

RELATIONSHIPS BETWEEN TRIHALOMETHANE FORMATION POTENTIAL AND NATURAL ORGANIC MATTER SURROGATES IN RAW WATER AND COAGULATED WATER OF SHALLOW WELLS NEAR A CLOSED UNSANITARY SOLID WASTE DUMPING SITE



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สถาบันวิทยบริการ  
จุฬาลงกรณ์มหาวิทยาลัย

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ความสัมพันธ์ระหว่างโอกาสการก่อตัวของสารไตรฮาโลมีเทนกับตัวแทนสารอินทรีย์ธรรมชาติใน  
น้ำดิบและน้ำที่ผ่านกระบวนการสร้างและรวมตะกอนของบ่อน้ำตื้นใกล้พื้นที่เทกองมูลฝอย  
ที่ไม่ถูกหลักสุขาภิบาลที่ปิดดำเนินการแล้ว



นางสาว วสุรี เจียรศิริกุล

## สถาบันวิทยบริการ จุฬาลงกรณ์มหาวิทยาลัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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POTENTIAL AND NATURAL ORGANIC MATTER SURROGATES IN  
RAW WATER AND COAGULATED WATER OF SHALLOW WELLS  
NEAR A CLOSED UNSANITARY SOLID WASTE DUMPING SITE.

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วสุรี เจียรศิริกุล: ความสัมพันธ์ระหว่างโอกาสการก่อตัวของสารไตรฮาโลมีเทนกับตัวแทนสารอินทรีย์ธรรมชาติ ในน้ำดิบและน้ำที่ผ่านกระบวนการสร้างและรวมตะกอนของบ่อน้ำดื่มใกล้พื้นที่เทกองมูลฝอยที่ไม่ถูกหลักสุขาภิบาลที่ปิดดำเนินการแล้ว. ( RELATIONSHIPS BETWEEN TRIHALOMETHANE FORMATION POTENTIAL AND NATURAL ORGANIC MATTER SURROGATES IN RAW WATER AND COAGULATED WATER OF SHALLOW WELLS NEAR A CLOSED UNSANITARY SOLID WASTE DUMPING SITE ) อ. ที่ปรึกษา : ผศ.ดร. สุรพงษ์ วัฒนจิระ , อ. ที่ปรึกษาร่วม : Assoc. Prof. Taha F. Marhaba, Ph.D. 152 หน้า. ISBN 974-17-4842-6.

ความสัมพันธ์ระหว่างโอกาสการก่อตัวของสารไตรฮาโลมีเทน (THMFP) กับตัวแทนสารอินทรีย์ธรรมชาติ (NOM surrogate parameters) ในน้ำดิบและน้ำที่ผ่านกระบวนการสร้างและรวมตะกอน (coagulated water) ของบ่อน้ำดื่มใกล้พื้นที่เทกองมูลฝอยที่ไม่ถูกหลักสุขาภิบาลที่ปิดดำเนินการแล้ว บริเวณตำบลแม่เหิยะ อำเภอเมือง จังหวัดเชียงใหม่ เป็นการศึกษา น้ำดิบของบ่อน้ำดื่มใกล้พื้นที่เทกองมูลฝอย จำนวน 2 บ่อ คือ บ่อหมายเลข 1 และ 3 และ บ่อน้ำดื่มในพื้นที่เทกองมูลฝอย จำนวน 1 บ่อ คือ บ่อหมายเลข 2 ซึ่งถูกนำมาวิเคราะห์เพื่อหาค่า THMFP TOC DOC และ UV-254 โดยทำการเก็บตัวอย่างทั้งหมด 6 ครั้ง ระหว่างเดือนกันยายน 2546 ถึงเดือนมกราคม 2547 พบว่า น้ำดิบของบ่อน้ำดื่มหมายเลข 1 2 และ 3 มีค่า THMFP เฉลี่ยเท่ากับ  $139.08 \pm 32.68$  ไมโครกรัม/ลิตร  $209.91 \pm 26.26$  ไมโครกรัม/ลิตร และ  $191.02 \pm 38.89$  ไมโครกรัม/ลิตร ตามลำดับ ซึ่งค่า THMFP ที่ได้จากการศึกษาในครั้งนี้มีค่ามากกว่า 80 ไมโครกรัม/ลิตร ตามมาตรฐานน้ำดื่มที่เสนอโดย USEPA โดย THMFP ที่อยู่ในรูปของคลอโรฟอร์มมีปริมาณมากที่สุด คือ ประมาณร้อยละ 60 รองลงมาคือ THMFP ที่อยู่ในรูปของไดคลอโรโบรมอฟอร์มและไตรโบรมอฟอร์มมีค่าประมาณร้อยละ 23 และ 15 ตามลำดับ ส่วน THMFP ที่อยู่ในรูปของโบรมอฟอร์มพบเพียงเล็กน้อยในบ่อหมายเลข 1 และ 2 แต่ไม่พบในบ่อหมายเลข 3 สำหรับการตรวจวิเคราะห์ค่าของตัวแทนสารอินทรีย์ธรรมชาติในน้ำดิบของบ่อน้ำดื่มทั้ง 3 บ่อ พบว่าค่าของตัวแทนสารอินทรีย์ธรรมชาติของบ่อน้ำดื่มหมายเลข 2 มีค่ามากที่สุด โดยมีรายละเอียดดังนี้ TOC มีค่าเฉลี่ยเท่ากับ  $2.58 \pm 1.53$  มิลลิกรัม/ลิตร  $12.22 \pm 5.37$  มิลลิกรัม/ลิตร และ  $3.03 \pm 1.81$  มิลลิกรัม/ลิตร DOC มีค่าเฉลี่ยเท่ากับ  $1.78 \pm 0.89$  มิลลิกรัม/ลิตร  $9.24 \pm 6.09$  มิลลิกรัม/ลิตร และ  $2.57 \pm 1.40$  มิลลิกรัม/ลิตร และ UV-254 มีค่าเฉลี่ยเท่ากับ  $0.25 \pm 0.04$  1/เซนติเมตร  $15.65 \pm 0.49$  1/เซนติเมตร และ  $0.32 \pm 0.06$  1/เซนติเมตร สำหรับบ่อน้ำดื่มหมายเลข 1 2 และ 3 ตามลำดับ ส่วนความสัมพันธ์ระหว่างโอกาสการก่อตัวของสารไตรฮาโลมีเทนกับตัวแทนสารอินทรีย์ธรรมชาติที่มีค่าความสัมพันธ์อยู่ในระดับดีตามเกณฑ์ของ AWWA นั้น พบว่าความสัมพันธ์ ในน้ำดิบเป็นความสัมพันธ์ระหว่าง THMFP กับ TOC ส่วนในน้ำที่ผ่านกระบวนการสร้างและรวมตะกอน พบว่านอกจากความสัมพันธ์ระหว่าง THMFP กับค่าความต้องการคลอรีนแล้ว ความสัมพันธ์ระหว่าง THMFP กับ DOC และ THMFP กับ UV-254 ก็อยู่ในระดับดีด้วย

