FACTORS AFFECTING THE FORMATION OF TRIHALOMETHANES DURING WATER CHLORINATION: A BENCH-SCALED STUDY

LEE CHEONG HONG

DISSERTATION SUBMITTED AS PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE WITH HONOURS

INDUSTRIAL CHEMISTRY PROGRAMME
SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH

MAY, 2008

UMS
UNIVERSITI MALAYSIA SABAH

PUMS99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS@

JUDUL: FAKTOR MENYEBABKAN PEMBENTUKAN TRIHALOMETANA SEMASA PENGKLORINAN AIR : KAJIAN BERSKALA

IJAZAH: SARJANA MUDA SAINS DENGAN KEPUJIAN (KIMIA INDUSTRI)

SAYA LEE CHEONG HONG (HURUF BESAR) SESI PENGAJIAN: 05/06

mengaku membenarkan tesis (LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institutsi pengajian tinggi.
4. Sila tandakan (/)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau Kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☑	TIDAK TERHAD	

Disahkan Oleh

(TANDATANGAN PENULIS)

(TANDATANGAN PUSTAKAWAN)

Alamat Tetap: 54, LORONG BENDAHARA 46, TAMAN SEJATI, KOTA RAJA, 41000 KLANG

Tarikh: 15/5/08

DR. NOOMI SURUGAU
Nama Penyelia

Tarikh: 15/5/08

CATATAN:- *Potong yang tidak berkenaan.
**Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa /organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
@Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM).

UMS
UNIVERSITI MALAYSIA SABAH

DECLARATION

I hereby declare that this literary work was resulted from my own work except for statements and summaries which each of it had been stated its source.

12 May 2008

LEE CHEONG HONG

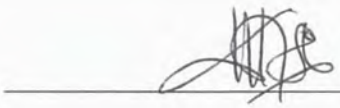
HS2005-2725

UMS
UNIVERSITI MALAYSIA SABAH

VERIFICATION

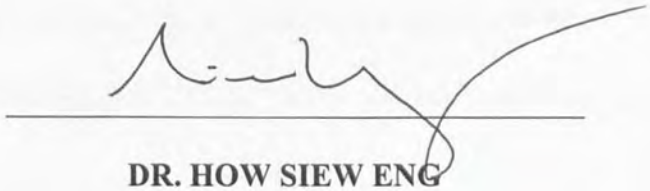
Name: Lee Cheong Hong

Title: Factors Affecting the Formation of Trihalomethanes During Water Chlorination: A Bench-Scaled Study

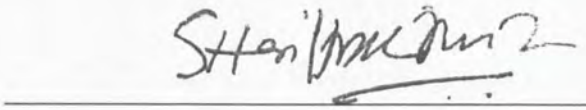


DR. NOUMIE SURUGAU

PROF. MADYA DR. MARCUS JOPONY



DR. HOW SIEW ENG



PROF. MADYA. DR SHARIFF A.K. OMANG

May, 2008

UMS
UNIVERSITI MALAYSIA SABAH

ACKNOWLEDGEMENT

First of all, I would like to take this advantage to thanks School of Science and Technology, University Malaysia Sabah for giving me chance and facilities to run this final year project. I also would like to express my sincere gratitude to my thesis supervisor Dr. Noumie Surugau for her valuable advice, guidance, and continuous encouragement at various stages throughout the completion of dissertation, also for her expert guidance and for her patience. Hence, her help is highly appreciated.

I also greatly in debt for Mr. Sani Gorudin (lab assistant) and Mr. Samudi (lab assistant) for their corporation of preparing the chemicals, glasswares and apparatuses and provide any helps when necessary. Their helps had simplified my lab work. I would like to extend my heartiest appreciation to Mr. Sim Hang Chiew (ex-director of Chemistry Department of Malaysia, Kuching branch) for the chromatogram of my samples analysis and Mr. Sarif Mohd. Ajni Bin Sarif Tawang (Pegawai Sains of Chemistry Department of Malaysia, Kota Kinabalu branch) for the permission and his help to process my samples to be analyses as soon as possible.

Finally, I would like to thank all the SST's staffs and my fellow course mates for helping me throughout my work and lastly a grateful thanks to my parents for giving me moral and financial supports.

