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REMOVAL OF ORGANOHALOGENS AND ORGANOHALOGEN PRECURSORS IN RECLAIMED WASTEWATER—I

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Abstract—Fractionation, using synthetic resins, of dissolved organic material in filtered secondary effluent from an advanced wastewater reclamation facility and unpolluted source water, based upon acidity, solubility and adsorbability indicated a strong correlation between organohalogen formation potential (THMFP, TOXFP) and organic carbon (NVTOC). Background organohalogens were quantified as TOX. In addition to humic substances, the classic trihalomethane precursors, hydrophilic substances that comprised the largest fraction of the dissolved material, were implicated for their tendency to form organic halogens upon chlorination. Evaluation of an existing comprehensive advanced treatment process for reclamation of municipal wastewaters indicated that it provides a high level of treatment with respect to removal of organohalogens and precursor organics.

Key words—chlorination, halogens, disinfection, dechlorination, water reclamation

INTRODUCTION

An increasing awareness of the potential toxicological hazards and carcinogenic risks associated with consumption of drinking water has developed over the past decade. Trace quantities, at $ng\,l^{-1}$ to $\mu g\,l^{-1}$ concentrations, of synthetic chemicals and disinfection byproducts, known to be hazardous to human health, have been detected in waters reaching the consumer (Ram, 1986).

In addition to reducing trace contaminants in drinking water, water suppliers are facing increasing water shortages. The city of San Diego (Calif. U.S.A.), in an effort to alleviate shortages, proposed reclamation of municipal wastewaters, with a subsequent retention in suface reservoirs, as an additional source of potable water. An advanced water reclamation facility (Aqua II) was constructed and is being evaluated for the purpose. The existing Aqua II facility tests wastewater of primarily domestic origin with limited industrial flow from small businesses. Primary treatment is effected by coarse screening and suspended solids removal with a rotary disk filter. Water hyacinth (*Eichhornia crassipes*) ponds operated in step feed mode provide secondary treatment. Advanced treatment is provided for 50,000 gpd and consists of ferric chloride coagulation, flocculation, filtration followed by u.v. disinfection, acidification, reverse osmosis using polyamide thin film composite membranes, aeration and fixed bed carbon adsorption treatment (Fam and Stenstrom, 1987).

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An unknown, but high level of treatment will be required if municipal wastewater effluents are to meet drinking water standards. Reclaimed wastewaters contain significant levels of potentially hazardous organohalogens derived from surface pollution. These compounds can be measured as instantaneous total organic halogens (TOX). In addition to background contaminant removal, disinfection would be of prime importance toward providing a safe product for consumption. Aqueous chlorine, a cost effective and efficient disinfectant, has come under scrutiny following Rook's initial discovery of trihalomethanes (THMs) in drinking water (Rook, 1974) and findings, in 1975 by the EPA's National Organic Reconnaissance Survey (NORS) of widespread occurrence of THMs in U.S. drinking supplies (Symons *et al.*, 1975). Disinfection of water with free chlorine can result in formation of significant concentrations of other organohalogens in addition to THMs: poorly defined hydrophilic and hydrophobic chlorination products which are accurately quantified as TOX.

Historically, humic and humic-like hydrophobic substances, derived largely from plant tissues, were implicated as primary THM precursors. Recently evidence has shown that these compounds can react with free chlorine to form significant concentrations of THMs and non-volatile TOX (Fam and Stenstrom, 1987).

Proposed alternatives to free-chlorine include ozone, chlorine dioxide and chloramines. However, chlorine will continue to remain in wide usage as there remains a great deal of uncertainty concerning the efficacy of alternative agents, particularly with

respect to disinfectant ability, byproduct formation, residual disinfecting action and health effects (Morris, 1986; Bull, 1980, 1982a b; Wolfe *et al.* 1984; Cooper 1981; Hoff and Geldreich, 1981).

The objective of this research is (1) to examine physico-chemical characteristics of organic matter as they relate to humic (hydrophobic) and hydrophilic content which affect removal of organic material during water treatment and (2) to provide practical data concerning treatability of filtered secondary effluent with existing and proposed advanced treatment processes that achieve adequate organic removal and result in a product that can be disinfected with free-chlorine with minimal byproduct formation.