สาขาวิชาการจัดการสิ่งแวดล้อม  
ปีการศึกษา 2546

ลายมือชื่อผู้คิด.....  
ลายมือชื่ออาจารย์ที่ปรึกษา.....  
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

# # 4589464920: MAJOR ENVIRONMENTAL MANAGEMENT

KEY WORD: TRIHALOMETHANE FORMATION POTENTIAL (THMFP) / NATURAL ORGANIC MATTER (NOM) / RAW WATER / COAGULATED WATER

VASUREE JIARSIRIKUL : RELATIONSHIPS BETWEEN TRIHALOMETHANE FORMATION POTENTIAL AND NATURAL ORGANIC MATTER SURROGATES IN RAW WATER AND COAGULATED WATER OF SHALLOW WELLS NEAR A CLOSED UNSANITARY SOLID WASTE DUMPING SITE. THESIS ADVISOR: ASSIST. PROF. SURAPHONG WATTANACHIRA, D. Eng. THESIS CO-ADVISOR: ASSOC. PROF. TAHA F. MARHABA, Ph.D, 152 pp. ISBN 974-17-4842-6.

Relationships between trihalomethane formation potential (THMFP) and natural organic matter (NOM) surrogates in raw water and coagulated water of shallow wells near a closed unsanitary solid waste dumping site at Mae-Hia District, Muang, Chiang Mai, Thailand were studied. Raw water samples from the observed wells near the area of dumping site named the observed well no. 1 and 3, and the observed wells in the area of dumping site named the observed well no. 2 were collected once a month from September 2003 to January 2004 for THMFP, DOC, TOC, and UV-254 determination. The results shows that the average values of THMFP in raw water from the observed well no.1, 2 and 3 were  $139.08 \pm 32.68 \mu\text{g/L}$ ,  $209.91 \pm 26.26 \mu\text{g/L}$  and  $191.02 \pm 38.89 \mu\text{g/L}$ , respectively, which were higher than a maximum contaminant level (MCL) of THMs in drinking water of  $80 \mu\text{g/L}$  proposed by the USEPA. The most THMFP species of about 60% of THMFP was found in term of Chloroform in raw water from the observed wells, in addition, the THMFP species of approximately 23% and 15% of THMFP in forms of Dichlorobromoform and Dibromochloroform were determined, respectively, while very low concentration of Bromoform was detected. Regard to NOM surrogates parameters, it was found that the values of NOM surrogates in the raw water of the observed well no. 2 was higher than those of in the observed wells no 1 and 3. The average values of TOC of  $2.58 \pm 1.53 \text{ mg/L}$ ,  $12.22 \pm 5.37 \text{ mg/L}$  and  $3.03 \pm 1.81 \text{ mg/L}$ , whereas the average values of DOC of  $1.78 \pm 0.89 \text{ mg/L}$ ,  $9.24 \pm 6.09 \text{ mg/L}$  and  $2.57 \pm 1.40 \text{ mg/L}$ , and the average values of UV-254 of  $0.25 \pm 0.04$ ,  $15.65 \pm 0.49$  and  $0.32 \pm 0.06$  were observed in the raw water from the observed wells no.1, 2 and 3, respectively. Based on, the matrix relationships among surrogates for NOM which established and according to the degree of correlations categorized by AWWA., it was demonstrated that the relationships between THMFP and TOC in raw water was classified as good correlations while, in coagulated water, the relationships between THMFP and chlorine demand, and that of THMFP and DOC, including and that of THMFP and UV-254 were also categorized as good correlations.