UMS
UNIVERSITI MALAYSIA SABAH

ABSTRACT

This study aimed to evaluate the role of chlorine dose, temperature and contact time on the formation of THMs as a result of chlorination of swamp water. All samples were extracted using purge-and-trap (PAT) technique followed by determination of trihalomethanes by gas chromatography-electrolytic conductivity detectors (GC-ELCD). Pearson correlation was applied during data analysis. Concentration of trihalomethanes increased progressively as chlorine dose increased from 2 mg/L to 8 mg/L with strong relationship between them. The relationship between temperature and trihalomethanes was weak. The reaction rate of trihalomethanes formation increased as temperature increased from 4 °C to 35 °C but showed a decreased at 25 °C. Increase in contact time from 4 hours to 12 hours showed strong relationship with trihalomethanes except bromodichloromethane. This result indicated that presence of trihalomethanes in water was exclusively due to chlorination.

UMS
UNIVERSITI MALAYSIA SABAH

FAKTOR MENYEBABKAN PEMBENTUKKAN TRIHALOMETANA SEMASA PENGKLORINAN AIR: KAJIAN BERSKALA

ABSTRAK

Kajian ini bertujuan untuk menilai peranan dos klorin, suhu dan tempoh tindak balas dalam pembentukan trihalometana semasa hasil daripada pengklorinan air paya. Kesemua sampel diekstrak dengan menggunakan teknik purge-and-trap (PAT) diikuti dengan penentuan trihalometana dengan kromatografi gas dengan penunjuk electrolytic conductivity (GC-ELCD). Korelasi Pearson digunakan dalam analisis data. Peningkatan kepekatan trihalometana adalah berkadar langsung dengan peningkatan dos klorin dari 2 mg/L ke 8 mg/L dengan hubungan yang kuat antara mereka. Hubungan antara suhu dan trihalometana adalah lemah. Kadar tindak balas pembentukan trihalometana meningkat denagn peningkatan suhu dari 4 °C hingga 8 °C tetapi menunjuk penurunan pada subu 25 °C. Peningkatan tempoh tindak balas dari 4 jam ke 8 jam menunjukkan hubungan yang kuat dengan trihalometana kecuali bromodwiklorometana. Keputusan ini menunjukkan bahawa kehadiran trihalometana dalam air adalah berpunca daripada pengklorinan.

UMS
UNIVERSITI MALAYSIA SABAH

TABLE OF CONTENTS

UMS
UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF TABLES

UMS
UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF FIGURES

UMS
UNIVERSITI MALAYSIA SABAH

List of Photos

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF APPENDIXES

UMS
UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF SYMBOLS

µg/L	Microgram per litre
Mg/L	Miligram per litre
kPa	kilopascal
°C	Degree Celsius
%	Percentage
mL	Millilitre
L	Litre
cm	Centimetre
km	Kilometre
mg	Milligram
h	hour
µS/cm	Microsiemens per centimetre
NTU	Nephelometric Turbidity Unit
+/-	Plus or minus
w/v	Weight over volume
mg/L	Miligram per litre
N	Normality
ID	Internal diameter
TFE	Teflon faced silicone septa
DBPs	Disinfection by-products
THMs	Trihalomethanes

UMS
UNIVERSITI MALAYSIA SABAH

$CHCl_3$	Chloroform
$CHCl_2Br$	Bromodichloromethane
$CHClBr_2$	Chlorodibromomethane
$CHBr_3$	Bromoform
TTHMs	Total trihalomethanes
EPA	US Environmental Protection Agency
WHO	World Health Organization
TOC	Total organic carbon
UV	Ultra-violet
NOM	Natural organic matter
THM-Br	Brominated trihalomethanes
GC	Gas chromatography
HPLC	High performance liquid chromatography
CE	Capillary electrophoresis
LLE	Liquid-liquid extraction
HS	Headspace
PTI	Purge and trap injection
PAT	Purge-and-trap
LPME	Liquid phase micro extraction
GC-ELCD	Gas chromatography-electrolytic conductivity detectors
VCHCs	Volatile halogenated hydrocarbons
HAAs	Haloacetic acids
EU	European Union

UMS
UNIVERSITI MALAYSIA SABAH

THMFP	Trihalomethanes total potential
IARC	International Agency for Research on Cancer
NaOCl	Sodium Hypochlorite
NaOH	Sodium Hydroxide
H_xO	Water molecule
HOCl	Hypochlorous acid
H^+	Hydrogen ion
OCl^-	Hypochlorite ion
HOBr	Hypobromite
NaOBr	Sodium Hypobromite
IPCS	International Programme of Chemical Safety
T_c	Critical Temperature