In this paper we report on TOX, THMFPs and TOXFPs of XAD-8 organic fractions of unpolluted source water and coagulated, flocculated filtered secondary effluent. We also report the unit operation removal of organohalogen and organohalogen precursors at the existing (Aqua II) advanced wastewater facility. In a second paper we report on efficacy of treatment alternatives, for organohalogen and precursor removal in coagulated filtered secondary effluent, to the existing Aqua II advanced treatment train.

EXPERIMENTAL

Sampling and laboratory protocol

Sample bottles and laboratory glassware were washed in acid dichromatic acid and rinsed thoroughly prior to use. Glass fiber filters were soaked in dichromate overnight and washed prior to use. Reagent water for blanks and standards consisted of commercially available ultrapure water or water purified in the laboratory using ion exchange and carbon adsorption. All chemicals and solvents were of reagent or GC-capillary grade. Laboratory analytical procedures were conducted according to manufacturers, *Standard Methods* (APHA, 1985), or the Environmental Protection Agency (EPA) protocol with laboratory blanks and standards included for each set of analyses.

Grab samples were untreated or acidified, and stored, if required, at 5°C. Raw sewage, primary and secondary effluent samples, which were collected to evaluate overall treatment plant removal efficiency, were vacuum filtered in a glass and ceramic device prior to TOX analysis. Travel blanks consisted of bottles filled with ultrapure water at the laboratory and transported to the field site where they were exposed to the atmosphere and sealed in head-space free containers.

TOX and TOC analysis

TOX analyses were conducted using a Dohrmann AD-3 Adsorption Unit equipped with four dual carbon adsorption modules and a MC-3 Total Organic Halide Analyzer (Dohrmann–Xertex Corp., Santa Clara, Calif.). The method is described in detail elsewhere (Takahashi *et al.*, 1981).

TOC analyses were conducted using a Dohrmann DC-80 TOC Analyzer (Dohrmann–Xertex, Sunnyvale, Calif.). Samples were acidified and purged with purified oxygen prior to analysis to remove inorganic carbon. The instrument was internally calibrated with stock solutions of aqueous organic acid.

Control charts, for TOX and TOC analyses, were used throughout the study to verify accuracy and precision.

Purge and trap gas chromatography

THM analyses were determined using a Hewlett–Packard 5890A gas chromatograph; DB 624 (J&W Scientific) capillary column (30 m × 0.53 mm i.d.); ECD and FID detectors coupled with a Tekmar LSC-2 Purge and Trap device (Tekmar, Cincinnati, Ohio). THM samples were diluted to the linear range of the ECD. An FID was subsequently used, without dilution, for THM analyses for concentrations $>5\,\mu g\,l^{-1}$. Samples were prepared for analysis by purging with purified helium (40 ml/min) for 11 min at 30°C, and desorption and baking at 180°C for 11 min. The GC was programmed at 35°C for 4 min and 8°C/min to 140°C for 1 min. Standard curves were prepared from methanolic stocks spiked into reagent water. Quantifications were based upon linear least square equations relating sample peak area to standards. Replicate analysis of stock THM solutions verified system accuracy and precision.

Formation potentials

TOX formation potentials (TOXFP) and THM formation potentials (THMFP) are defined as the difference between instantaneous TOX or THM concentrations (ITOX and ITHM) before chlorination and total measured concentrations after chlorination under specified conditions (TTOX and TTHM).

Formation potentials were prepared by chlorinating phosphate buffered (pH 7) water samples (calcium hypochlorite stocks) at chlorine to carbon mass ratios (Cl_2:NVTOC) of 3.0. Additional chlorine was added stoichiometrically to samples containing ammonia to exceed the breakpoint, preventing formation of chloramines which modify the chemistry and quantity of chlorination products. Samples were then incubated in head-space free BOD bottles (310 ml) at 20 ± 0.01°C in a water bath (Lauda K-2/R Circulator, Brinkman, N.Y.) for 7 days. Incubated samples were dechlorinated, acidified and analyzed for TTOX and TTHMs.

Ultraviolet absorbance

Ultraviolet (u.v.) absorbance and scans were conducted using a HP 8452A Diode Array UV/Visible Spectrophotometer coupled to an HP Vectra CS computer with supporting software.