Field of study Environmental Management  
Academic year 2003

Student's signature.....  
Advisor's signature.....  
Co- Advisor's signature.....

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## ABBREVIATIONS AND SYMBOLS

abs.	Absorbance
Al	Aluminium
Al(OH) <sub>3</sub>	Aluminium Hydroxide
Al <sub>2</sub> O <sub>3</sub>	Aluminium Oxide
Al <sub>2</sub> SO <sub>4</sub>	Aluminium Sulfate
AlCl <sub>3</sub>	Aluminium Chloride
amu	apparent molecular unit
AMW	Apparent Molecular Weight
AWWA	American Water Works Association
CaCO <sub>3</sub>	Calcium Carbonate
CHBr <sub>3</sub>	Bromoform
CHCl <sub>2</sub> Br	Bromodichloromethane
CHCl <sub>3</sub>	Chloroform
CHClBr <sub>2</sub>	Dibromochloromethane
Cl	Chlorine
cm	Centimeter
°C	Degree Celsius
D/DBPD	Disinfection /Disinfection by Products
DBPFP	Disinfection by Product Formation Potential
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DPD	<i>N, N</i> -diethyl- <i>p</i> -phenylenediamine
ECD	Electron Capture Detector
EDTA	Disodiummethylenediamine Tetraacetate Dehydrate
EPA	Environmental Protection Agency
FA	Fulvic Acid
FAS	Ferrous Ammonium Sulfate
FeCl <sub>3</sub>	Ferric Chloride
g/cm <sup>3</sup>	Gram per Cubic Centimeter
g/L	Gram per Liter

g/mol	Gram per Molar
GC	Gas Chromatograph
h	Hour
HA	Humic Acid
HAAs	Haloacetic acid
HANs	Haloacetonitrile
I	Iodine
KHP	Potassium Hydrogen Phthalate
KI	Potassium Iodine
L/mg-m	Liter per milligram-meter
m	Meter
M	Molar
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
µg/L	Microgram per Liter
µm	Micrometer
mg/L	Milligram per Liter
MW	Molecular Weight
Nm	Nanometer
NOM	Natural Organic Matter
NTU	Nepheo Turbidity Unit
POC	Particle Organic Carbon
ppm	Part per Million
SS	Suspended Solid
SUVA	Specific Ultraviolet Absorption
THMFP	Trihalomethanes Formation Potential
THMs	Trihalomethanes
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
USEPA	United States Environmental Protection Agency
UV-254	Ultraviolet absorbtion at wave length 254 nanometer
UVA	Ultraviolet Absorbtion

# CHAPTER 1

## INTRODUCTION

### 1.1 Motivation

The dumping of wastes on land has been the prime means of waste disposal since the birth of human society. Since the late nineteenth century, the volume and hazardous nature of the generated waste have increased considerably and has led to the need for proper waste disposal sites. More recently, waste disposal sites have been created with the idea that leachate can be contained by natural soil. In recently years, many disposal sites have caused a lot of problems by polluting the environment. In most cases, the design, selection, and management of the land disposal site are not good enough to reverse the adverse impacts on the surface water and groundwater of the surrounding area (Wipha Osatharanyakul, 1999).

From 1958-1989, Chiangmai city also coped with solid waste by means of an open dumping site near Mae-Hia town in Mae-Hia district, where garbage from various sources were dumped. Later on, open dumping alone was used due to increased waste generation resulting from the municipal area in 1983 (Wipha Osatharanyakul, 1999). The villagers living near the dump, protested against the dumping site because of the smell and water quality problems. At that time, Chiangmai Municipality tried hard to find a new landfill site, but encountered a lot of problems; for example, the high price of land, protests by residents, and political corruption. In May of 1989, the local villagers blocked the road that enters the dump and didn't allow the Chiangmai Municipality to take garbage to be dumped there. The Mae-Hia dumping site was then closed (Karnchanawong et al., 1993).

Karnchanawong et al. (1993) studied the water quality of 40 shallow wells around the Mae-Hia disposal site. The study revealed that the water was not suitable

for drinking due to a high level of contamination by nitrate and manganese. It was also found that the levels of conductivity, total solids, color, chloride, chemical oxygen demand (COD), sodium, copper, and lead in the groundwater of the wells situated adjacent to the disposal site were higher than those of the other areas.