UMS
UNIVERSITI MALAYSIA SABAH

CHAPTER 1

INTRODUCTION

1.1 Research Background

Chlorination is a widely used method of disinfection where pathogenic or micro organisms in drinking water are deactivated by application of chlorine in order to ensure the residual concentration in drinking water distribution systems is harmless. In another word, it protects the regrowth of pathogenic or micro organism in drinking water. Disinfection is the most important stage in the treatment of drinking water in water treatment plant. Pathogenic or micro organisms are responsible for water borne diseases such as typhoid fever, cholera and dysentery. Chlorine is used for decades in disinfection as disinfection agent due to its proven effectiveness and inexpensive. Indeed, chlorination is used for most municipal water supply system in Malaysia for disinfection (Md Pauzi Abdullah *et al.*, 2003).

Although chlorination is cheap and effectively deactivate pathogenic or micro organisms, but its cause formation of disinfection by-products (DBPs) as side product. Among DBPs formed, trihalomethanes (THMs) are toxic and carcinogec. Four main

UMS
UNIVERSITI MALAYSIA SABAH

trihalomethanes that responsible for the carcinogens risk are chloroform ($CHCl_3$), bromodichloromethane ($CHCl_2Br$), chlorodibromomethane ($CHClBr_2$) and bromoform ($CHBr_3$). Various researches are done on the THMs in drinking water by many scientists. Many countries have set the maximum contamination level for total trihalomethanes (TTHMs) in drinking water. US Environmental Protection Agency (EPA) has set 80 μg/L as TTHMs concentration in drinking water. On the other hand, European Union Legislation has set 150 μg/L until December 2008 and 100 μg/L thereafter as TTHMs concentration (Nikolaou *et al.*, 2004).

During chlorination, chlorine reacted with organic matters that naturally presence in water and cause formation of THMs by addition and substitution reactions. Humic and fulvic acid are the organic matter, the main precursor that usually measured with non-specific parameters like total organic carbon (TOC) or UV absorbance. Formation of THMs depend on few primary factors, that is raw water quality, type and concentration of natural organic matter (NOM), bromide ion concentration, chlorine form and dose, contact time, pH, alkalinity, temperature, and organic nitrogen concentration. Chlorinated THMs will continue to form as there is residual of chlorine in the water distribution system with the presence of organic matter until all the free chlorine is consumed. While for brominated THMs, its formation happened when presence of bromide due to oxidation by hypochlorous acid to yield hypobromous acid with residual hypochlorous acid. Its reacts with precursor organic compound which result in mixed chloro-bromosubstitution products. THMs also increase with the increase of temperature and pH. Formation of THMs decrease with decrease of ammonia concentration. Chlorinated and

UMS
UNIVERSITI MALAYSIA SABAH

brominated speciation THMs are mainly influenced by organic matter and bromide concentration in drinking water. For example, brominated THMs (THM-Br) increase with the ratio of bromide and TOC. On the other hand, formations of chloroform increase with TOC but decrease with bromide, while formations of $CHBr_3$ show the opposite behavior. $CHCl_2Br$ and $CHClBr_2$ show the similar behaviors but they increase very quickly with bromide and slowly with organic matter. (Solini and Collivignarelli, 2004; Zoccolillo *et al.*, 2005; Juan *et al.*, 2006)

The determination of THMs is generally performed by chromatographic methods. The most used method are gas chromatography (GC), followed by high performance liquid chromatography (HPLC) and capillary electrophoresis (CE). There are number of techniques have been reported for analyze THMs in water, such as direct injection, liquid-liquid extraction (LLE), static headspace technique, dynamic headspace (HS) technique or purge and trap injection (PAT), solid phase micro extraction (SPME) technique and liquid phase micro extraction (LPME) technique (Nikolaou *et al.*, 2002).

All the technique has different recoveries, detection limit and effectiveness in determination of THMs in drinking water. For direct injection, although it is an attractive technique, but there is problem with column stability and critical temperatures for both column and injector. While PAT technique showed good result, but it is more time consuming. On the other hand, purge and PAT have relatively high detection limits from 0.1 to 0.04 μg/L due to the low recoveries of analytes when cartridges are used as trap and this method is not specific for THMs determination. HS techniques is relatively less

UMS
UNIVERSITI MALAYSIA SABAH

sensitive compared LLE and headspace method only suitable to analyze sample with high concentration due to high detection limits from 0.05 to 0.2 μg/L. HS technique also have low recoveries (Nikolaou *et al.*, 2002).

