the SBA water. In November 2005, the bromate concentration in the finished water was 0.011 mg/L when ozonating to achieve 2.0-log virus inactivation. Bromate formation mitigation tests were performed in December.

Bromate mitigation with sulfuric acid was done on December 20, 2005. The data are listed in Table 6 and show that lowering the pH to less than 7.1 effectively mitigated bromate formation. At an ambient pH of 7.7, the bromate formation was 0.010 mg/L.

Ozone decays more slowly at lower pH values. Under ambient pH conditions, the CT was 0.62 mg-min/L; however, when the pH was lowered, the CT increased to > 0.8 mg-min/L with the same transferred ozone dosage.

SUMMARY

- An ozone dosage to achieve 2.0 log inactivation of viruses was maintained throughout the pilot study. The concentrations of TTHM and HAA in chloraminated samples were very low.
- Post-filtration ozone application effectively oxidized geosmin and MIB. At ozone dosages to meet disinfection requirements, MIB removal was about 50 percent, whereas higher ozone dosages resulted in higher levels of MIB removal.
- Bromate formation to concentrations above 0.005 mg/L occurred in the later months of Phase 1 pilot testing when the bromide concentration in the Delta water exceeded 0.3 mg/L. However, testing showed that bromate formation can be effectively controlled by lowering the pH of the ozone system feed water to less than 7.