Karnchanawong et al. (1999) indicated that there is no evidence for stabilization of the waste, degradation of the contaminant plume from the Mae-Hia dumping site ten years after the closure. A dangerous amount of a carcinogen (i.e. Mn) is present in the ground water. System toxic compounds and a lot of fecal coliform, which are risks to human health, are present.

The Mae-Hia waste dumping site was covered in soil although a leachate lagoon was located within the original dump area. The site was situated on a sequence of quaternary colluvial deposits consisting of sand and gravel layers interbedded with clayey units. Approximately 100 houses exist in the vicinity of the site. Originally the water supply flowed from the dug wells into the colluvial aquifer. The water level was shallow (between 0.5 to 10 m). Many of these wells contain poor quality water (Stuart et al., 2001).

Shallow wells are sources of water for the local community's daily activities (Karnchanawong et al., 1993) such as for irrigation, cleaning, and cooking. Since many wells are located near the disposal area and were constructed by connecting the ready-made concrete rings, runoff water from the waste tip may flow directly into the wells. Hence, the shallow well water quality near the waste dumping site in terms of the parameters related to NOM is an interesting topic to research.

Trihalomethanes (THMs) are compounds that are primarily formed in raw or treated water through the reaction of chlorine or bromine with humic acids associated with decaying vegetation. Chlorine can react with humic substances in natural organic matter (NOM) to form THMs. They are all considered to be possible carcinogens and therefore, human exposure to such compounds should be minimized (Norin and Renberg, 1980). The most well known THMs, causes not only a depression of the

central nervous system but also hepatotoxicity, nephrotoxicity, teratogenicity and carcinogenicity.

To deal with above problems, shallow well water will be used as the water sample. The water sample may consist of organic compounds that are THMs precursor. Therefore, this study focuses on the determination of THMFP and NOM surrogates, and their reduction in shallow well water from a closed unsanitary solid waste dumping site.

## 1.2 Objectives

- To determine THMFP and NOM surrogates in raw water and coagulated water of shallow wells near a closed solid waste dumping site in Chiangmai city.
- To establish the correlation among THMFP and NOM surrogates in raw water and coagulated water of shallow wells near a closed solid waste dumping site.
- To determine the optimum concentration of alum coagulation for THMFP and NOM surrogates reduction.

## 1.3 Scopes of Work

- Water samples will be taken from the selected shallow wells near the Mae-Hia unsanitary solid waste dumping site.
- The THMFP and NOM surrogates in raw water and coagulated water of shallow wells in the Mae-Hia solid waste dumping site were determined.
- The correlation among the THMFP and NOM surrogates in raw water and coagulated water were also established
- The optimum concentration of alum coagulation for THMFP and NOM surrogates reduction from Jar-Test experiments were also determined by

using the same raw water under various dosages of alum and different controlled pH values.

#### **1.4 Benefits of this work**

- To investigate the primary on the quality of the shallow well water near a closed unsanitary solid waste dumping site.
- To determine THMFP in the shallow wells near a closed unsanitary solid waste dumping site.
- The possibility of THMFP and NOM surrogates reduction by the coagulation process with alum were notified.
- Results from this study would be useful for developing THMs standard for Thailand in the future.
- Correlations among surrogates of NOM were demonstrated.



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## CHAPTER 2

### BACKGROUND AND LITERATURE REVIEWS

#### 2.1 Trihalomethanes (THMs)

##### 2.1.1 Background and Regulatory History

In 1974, the Dutch scientist Johannes Rook was the first to identify chloro- and bromo-trihalomethanes (THMs), the first class of halogenated disinfection by-products (DBPs) discovered in chlorinated drinking water (Rook, 1974). Symon et al. (1975) described a survey of halogenated organic compounds from 80 water supply plants. The four THMs; Chloroform ( $\text{CHCl}_3$ ), Bromodichloromethane ( $\text{CHBrCl}_2$ ), Dibromochloroform ( $\text{CHBr}_2\text{Cl}$ ) and Bromoform ( $\text{CHBr}_3$ ) are found in chlorinated drinking water in the United States. Rook, Kissinger and Fitts (1976) demonstrated that humic acid and fuvic acid would create chloroform upon chlorination and mixed haloform upon chlorination if bromide were present. Oliver and Lawrence (1979) proposed that humic materials present at high concentration in most surface water seem to be the main haloform precursors in the natural water. The US Environmental Protection Agency (USEPA) has set a maximum contaminant level (MCL) of  $100 \mu\text{g/L}$  for total trihalomethanes and has set a new MCL of  $80 \mu\text{g/L}$  for stage 1 of the disinfection by product rule (D/DBP Rule; USEPA 1998). In stage 2, the D/DBP Rule may lower the MCL for THMs to  $40 \mu\text{g/L}$ .

