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Factors Influencing the Formation of Trihalomethanes in Drinking Water Treatment Plants

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Chlorination is the most widely used technique for disinfecting drinking water. The formation of trihalomethanes (THMs) in chlorinated water was confirmed by many investigators (Trussel et al. 1978, Allgeier et al. 1980) The presence of THMs in drinking water may adversely affect human health .

Three drinking water treatment plants were selected as models for the study of the formation of THMs during water treatment process in Cairo, Egypt. These are Tebbin, Rod El-Farag and Mostorod water treatment plants.

A number of treatment methods have been developed to meet the necessities of the modern community . The character and degree of treatment required will depend upon the type and nature of the raw water source .

The aim of this study is to illustrate the drinking water treatment process applied in selected water plants in Cairo, Egypt and to discuss the factors influencing trihalomethanes formation in drinking water treatment plants .

MATERIALS AND METHODS

Water samples were collected during water treatment process from the three water treatment plants in Cairo, Egypt, including : Mostorod , Tebbin and Rod El-Farag . These water samples were collected in summer and winter seasons. Water samples collection, preservation, dechlorination by sodium thiosulfate and liquid - liquid extraction with n-hexane were carried out according to standard methods (USEPA 1985) . Samples analyses were performed using a Hewlett - Packard GC, model 5890A, equipped with Ni 63 electron capture detector, split / splitless injector and HP 763 A Auto sampler (El-Shahat et al. 1998).

Standard reference solutions of chloroform, dichlorobromomethane, chlorodibromomethane and bromoform were prepared in organic free distilled water and were used for the identification and calculation of their specific concentrations in water samples. Percentage recoveries of standard aqueous solutions of $CHCl_3$, $CHCl_2Br$, $CHClBr_2$ and $CHBr_3$ amounted to 93, 94, 95 and 97, respectively.

RESULTS AND DISCUSSION

The drinking water treatment process applied in the selected water plants in Cairo includes several successive steps : Pre - chlorination, addition of alum (coagulant), flash mixing, flocculation and sedimentation (as applied in both Tebbin and Rod

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El-Farag water plants, while at Mostorod the clarification is in up-flow sludge blanket clarifiers i.e pulsator) . Then followed by rapid sand filtration and finally the water is post - chlorinated in the finished water reservoir before it is pumped out through the water treatment plant output to the distribution system. Detention time of water through water treatment plant ranges between 3 - 4 hours. The alum doses used ranged between 25 - 40 mg/l. The chlorine doses used as pre-chlorine in the pre-chlorination step ranged between 4 - 6 mg/l, while about 1 mg/l chlorine was used as post- chlorination dose. The chlorine residuals in the finished water ranged between 1-1.5 mg/l at the output. Water samples were collected at the different stages of water treatment in the water treatment plants selected for our study during summer and winter seasons, in order to investigate the factors influencing THMs formation. Trihalomethanes occur in drinking water as products of the reaction of chlorine with naturally occurring organic materials and with bromide which may also be present in the water through the water treatment processes.

Raw Nile river water samples sometimes contained trace amounts of chloroform (Table 1) . This may be attributed to environmental impact resulted from the discharging of chlorinated wastes, industrial and agricultural discharges and pollutants that may discharged to the raw water sources. This is in agreement with the United States Environmental Protection Agency (USEPA) findings of the National Organics Reconnaissance survey (NORS) which showed that THMs could be found in almost every finished water but only occasionally in raw water supplies (Symons et al. 1975 and Trussel et al. 1979).

The formation of trihalomethanes is a function of precursor concentration, contact time, chlorine dose, bromide concentration and temperature.

Plant decomposition products are leached into unpolluted water and form the majority of the organic carbon present in raw water. These compounds are generally classed as aquatic humic materials (Christman et al. 1983) and are presumed to be the major precursors of THMs formed in the chlorination process. Gjessing (1976) indicated that the formation of THMs is affected by the type and nature of the raw water source.

The values of total trihalomethanes TTHMs in water treatment plant outputs amounted to be 50 - 55 µg/l in Tebben and Rod El-Farag and 40 µg/l in Mostorod water treatment plants during summer. Variation in the concentration levels of TTHMs may be attributed to the possible change in the concentrations of the precursors in the raw water source supplying the water treatment plant intake. Since the source for Tebbin and Rod El-Farag plants is the Nile river and that for Mostorod plant is Ismailia Canal. So the raw water sources for the three plants differ in the concentrations of the trihalomethanes precursors.