XAD-8 fractionations

Dissolved organics contained in the coagulation, flocculation, filtration effluent from the Aqua II plant and in the source surface water (Miramar reservoir), were fractionated according to a modification of the procedure developed and verified by Giabbai *et al.* (1984) TOX, NVTOC, THMFP, TOXFP and u.v. absorbance data were collected for each fraction. XAD-8 resins (Rohm & Hass) were thoroughly cleaned using a method similar to that described by Thurman and Malcolm (1984). Glass columns (100 ml capacity), with 300 ml reservoirs and Teflon stopcocks, were used for fractionation experiments. Four liters of each water sample were adjusted to pH 2 with H_2SO_4, and eluted through parallel XAD-8 columns. Flow rates were approx. 5 ml/min. The eluent consisted of hydrophilic acids and bases. The adsorbed organics were eluted from the resin with 300 ml aliquots of 0.1 NaOH and consisted of hydrophobic acids. The hydrophilic acid and base fractions were then adjusted to pH 10, with NaOH, and re-eluted through the columns. The adsorbed organics, hydrophobic bases, were eluted with 300 ml fractions of 0.1 N H_2SO_4. Each fraction was analyzed for TOX, NVTOC, TOXFP, THMFP and u.v. absorbance. Hydrophobic neutrals were determined by difference.

Table 1. XAD-8 fractions* of source and polluted waters

Fraction	u.v. Abs. (254-nm)	NVTOC (mg/l)	ITOX (μg/l)	TOXFP (μg/l)	THMFP (μg/l)	TOXFP/NVTOC (μg/mg)	THMFP/NVTOC (μg/mg)
Miramar 1‡	0.06	3.34	40.4	384.4	237.1	115.2	71.0
Miramar 2	0.32	0.84	8.3	140.0	62.1	166.6	73.9
Miramar 3	0.05	0.11	0.9	8.9	9.6	83.2	88.9
Miramar 4	0.03	2.16	34.2	225.8	154.2	104.6	71.5
Miramar 5†	—	0.23	0.0	9.7	11.2	42.2	48.4
Filt. Eff. 1§	0.15	8.30	64.4	1280.0	547.6	154.2	66.0
Filt. Eff. 2	0.60	1.83	12.1	361.5	153.7	197.6	84.0
Filt. Eff. 3	0.10	0.38	1.2	15.0	0	39.4	0.0
Filt. Eff. 4	0.10	5.16	37.2	842.8	366.3	163.4	71.0
Filt. Eff. 5†	—	0.93	14.0	60.6	27.7	65.2	29.8

*Fraction codes: 1, untreated; 2, hydrophobic acids; 3, hydrophobic bases; 4, hydrophilic acids and bases; 5, hydrophobic neutrals.
†Values determined by difference.
‡Miramar reservoir.
§Aqua II filter effluent.

RESULTS AND DISCUSSION

XAD-8 fractionation

Fractionation, using XAD-8 resin, of the organic content of the source water (Miramar reservoir) and filtered secondary effluent at Aqua II indicate a great deal of similarity between the two waters.

The average NVTOC content of the filter effluent (Aqua II) is roughly 2.5 times higher than the reservoir water which has an NVTOC averaging around 3.0 mg l^{-1}. The additional organic material in the sewage, is derived from various polluting sources and, possibly, a portion from the secondary treatment process itself. Nevertheless, the distribution of the functional groupings, based upon solubility and adsorbability, of NVTOC levels in the two sources are nearly identical (Table 1). Hydrophilic acids and bases account for nearly 2/3 of the total organic carbon, while hydrophobic acids account for about 1/4. Hydrophobic neutrals and bases account for the remainder.

XAD-8 fractions and untreated samples from both Miramar reservoir and the Aqua II filter effluents were analyzed for u.v. absorbance at 254 nm and scans were conducted over the u.v. visible range. Statistically significant correlations were observed between u.v. absorbance (pH 7, 254 nm) and NVTOC as well as TOXFP and THMFP (Table 2); however, the correlations were different for samples collected at different points in the treatment processes. Each unit operation changed the organic matrix, which indicates the importance of developing and using correlations cautiously, and only for specific water samples.