##### 2.1.2 Chemistry of Trihalomethanes (THMs)

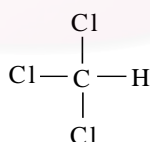
Trihalomethanes (THMs) are halogen-substituted single-carbon compounds with a general formula of  $\text{CHX}_3$ , where X may be fluorine, chlorine, bromine or iodine, or combinations thereof. THMs are a group of organic chemicals formed in water when chlorine reacts with natural organic matters (such as humic acids from decaying vegetation). The primary biochemical ancestors of THM identified by many

researchers are humic substances including humic acid and fulvic acid (Rook, 1976; Trussell and Umphes, 1978; Oliver and Lawrence, 1979). These materials also contribute to the natural color of the water (Amy et al., 1983). Bromine was also identified as a precursor in the natural water, since its presence in chlorinated water may be oxidized by chlorine to form hypobromous acid (HOBr), which led to the formation of brominated THM species. Gould et al. (1983) also observed iodine, to a lesser extent.

Four THM species that actually occur in water supplies: Chloroform ( $\text{CHCl}_3$ ), Bromodichloromethane ( $\text{CHBrCl}_2$ ), Dibromochloroform ( $\text{CHBr}_2\text{Cl}$ ) and Bromoform ( $\text{CHBr}_3$ ).

### 2.1.2.1 Chloroform

Chloroform is not only causes the depression on the central nervous system, but also hepatotoxicity, nephrotoxicity, teratogenicity and carcinogenicity (USEPA, 1998). The basic chemical and physical characteristics of Chloroform or trichloromethane ( $\text{CHCl}_3$ ) are shown in Table 2.1 and its chemical structure is as follows:



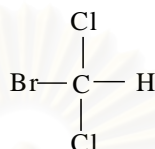
**Table 2.1** Basic chemical and physical characteristics of Chloroform

Empirical Formula	Molecular weight (g/mol)	Specific gravity ( $\text{g}/\text{cm}^3$ )	Boiling point ( $^{\circ}\text{C}$ )	Melting point ( $^{\circ}\text{C}$ )	Solubility in water (g/L)
$\text{CHCl}_3$	119.37	1.472	61	-63	8.1

(Source: Ghazali, 1989)

### 2.1.2.2 Bromodichloromethane

The basic chemical and physical characteristics of dichlorobromomethane or Bromodichloromethane ( $\text{CHCl}_2\text{Br}$ ) are shown in Table 2.2 and its chemical structure is as follows:



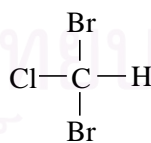
**Table 2.2** Basic chemical and physical characteristics of Bromodichloromethane

Empirical Formula	Molecular weight (g/mol)	Specific gravity ( $\text{g}/\text{cm}^3$ )	Boiling point ( $^{\circ}\text{C}$ )	Melting point ( $^{\circ}\text{C}$ )	Solubility in water (g/L)
$\text{CHCl}_2\text{Br}$	163.82	1.472	90.1	-57.1	Insoluble

(Source: Ghazali, 1989)

### 2.1.2.3 Dibromochloromethane

The basic chemical and physical characteristics of Dibromochloromethane or chlorodibromomethane ( $\text{CHClBr}_2$ ) are shown in Table 2.3 and its chemical structure is as follows:



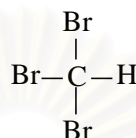
**Table 2.3** Basic chemical and physical characteristics of Dibromochloromethane

Empirical Formula	Molecular weight (g/mol)	Specific gravity ( $\text{g}/\text{cm}^3$ )	Boiling point ( $^{\circ}\text{C}$ )	Melting point ( $^{\circ}\text{C}$ )	Solubility in water (g/L)
$\text{CHClBr}_2$	208.29	2.38	120	-63	4.75

(Source: Ghazali, 1989)

### 2.1.2.4 Bromoform

The basic chemical and physical characteristics of Bromoform or tribromomethane or methyl tribromide ( $\text{CHBr}_3$ ) are shown in Table 2.3 and its chemical structure is as follows:



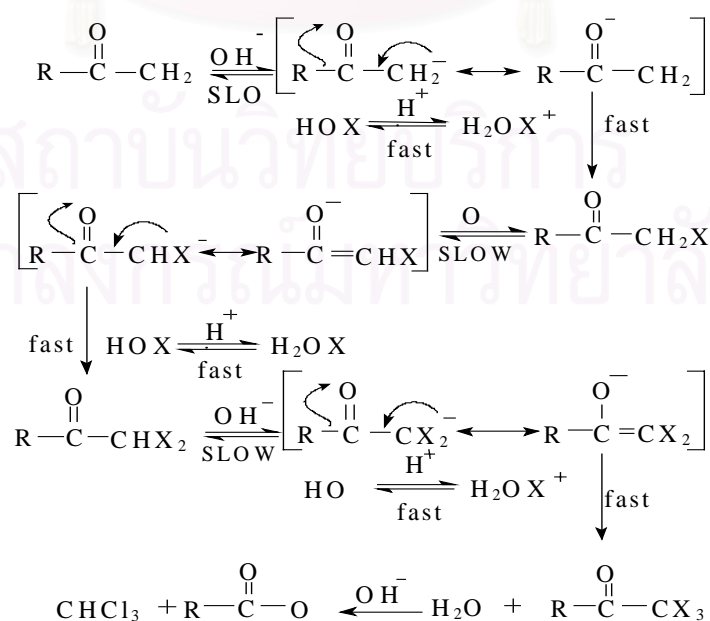
**Table 2.4** Basic chemical and physical characteristics of bromoform