The technique used in this study is purge and trap for gas chromatography-electrolytic conductivity detectors (GC-ELCD). GC-ELCD is an element-detective selection method for compounds containing halogen, nitrogen and sulphur. The high selectivity for halogen makes the detector suitable for analysis of halogen compounds in complex samples matrices such as environmental sample. PAT-GC-ELCD is a technique with lowest detection limit, ranging from 0.01 to 3 μg/L and applicable concentration range of this method is also compound and instrument dependent and is approximately 0.02 to 200 μg/L (Mu *et al.*, 1999, USEPA, 1995).

1.2 Objectives of Study

The objectives of this study were:

a. to determine the extent of THMs presence in chlorinated swamp water
b. to study the effect of chlorine dose, temperature and contact time on formation of trihalomethanes of chlorinated natural water by bench-scaled study

UMS
UNIVERSITI MALAYSIA SABAH

1.3 Scope of Study

Due to the diversity of this field, the scope of this study was to determine THMs only, and not the whole variety of DBPs. Out of the so many types of THMs, only four main trihalomethanes were studied, namely $CHCl_3$, $CHCl_2Br$, $CHClBr_2$ and $CHBr_3$. Compounds in these four main THMs are known as carcinogenic compounds in drinking water. Water samples are taken from swamp at Likas, Sabah as natural water. A bench-scaled chlorination experiment was conducted using swamp water from Likas, Sabah in order to investigate the effect of different factors on the formation of THMs. These factors were contact time, chlorine dose and temperature.

UMS
UNIVERSITI MALAYSIA SABAH

REFERENCE

Culp, Gordon, 1984. *Trihalomethanes reduction in drinking water: technologies, costs, effectiveness, monitoring, compliance*. Pollution Technology Review 114, Noyes Publication, USA. p 67-71.

Department of Environment and Conservation of Newfoundland and Labrador – Canada, 1999. Trihalomethane (THMs) Levels in Public Water Supplies of Newfoundland and Labrador. *Water Resources Management Division*, 2-1 – 2-12.

Eaton, Andrew D., Clesceri, Lenore S., and Greenberg, Arnold E., 1995. *Standard methods for the examination of water and wastewater* . 19th edition, American Public Health Association, Washington DC. p 4-36 – 4-47, p 6-61 – 6-66, p 2-8 – 2-11, p 4-65 – 4-69, p 2-43 – 2-45.

Fayad, Nabil M. and Shahid Iqbal, 1985. Analysis of drinking water for the detection of trihalomethanes. *Environmental, Contamination and Toxicology* **35**, 576-582.

Garcia-Villanova RJ, Garcia C., Gomez JA, Garcia MM, and Ardanny R. Formation, evolution and modelling of trihalomethanes in the drinking water of a town: I. At the municipal treatment utilities. *Journal of Water Research* **41**, 251-255.

Golfinopoulos, Spyros K., Lekkas, Themistokles D., and Nikolaou, Anastasia D., 2000. Comparison of methods for determination of volatile organic compounds in drinking water. *Chemosphere* **45**, 275-284.

Google Earth, 2007. Map of Likas Bay and Kota Kinabalu city centre. http://www.google.com.

Google Earth, 2007. Map of Likas Bay and University Malaysia Sabah. http://www.google.com.

UMS
UNIVERSITI MALAYSIA SAB

Google Earth, 2007. Picture of sampling site at Likas. http://www.google.com.

Gopal, Krishna, Tripathy, Sushree Swarupa, Bersillon, Jean Luc, Dubey, Shashi Prabha, 2006. Chlorination byproducts, their toxidynamiucx and removel from drinking water. *Journal of Hazardous Material* **140**, 1-6.

Harp, L. Daniel, 2002. Current technology of chlorine analysis for water and wastewater. *Technical information series* – **Booklet No. 17**, Hach Company, USA. 1-31.

Hua, Guanghui and Reckhow David A., 2007. Comparison of disinfection byproducts formation from chlorine and alternative disinfectants. *Water Reseach* **41**, 1667-1678.

Huang Xin, Gao Naiyun and Deng Yang, 2007. Bromate ion formation in dark chlorination and ultraviolet/chlorination processes for bromide-containing water. *Journal of Environmental Sciences* **20**, 246-251.

International Programme of Chemical Safety, (IPCS), 2000. *Environmental Health Criteria 216: Disinfectants and Disinfectant By-Products. http://www.inchem.org/documents/ehc/ehc/ehc216.htm.*

Intenational Agency For Research On Cancer, (IARC) 1997. Chlorinated drinking-water; chlorination by-products; some other halogenated compounds; cobalt and cobalt compounds. *IARC Monographs for the Evaluation of the Carcinogenic Risk of Chemicals to Humans* **52**, 179-244.