Table 2. Regression equations

Regression	Equation*	R	Significance
u.v. vs TOC	$Y = 41.54 \times$ [u.v.]	0.983	0.01
u.v. vs TOXFP	$Y = 7858.4 \times$ [u.v.]	0.977	0.01
u.v. vs THMFP	$Y = 3250.2 \times$ [u.v.]	0.971	0.01
TOC vs TOXFP	$Y = 203.19 \times$ [TOC]	0.994	0.01
TOC vs THMFP	$Y = 83.82 \times$ [TOC]	0.986	0.01
TOC vs $CHCl_3$	$Y = 70.78 \times$ [TOC]	0.990	0.01
TOC vs $CHBrCl_2$	$Y = 1.838 \times$ [TOC]	0.326	NS†
TOC vs $CHBr_2Cl$	$Y = 2.846 \times$ [TOC]	0.724	0.05
TOC vs $CHBr_3$	$Y = 8.361 \times$ [TOC]	0.916	0.01
TOXFP vs THMFP	$Y = 0.415 \times$ [TOXFP]	0.997	0.01

*Values of TOX and THM given in μg/l, TOC in mg/l, u.v. as absorbance (254 nm). $N = 10$.
†NS—not statistically significant.

Ultraviolet–visible scans of the XAD-8 fractions yielded spectra, plotted with the logarithm of extinction (log K) against wavelength, with almost straight lines increasing in the direction of shorter wavelengths. These spectra are typical of humic solutions (Gieseking, 1975). However, the multitude of molecular constituents of humic acids which absorb in the visible and u.v. range, such as phenolic compounds, phenolic oxidation products, amino acids and heterocyclic components lead to uncharacteristic spectra of mixtures. There are no distinct differences, in absorption properties, for different types of humic substances (Gieseking, 1975). However, the high degree of absorption of XAD-8 hydrophobic fractions over the spectrum, of both the Miramar and Aqua II filter effluent samples, suggest that this fraction can be characterized, at least operationally, as humic substances.

The relative THMFP and TOXFP distributions between the Miramar reservoir and Aqua II filter effluent samples are also very similar, and parallels the distribution of NVTOC. This is confirmed by the significance of the observed correlation between NVTOC vs TOXFP and NVTOC vs THMFP (Table 2). For the Miramar water hydrophilic acids and bases account for 65.0%, and hydrophobic acids for 26.2% of the THMFP. For the Aqua II filter effluent, hydrophilic acids and bases account for 66.9% and hydrophobic acids for 28.1% of the THMFP (Table 1). However, total THMFP levels are much higher in the filter effluent. The dependence of THMFP on initial NVTOC levels, independent of the source in these samples, is demonstrated by examining the similarity of the ratio of THM to organic carbon between the two sources (Table 1).

For the Miramar reservoir water, hydrophilic acids and bases accounted for 59.2%, hydrophobic acids 36.7% hydrophobic bases 2.3% and hydrophobic neutrals 1.8% of the TOXFP. In the filter effluent hydrophilic acids and bases accounted for 65.8%, hydrophobic acids 28.2% hydrophobic bases 1.2% and hydrophobic neutrals 4.7% of the TOXFP. Similar to the THMFP, TOXFPs are

highly dependent upon NVTOC levels. Note that the hydrophobic acids (possibly humics) have a slightly higher TOXFP to carbon ratio than the hydrophilic component.

Collins *et al.* (1986), conducting studies on a variety of water sources, fractionated water samples using XAD-8 resins with subsequent characterization by NVTOC and THMFP. Their results for untreated Colorado River water are very similar to results obtained here for untreated Miramar reservoir water of which approx. 60% is derived from the Colorado River. For a sample with an NVTOC of 3.02, the hydrophilic fraction comprised 65.2% of the NVTOC, with the remainder as hydrophobic (hydrophobic base and neutral fractions not determined). Furthermore, THMFP/NVTOC ratios were 69 $\mu g\,mg^{-1}$ for hydrophobic and 48 $\mu g\,mg^{-1}$ for the hydrophilic fraction indicating that the hydrophilic fraction has about 70% the potential to form THMs per mg dissolved organic carbon. In this study, for Miramar reservoir the hydrophilic fraction represented 97% of the THMFP/NVTOC and 63% of the TOXFP/NVTOC ratios of the hydrophobic fraction. The hydrophilic fraction, of the filter effluent, represented 85% of the THMFP/NVTOC and 82% of the TOXFP/NVTOC hydrophobic fraction ratios. Collins *et al.* (1986), note the significance, and implication concerning treatability, of the contribution of non-humic substances to the THMFP of the Colorado River water. Both NVTOC levels and THMFP/NVTOC of the hydrophilic fraction were higher than other observed sources. The data gathered in this study support their observations and demonstrate the tendency of hydrophilic, non-humic like, compounds from both natural and polluted sources to form significant concentrations of both volatile and non-volatile halogenated compounds upon chlorination.