Empirical Formula	Molecular weight (g/mol)	Specific gravity (g/cm <sup>3</sup> )	Boiling point (°C)	Melting point (°C)	Solubility in water (g/L)
$\text{CHBr}_3$	257.73	2.894	150	8.3	Insoluble

(Source: Ghazali, 1989)

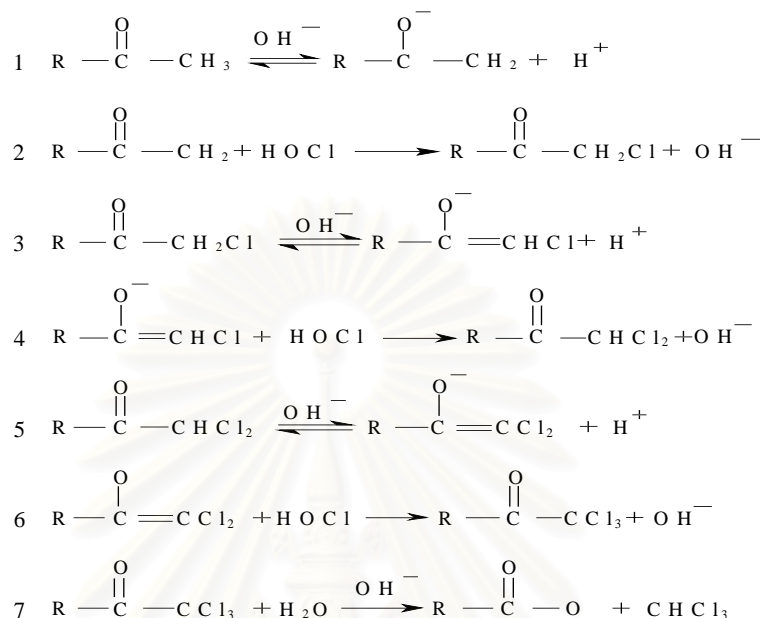
### 2.1.3 Possible Reaction Pathway of THMs in Water Treatment

Reckhow and Singer (1990) summarized a series of possible reactions that the basic steps by which chloroform can be produced during water treatment, as follows:



**Figure 2.1** Haloform reaction pathways

The National Environmental Board (1984) demonstrated a series of reactions of chloroform that may be produced during water treatment are shown in Figure 2.2.



**Figure 2.2** Reaction steps of chloroform produced during water treatment

#### 2.1.4 Trihalomethanes Formation Potential (THMFP)

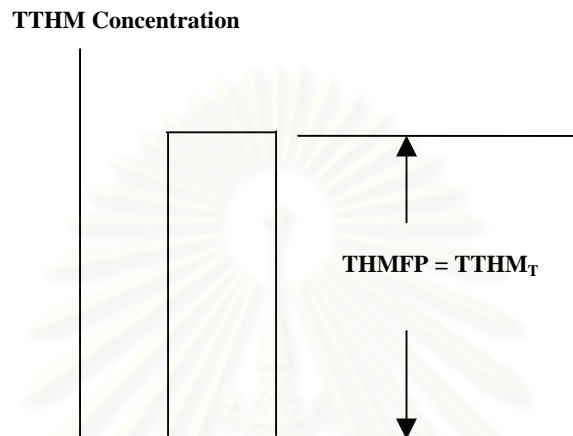
##### Definition of Terms

Total trihalomethanes (TTHMs) are the sum of all four compounds concentration, which include chloroform, bromoform, dichlorobromomethane and dibromochloromethane.

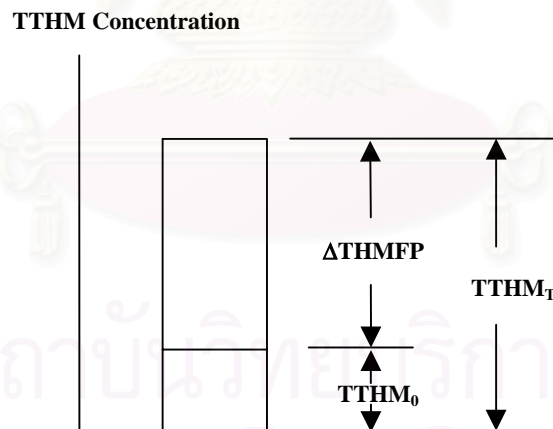
THM<sub>0</sub> is the total THMs concentration at the time of the sampling. It can range from non-detectable to several hundred micrograms per liter if the sample has been chlorinated.

TTHM<sub>7</sub> is the total concentration of all four THMs compounds that are formed when the sample is incubated at 25± 2°C in the presence of excess free chlorine over a 7-day reaction time. Under the standard reaction condition, which are as follows: free chlorine residual of at least 3 mg/L and not more than 5 mg/L at the end of the 7-day reaction (incubation) period and pH controlled at 7± 0.2 with a phosphate buffer.