Water samples were collected at the different stages of water treatment in the selected plants during summer and winter seasons in order to reveal the impact of chlorination on trihalomethanes formation. The results revealed that the concentration of TTHMs in raw water samples after pre-chlorination stage amounted to 20 - 46 µg/l and 30 - 60 µg/l in the finished water samples (Table 1) . This results reveal that the increase in the chlorine concentration during post - chlorination stage (1.0 mg/l) results in an increase in TTHMs formed and a concomitant increase in the chlorinated species formed. So chloroform and dichlorobromomethane constituted the major fraction of the TTHMs (Table 1). This is in agreement with the study done by (Otson et al. 1982) .

Table 1.: Levels of THMs in various stages of water treatment process in Tebbin, Rod El-Farag and Mostorod water treatment plants during summer and water seasons .

Water treatment plant	Season	Sampling Site	THMs species µg/l				
			$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs
Tebbin	Summer	Raw Water In	3.6	ND	ND	ND	3.6
		Clarifier	14.60	15.70	5.10	ND	35.40
		Filter Effluent	18.00	21.40	6.90	ND	46.30
		Finished Water	20.20	23.00	8.40	2.9	54.50
	Winter	Raw Water In	1.2	ND	ND	ND	1.2
		Clarifier	7.60	12.80	4.30	ND	24.70
		Filter Effluent	8.90	13.60	4.90	ND	27.40
		Finished Water	13.50	15.40	6.00	ND	34.90
Rod El-Farag	Summer	Raw Water In	3.8	ND	ND	ND	3.8
		Clarifier	17.90	15.70	6.40	ND	40.00
		Filter Effluent	19.20	18.10	7.50	ND	44.80
		Finished Water	21.40	20.20	8.60	ND	50.20
	Winter	Raw Water In	ND	ND	ND	ND	ND
		Clarifier	8.30	10.50	2.20	ND	21.00
		Filter Effluent	9.50	12.20	2.80	ND	24.50
		Finished Water	12.50	14.60	4.20	ND	31.30
Mostorod	Summer	Raw Water In	2.6	ND	ND	ND	2.6
		Clarifier	10.10	12.80	4.90	ND	27.80
		Filter Effluent	13.60	14.20	6.30	ND	34.10
		Finished Water	16.20	17.60	7.90	ND	41.70
	Winter	Raw Water In	1.80	ND	ND	ND	1.80
		Clarifier	8.00	8.50	4.50	ND	21.00
		Filter Effluent	9.20	11.20	4.70	ND	25.10
		Finished Water	11.20	12.60	5.20	ND	29.00

ND : not detected, In. : Intake.

Bromide is being recognized as an improtant precursor in the formation of THMs. In the presence of chlorine, bromide is oxidized to intermediates (likely Br_2, HOBr and OBr) which apparently participate in the halogenation step of the THMs reaction sequence much more effectively than does chlorine (Carpenter et al.1978) . Results obtained for THMs analysis revealed that chlorinated THMs constituted the major fraction of the TTHMs (Table 1) . However results obtained by (Rav - Acha et al. 1983 and Fayad 1993) revealed that brominated THMs constituted the mojor fraction of the TTHMs. This is attributed to the relatively high concentration of bromide ions in water sources. Several investigators have shown that the presence of bromide ions in chlorinated water results in a general increase in TTHMs formed and a concomitant increase in the brominated species formed (Cooper et al. 1985) .

Numerous investigators have shown that the concentration of THMs increases with increasing chlorine contact time (Fleischacker et al . 1983 and Chow et al. 1981). It is evident that the values of TTHMs in the water samples (after pre-chlorination) amounted to 20 - 40 µg/l in the clarifier influent stage and increased to 25 - 50 µg/l in the filters effluent as the chlorine contact time increased at the filtration stage . This reveals that pre-chlorination of raw water results in instantaneous THMs formation. This is in agreement with the study done by (Rook 1974) .

Available results (Table 1) reveal that the values of TTHMs amounted to 40 - 60 and 30 - 35 µg/l in the finished water samples during summer and winter seasons, respectively. This may be attributed to the relatively large difference in water temperature between summer and winter seasons compared with temperature variations within the same season.

It is evident that the rate and extent of THMs formation increased at high temperature and the THMs concentrations increased during summer as compared to winter season.

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