The distribution of instantaneous TOX (ITOX), or levels of background organohalogens in unchlorinated water, in the various fractions again parellels NVTOC distribution with the largest fractions in the hydrophilic portions of the samples (Table 1). The total level of ITOX in the filter effluent is approx. 60% higher than the Miramar reservoir water. This indicates a significant reduction in background halogenated organics has occurred during the hyacinth/filtration treatment process.

These results indicate that the treated effluent contains organics that fractionate similarly, with respect to solubility, acidity and adsorbability, to unpolluted source waters. Although the chemical structures of the dissolved substances remains unknown, approx. 25% of the NVTOC (hydrophobic acids), based upon XAD-8 adsorbability and u.v. spectra, can be operationally defined as humic substances. The most significant result, with respect to disinfection of these waters with chlorine, is the dependence of THMFP and TOXFP on total NVTOC levels—regardless of broad chemical classifications. Therefore unit operations must be designed to maximize NVTOC removal to produce en effluent with acceptable TOX and THM formation potentials.

Plant precursor and organohalogen removal profile

Data from the April 1988 sampling of Aqua II indicate that, with respect to filtered primary effluent (48.74 $mg\,l^{-1}$ NVTOC), approx. 73% of NVTOC is removed in the secondary treatment process. The advanced treatment process results in removal of 97% of the *remaining* NVTOC. The removal of NVTOC by each unit operation from the secondary effluent concentrations (13.34 $mg\,l^{-1}$) is 46% for coagulation/flocculation/filtration (7.21 $mg\,l^{-1}$), 49.6% for RO (0.583 $mg\,l^{-1}$) and 1.4% for aeration and carbon adsorption (0.40 $mg\,l^{-1}$).

Occasional NVTOC and TOX samplings, taken over a 20 month period, from the final effluent of the treatment facility (NVTOC 0.33 ± 0.1 $mg\,l^{-1}$; TOX 19.24 ± 7.9 $\mu g\,l^{-1}$) and from the City of San Diego's Miramar reservoir (NVTOC 3.3 ± 0.2 $mg\,l^{-1}$; TOX 36.9 ± 15.61 $\mu g\,l^{-1}$) indicate that the Aqua II final effluent compares favorably, with respect to these parameters, to the City's existing water source.

Samples taken in April 1988 indicate that instantaneous, total THM levels in the Aqua II final effluent were below 1 $\mu g\,l^{-1}$, with $CHCl_3$ being the dominant species, and were essentially removed by the tertiary process (Fig. 1). Total organic halide levels in the primary effluent were relatively high. The secondary treatment process removed 32.2%, coagulation/flocculation/filtration 22.4%, RO 42.8% and aeration/carbon adsorption 1.8% of influent organic halogen. Final TOX levels were below 1 $\mu g\,l^{-1}$ approaching the limit of detection for the analysis (Figs 2 and 3).

THMFP and TOXFP provide both an alternative measure of TOC and a practical estimate, as XAD-8 fractionation experiments revealed, of the suitability of a potable water source for disinfection with chlorine (or chloramines). Of the THM products

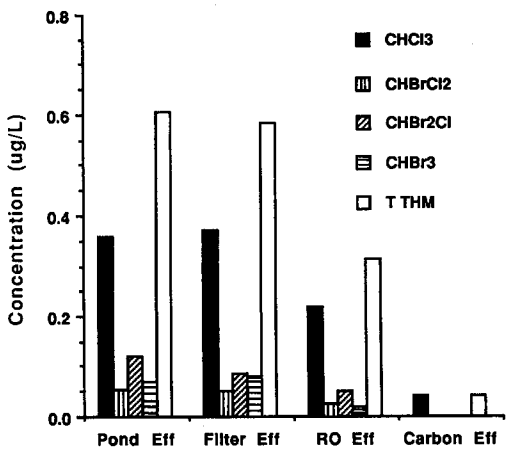

Fig. 1. THM concentrations at Aqua II.

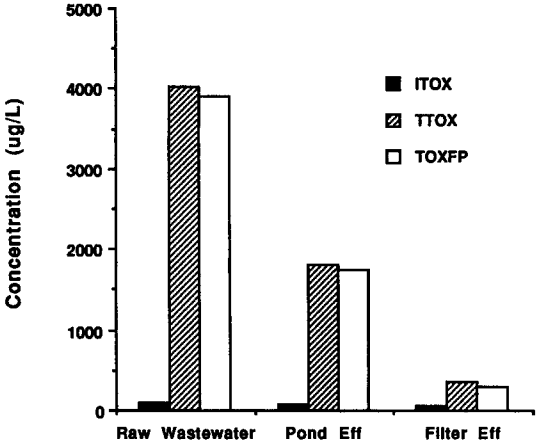

Fig. 2. ITOX and TOXFP concentrations at Aqua II.