TTHMF<sub>P</sub> or  $\Delta$ TTHMF<sub>P</sub> is the difference between the final TTHM<sub>T</sub> concentration and the initial TTHM<sub>0</sub> concentration (Figure 2.3 and 2.4). TTHMF<sub>P</sub> determinations provide a worst-case scenario of the concentration of THMs that may be formed.



**Figure 2.3** Definition used in the formation potential test of a sample without free chlorine at the time of sampling.



**Figure 2.4** Definition used in the formation potential test, of a sample with free chlorine at the time of sampling

El-Shahat, Abdel-Halim and Hassan (1998) evaluated trihalomethnes in water treatment plants output in Cairo, at three sampling locations, Mostord, Tebbin and Rod El-Frag. Mean values of THMs in the water treatment plants outputs (Sept. 1991- Dec. 1991) ranged from 31.70 to 61.41  $\mu$ g/L. Moreover, mean vaules of THMs in

water treatment plant outputs (Jan. 1992 - August 1992) ranged from 19.19 to 42.30  $\mu$ g/L.

El-Shahat, Abdel-Halim and Hassan (2001) investigated THMs in various stages of the water treatment process at the Tebbin, Rod El-Farag and Mostorod water treatment plants during summer and water seasons. Stages of the water treatment process that were investigated consist of raw water, clarifier and filter effluent and finished water. The results showed that the highest THMs concentration occurred in finish water and its range was between 41.70 and 54.50  $\mu$ g/L in the summer, and 29.00 and 34.90  $\mu$ g/L in the winter. Moreover, THMs concentration in filter effluent is higher than that of clarifier and THMs concentrations in clarifier is higher than that of raw water.

### **2.1.5 Factors Influencing THMs Formation**

Many studies have concluded that THM formation in drinking water is extremely sensitive to the solution pH, turbidity, concentration of precursors, chlorine dosages, temperature, and reaction time.

#### **2.1.5.1 pH**

Rook (1976) suggested that THM formation increased significantly at pH values of 8 to 10, whereas in the range pH 1 to 7, pH has less of an influence on THM formation. Trussell (1978) demonstrated that THM can form in none existing of chlorine residual once the pH is raised. The chlorinated intermediates form at low pH and hydrolyze to form THMs once the pH is raised.

From the previous research works may lead one to the conclusion that THMs formation levels increase with pH. This supports the hypothesis that THM formation via the haloform reaction is basic-catalyzed. The other factors that influence the formation of THMs are a function of precursor concentration, contact time, chlorine dose, bromide concentration and temperature (El-Shahat et al., 2001)

### **2.1.5.2 Turbidity**

Turbidity, or the cloudiness of the water, is caused by multiple factors such as clay, silt, fine organic and inorganic matter, soluble colored organic compounds, plankton, and other microscopic organisms. The Department of Environmental and Labor (2000) illustrated that chlorine efficiency increased as turbidity is decreased. This was attributed to the fact that turbidity interfered with the interaction between chlorine and substances in water.

### **2.1.5.3 Precursor Concentration**

Since THM formation is a result of a reaction between chlorine and THM precursors, it is obvious that the precursor concentrations would influence THM concentrations. Rook (1976) studies varied concentrations of organic precursors, which are called total organic carbon (TOC) should be reduced before chlorinating. In this regard, it was found that Chloroform production from organic matter is linear in concentration up to 250 mg/l TOC.

The Natural Environmental Board, (1984), demonstrated the relationship between TOC in raw water and total THM concentration after chlorination. Chlorine dosage 10 mg/L, temperature 20 °C and contact time 24 hour was utilized. The results show that the total THM concentration increased as TOC increased. The result showed the total THM concentration ranged from 1 to 250 µg/L while TOC ranged from 1 to 11 mg/L.

### **2.1.5.4 Chlorine Dosages**

The chlorine dosages is the most important factor influencing THM formation. Trussell and Umphres (1978) conducted a laboratory test with synthetic water prepared by adding 10 mg/L of humic acid, 1 mg/L of  $\text{NH}_3\text{Cl}$  (as  $\text{NH}_3$ ) and 10 mg/L of standard pH 7 buffers to demineralized water (TOC 0.2 mg/L). Different amounts of chlorine were added to various portions. After 2 hours of contact time, the



results show that higher THM concentration occurred within a certain range of chlorine precursor to form THM as chlorine has been used up to react with ammonia, bacterial disinfecting, etc. Muttamara et al. (1995) showed the relationship between THM concentrations and chlorine dosages. THM concentrations increased as the chlorine dosages increased. At dosages of 7 and 10 mg/L chlorine, the total THM concentrations at the end of the test run were found to be 124.5 µg/L and 158.3 µg/L, respectively. The level of THM concentration increased with respect to the level of THM precursors.

#### **2.1.5.5 Temperature**

The effect of temperature on the rate of THM formation was investigated by Stevens et al. (1976) using the Ohio River water collected from the winter to the summer. The results showed that the temperature differentials could easily account for most of the winter to summer in THMs concentration variations. The concentrations of THMs were higher during the summer and autumn than in the winter and spring.