Intenational Agency For Research On Cancer, (IARC), 1999. Some chemicals that cause tumours of kidney or urinary bladder in rodents and some other subtances. *IARC Monographs for the Evaluation of the Carcinogenic Risk of Chemicals to Humans* **73**, 131-133.

UMS
UNIVERSITI MALAYSIA SABA

Juan, Pedro Manuel San, Carrillo, Jose David, Tena, and Maria Teresa, 2006. Fibre selection based on an overall analytical feature comparison for the solid-phase microextraction of trihalomethanes from drinking water. *Journal of Chromatography* **A**, 27-29.

Kavcar, Pinar, Odabasi, Mustafa, Kitis, Mehmet, Inal, Fikret, Sofuoglu, Sait C., 2006. Occurance, oral exposure and risk assessment of volatile organic compounds in drinking water for Izmir. Water Reseach 40. 3219-3230.

Keiko Ichihashi, Kiyoshi Teranishi and Akio Ichimura, 1998. Brominated trihalomethane formation in halogenation of humic acid in the coexistence of hypochlorite and hypobromite ion.*Water Research* **33**, 477-483.

Krauser, Stuart., McGuire, M., Jacengelo, J., Patania, N., Reagen, K. and Aieta, E., 1989. The occurance of disinfection by-products in US drinking water. *Journal of American Water Works Assiciation* **81**, 41-53.

Mohd. Pauzi Abdullah, Yew, C.H., and Mohamad Salleh bin Ramli, 2003. Formation, modeling and validation of trihalomethanes (THM) in Malaysian drinking water: a case study in the district of tampin, Negeri Sembilan and Sabak Bernam, Selangor, Malaysia. *Water Research* **37**, 4637-4642.

Muddassir Nazir, and Faisal I. Khan, 2005. Human health risk modelling for various exposure routes of trihalomethanes (THMs) in potable water supply. *Environmental Modelling & Software* **21**, 1416-1421.

Nikolaou, Anatasia D., Golfinopoulos, Spyros K., Lekkas, and Themistokles D., 2002. Formation of organic by-products during chlorination of natural waters. *Journal of Evironmental Monitoring* **4**, 910-916

UMS
UNIVERSITI MALAYSIA SABA

Nikolaou, Anastasia D., Golfinopoulos, S., Rizzo, L., Lofrano, G., Lekkas, Themistokles D., and Belgiorno, V., 2005. Optimization of analytical methods for determination of DBPs: Application to drinking waters from Greece and Italy. *Desalination* **176**, 25-36.

Nikolaou, Anastasia D., Golfinopoulos, Spyros K., Lekkas, Themistokles D., and Arhonditsis, George B., 2004. Factors affecting the formation of organic by-products during water chlorination: a bench-scale study. *Water, Air and Soil pollution* **159**, 357-371.

Nikolaou, Anastasia D., Lekkas, Themistokles D., Golfinopoulos, Spyros K., Kostopoulou, and Maria N., 2002. Application of different analytical methods for determination of volatile chlorination by-products in dirnking water. *Talanta* **56**, 717-726.

Nikolaou, Anastasia D., Lekkas, Themistokles D., and Kostopoulou, M. N., 1999. Organic by-products of drinking water chlorination. *Global Nest* **3**, 143-156.

Potter, C.L., Chang, L.W., DeAnhelo, A.B., and Daniel, F.B., 1996. Effects of four trihalomethanes on DNA strand breaks, renal hyaline droplet formation and serum testosterone in male F-344 rats. *Cancer Letters* **106**, 235-242.

Richardson, Susan D., 2003. Disinfection by-products and other emerging contaminants in drinking water. *Trends in Analytical Chemistry* **22**, 666-675.

Rodrigues, Pedro M.S.M., Esteves da Silva, Joaquim C.G., Antunes, Maria Cristina G., 2007. Factorial analysis off the trihalomethanes formation in water disinfection using chlorine. *Analytica Chimica Acta* **595**, 266-274.

Serano, A., Gallego, M., 2007. Rapid determination of total trihalomethanes index in drinking water. *Journal of Chromatography* **A**, 1-4.

UMS
UNIVERSITI MALAYSIA SABAH

Singer, Philip C., 1994. Control of disinfection by-products in drinking water. *Journal of Environmental Engineering* **120**, 727-744.