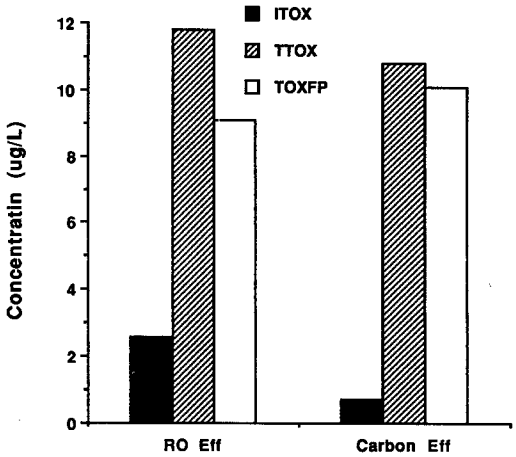

Fig. 4. THMFP concentrations.

from rotary disk filter effluent, secondary effluent and coagulation/flocculation/filter effluents, chloroform was dominant with lesser quantities of bromodichloromethane, dibromochloromethane and bromoform. Bromoform constituted a larger fraction in the RO and carbon effluents. The secondary treatment process removed 51%, coagulation/flocculation/filtration 35.1%, RO 13.7% and aeration/carbon adsorption 0.08% of THM forming potential. Final total THM forming potentials were below 1 $\mu g\,l^{-1}$, far below the E.P.A. limit for drinking water (Figs 4 and 5).

TOXFP removal parallels that of THMFP removal with the secondary treatment process removing 54.9%, coagulation/flocculation/filtration 38.2% and RO 6.59% of influent concentrations. No removal was observed through the aeration/carbon adsorption process. Final plant concentrations were extremely low at 10 $\mu g\,l^{-1}$ (Fig. 3).

Total THM values may be converted to micromoles as Cl allowing for direct comparison to TOX levels. When ratios of TTHM and TTOX are compared to NVTOC (as μM Cl/μM C) a measure of degree of halogen substitution on the dissolved organic material is given. Furthermore, TTHM/TTOX ratios give an indication ease of oxidation and/or molecular size of precursor molecules. An increase in TTHM/TTOX may represent a shift in the precursor matrix to more easily oxidized and/or lower molecular weight species. Fam (1987) fractionated Aqua II secondary effluent into five molecular weight ranges by ultrafiltration. Analysis after chlorinating fractions indicated that the less than 1000 MW fraction yielded the highest apparent quantities of gas chromatographable halogenated species.

Observations of ratios throughout the treatment scheme indicate that TTHM values generally contribute less than 1/6 of the total organically bound halogen species in the chlorinated samples. A slight increase in both TTHM and TTOX to NVTOC ratios were observed after secondary treatment. This indicates that a larger fraction, on a mass basis, of the remaining organics are susceptible to substitution reactions with chlorine. It is interesting to note that while coagulation/filtration reduces TTOX levels an increase is observed in THM/TOX levels which may possibly be due to a shift in precursor molecular weight. Finally, ratios in carbon and RO effluents

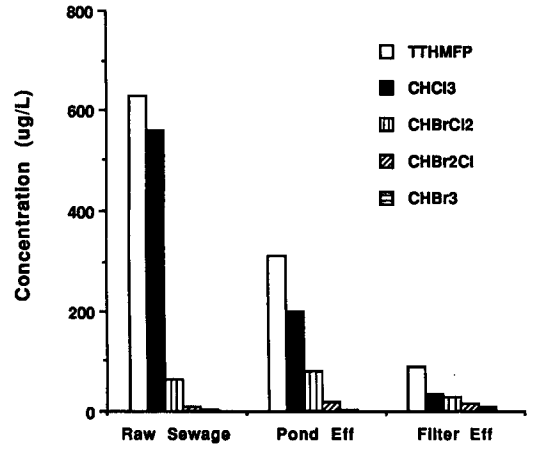

Fig. 3. ITOX, TTOX and TOXFP at Aqua II.

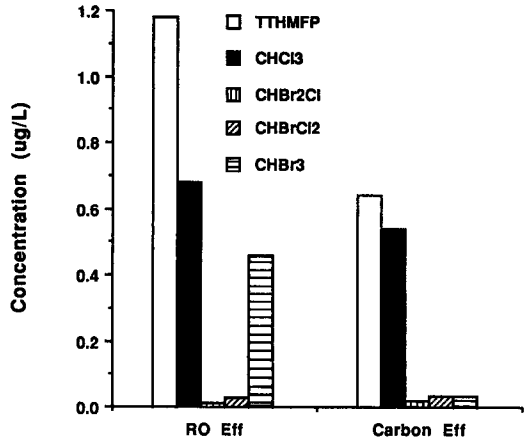

Fig. 5. THMFP concentrations at Aqua II.

Table 3. Ratio of % organohalide (as μM Cl, from forming potentials to NVTOC (as μM C) at sampling stations throughout treatment scheme

	Raw (%)	Pond (%)	Filter (%)	RO (%)	Carbon (%)
TTHM/NVTOC	0.38	0.63	0.28	0.05	0.05
TTOX/NVTOC	2.71	4.45	1.25	0.53	0.85
TTHM/TTOX	14.04	14.06	22.53	8.97	5.27

indicate that organics penetrating the treatment process are approx. 1/3, on a mass basis, as susceptible to chlorine addition in comparison to untreated precursors (Table 3).

SUMMARY

Fractionation experiments compared unpolluted source water (Miramar reservoir) to the same water that was used for municipal purposes, secondarily treated and final filter effluent (Aqua II). NVTOC characteristics and contribution of NVTOC fractions to background TOX and organohalogen formation potentials were determined. The following conclusions are presented.

XAD-8 fractionation of Miramar water and Aqua II filter effluent indicated similar functional distributions, based on adsorbability, acidity and solubility, of dissolved NVTOC in the two sources. Implications are that recycling, by mixing and storage with source waters, of reclaimed effluents may not significantly alter treatability of NVTOC by adsorptive processes.

Functional distribution of background organohalogens (ITOX), presumably derived from anthropogenic sources or prior chlorination of source waters, were similar in both sources. ITOX concentrations in Aqua II filter effluent were approx. 60% higher than Miramar reservoir water.

Correlation of XAD-8 fractional NVTOC, THMFP and TOXFP data revealed that NVTOC is an excellent predictor of organohalogen formation potentials. Hydrophilic acids and bases and hydrophobic acids, in Miramar water, contribute 90% of NVTOC and 95% of the TOXFP. Miramar water hydrophilic NVTOC had 63% of the TOXFP and 97% of the THMFP of humic-like hydrophobic acids. Hydrophilic acids and bases and hydrophobic acids in filter effluent, contribute 84% of NVTOC and 94% of the TOXFP. Filter effluent hydrophilic NVTOC comprised 83% of the TOXFP and 85% of the THMFP of humic-like hydrophobic acids. Results indicate that unit operations must be designed to remove total NVTOC, in addition to classic humic THM precursors, to achieve acceptable TOX and THM concentrations in these finished waters.

Examination of an existing wastewater facility, designed to treat municipal sewage to drinking water standards, documents efficiency of unit operations in removal of background organohalogens (ITOX) and organohalogen precursors as follows:

Secondary treatment removes approx. 73% of NVTOC. Advanced treatment resulted in removal of 97% of the remaining NVTOC. Removal efficiency of NVTOC from secondary effiuent was 46% for coagulation/flocculation/filtration, 49.6% for reverse osmosis and 1.4% for aeration and carbon adsorption.

Secondary treatment removed 32.2%, coagulation/flocculation/filtration 22.4%, RO 42.8% and aeration/carbon adsorption 1.8% influent ITOX. Final plant effluent ITOX concentrations were below 1 $\mu g\,l^{-1}$.

Secondary treatment removed 51% coagulation/flocculation/filtration 35.1%, reverse osmosis 13.7% and aeration/carbon adsorption 0.08% of THMFP. TOXFP removal was 54.9% for secondary treatment, coagulation/flocculation/filtration 38.2% and reverse osmosis 6.59% of influent levels. No removal was observed for aeration/carbon adsorption. Plant effluent concentrations were 1 $\mu g\,l^{-1}$ for THMFP and 10 $\mu g\,l^{-1}$ for TOXFP.

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