Soh, Shiau-Chian and Md. Pauzi Abdullah, 2005. Applicability of direct extraction of solid phase micro-extraction to the determination of 54 volatile organic compound in drinking water. *Malaysian Journal of Chemistry* **Volume 7**, 019-025.

Sorlini, Sabrina, and Collivignarelli, Carlo, 2004. Trihalomethanes formation during chemical oxidation with chlorine dioxide and ozone of ten Italian natural waters. *Desalination* **176**, 103-111.

Tardiff, Robert G., Carson, M. Leigh, Ginevan, Micheal E., 2006. Updated weight of eveidance of an association between adverse reproductive and development effects and exposure to disinfection by-products. *Regularoty Toxicology and Pharmacology* **45**, 185-205.

Tee O. S., Paventi M. and Bennett, J. M., 1989. Kinetics and mechanism of the bromination of phenols and phenoxide ions in aqueous solution. Diffusion-controlled rates. *Journal of America Chemistry Society* **111**, 2233-2240

The Clorox Company, 2005. Material safety data sheet: Clorox regular-bleach. http://www.thecloroxcompany.com/products/msds/bleach/cloroxregularbleach0505_.pdf.

United Nations Environment Programme/World Health Organization, (UNEP/WHO), 1996. Water Quality Monitoring – A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. 1-212.

UMS
UNIVERSITI MALAYSIA SABA

United State Environmental Protection Agency, (EPA), 1979. EPA method 501.2: Analysis of trihalomethanes in drinking water by liquid/liquid extraction. *EPA* **500-Series**, 1-12.

United State Environmental Protection Agency, (EPA), 1979. EPA method 501.3: Measurement of trihalomethanes in drinking water with gas chromatography/mass spectrometry and selected ion monitoring. *EPA* **500-Series**, 1-19.

United State Environmental Protection Agency, (EPA), 1995. EPA method 502.2: Volatile organic compounds in water by purge and trap capillary column gas chromatography with photonization and electrolytic conductivity detectors in series. *EPA* **500-series**, 1-35

United State Environmental Protection Agency, (EPA), 1997. Criteria and procedures quality assurance. *Manual for the Certification of Laboratories Analyzing Drinking Water* **5th Edition**, 41-80.

United State Environmental Protection Agency, (EPA), 1998. National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts. http://www.epa.gov/OGWDW/mdbp/dbpfr.html.

Uyak, Vedat and Ismail, Toroz, 2007. Investigation of bromide ion effects on disinfection by-products formation and speciation in an Istanbul water supply. *Journal of Hazardous Materials* **149**, 445-451.

Uyak, Vedat, Ismail, Toroz and S. Meric, 2004. Monitoring and modelling of trihalomethanes (THMs) for a water treatment plant in Istanbul. *Desalination* **176**, 91-101.

UMS
UNIVERSITI MALAYSIA SAB

Villanueva, Cristina M., Gaginiere, Bertrand, Monfort, Christine, Nieuwenhuijsen, Cordier, Sylvaine, 2006. Source of variability in levels and exposure to trihalomethanes. *Environmental Research* **103**, 211-220.

Wang, Zhendi, Li, K., Fingas, M., Sigouin, L., and Menard, L., 2002. Characterization and source identification of hydrocarbons in water samples using multiple analytical techniques. *Journal of Chromatography* **971**, 173-184.

World Health Organization, (WHO), 2005. Trihalomethanes in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. *Guidelines for Drinking-water Quality* **3rd Edition**, 1-67.

Williams, D., LeBel, G. and Benoit, F., 1997. Disinfection by-products in Canadian drinking water. *Chemosphere* **34**, 299-316.

Xin Yang, Chii Shang, Huang, and Ju-Chang, 2005. DBP formation in breakpoint chlorination of wastewater. *Water Research* **39**, 4755-4767.

Yang, Chun-Yuh, Xiao, Zhi-Pimg, Ho, Shu-Chen, Wu, Trong Neng, Tsai, Shang-Shyue. 2007. Association between trihalomethanes concentrations in drinking water and adcerve pregnancy outcome in Taiwan. *Environmental Research* **104**, 390-395.

Zoccolillo, Lelio, Amendola, Luca, Cafaro, Claudia, and Insogna, Susanna, 2005. Improved analysis of volatile halogenated hydrocarbons in water by purge-and-trap with gas chromatography and mass spectrometric detection. *Journal of Chromatography* **1077**, 181-184.

UMS
UNIVERSITI MALAYSIA SABAH