#### **2.1.5.6 Reaction Time**

Recknow and Singer (1984) ran a few sets of experiments. One of these experiments studied the formation of these chlorinated products as a function of the reaction time. They found that by varying the chlorine contact time, chloroform and total THM increases rapidly in the first few hours and then slows to a generally steady rate of increase. This result is quite similar to that of previous researchers, who concluded that the active rate of reaction is within the first few hours of contact time.

#### **2.1.6 Toxicity of THMs**

Some scientific studies have linked THMs to an increased risk of some cancers. Several studies suggest a small increase in the risk of bladder cancer and colorectal cancer. Beyond the cancer and reproduction concerns, some investigations

have found that chlorination by-products may be linked to heart, lung, kidney, liver, and central nervous system damage as shown in Table 2.5. Exposure to THMs is not limited only to drinking water. An article in the Washington Post Health Section in 2002 stated that one study showed that a 10-minute shower produced more absorption of THMs through the skin than drinking 5 glasses of water. When taken in total, the cancer evidence is probably the strongest among the possible THMs health risks (John, 1998).

**Table 2.5** United States Primary Drinking Water Regulations establishing MCLs and MCLGs related to DBPs

Compound	MCLG (mg/L)	MCL (mg/L)	Potential Health Effects	Sources of Water Contamination
<b>Bromodichloromethane</b>	Zero <sup>b</sup>	see TTHMs	Cancer, liver, kidney, Reproductive effects	Drinking water chlorination and chlorination by-product
<b>Bromoform</b>	Zero <sup>a</sup>	see TTHMs	Cancer,nervous system, liver, kidney effects	Drinking water ozonation, chloramination,and chlorination
<b>Chloroform</b>	Zero <sup>a</sup>	see TTHMs	Cancer, liver, kidney, Reproductive effects	Drinking water chlorination and chloramination by- product
<b>Dibromochloromethane</b>	0.06 <sup>a</sup>	see TTHMs	Nervous system, liver, kidney,reproductive	Drinking water chlorination and chloramination by- product
<b>Total trihalomethanes<sup>c</sup> (TTHMs)</b>	N/A	0.08 <sup>b</sup>	Cancer and other effects	Drinking water chlorination and chloramination by- product

(Source: 63 Federal Register 69390)

<sup>a</sup> Finalized on December 16,1998 (63 federal Register 69390 ) as established in 40 CFR 141.53.

<sup>b</sup> Finalized on December 16,1998 (63 federal Register 69390 ) as established in 40 CFR 141.64.

<sup>c</sup> Total trihalomethanes are the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane and bromoform in mg/L

Of the THMs compounds, Dibromochloromethane may be the most closely associated with cancer risks, (0.060 mg/l to cause a one in one million cancer risk increase) followed in order by Bromoform, Chloroform, and Dichlorobromomethane (John, 1998). Chloroform was identified in 1978 by the National Cancer Institute (NCI) as a suspected human carcinogen (NCI, 1978) which led the United States Environmental Protection Agency (USEPA) to set a maximum contaminant level (MCL) for total THMs (TTHMs) at 0.10 mg/L (USEPA, 1997). This standard applied to systems serving over 10,000 people. Due to wide occurrence and potential health risks of DBPs, the USEPA proposed the Disinfectants/Disinfection By-Products (D/DBP) Rule in two stages. Stage 1 of the D/DBP Rule was proposed in 1994 (USEPA, 1994). It proposed TTHM MCLs of 0.080 mg/L. Stage 2 of the D/DBP Rule was proposed in 1994, which required even lower MCLs for DBPs than that of Stage 1 (0.040 mg/L).

In 1981, Cotruvo noted that it has been reported since 1945 that chloroform induced carcinogenicity. Hepatomas were produced in female Strain A mice given a repeated dose of 0.145-2.32 mg for a four month period. In the same year Cotruvo also reported that in a bioassay performed by NCI, rat and mice of both sexes were fed chloroform 90-200 mg/kg-d (rats) and 138-147 mg/kg-d (mice), five days a week for 72 weeks. Hepatocellular carcinomas were observed in male and female mice at both the high and low doses at a statistically significant level (Cotruvo, 1981).

Mammalian responses to chloroform include effects on the central nervous system, hepatotoxicity, nephrotoxicity, teratogenicity and carcinogenicity. In 1979, a comprehensive carcinogen test programme by the U.S.NCI on diverse chlorohydrocarbon, both fully saturated or with an ethylenic bond, uniformly induced liver tumors in male and female mice. It also gives evidence of severe nephrotoxicity in the mice. In several instances, the sample Osborne-Mendel Strain rat demonstrated a low yield carcinogenic effect on the kidney. The study of bromohydrocarbons also showed that they are genotoxic causing liver tumors in mice, and induce fore stomach tumors in rats and mice rather quickly in high percentage (NCI, 1979).

Chloroform is the most common THMs found in chlorinated water and can be rapidly adsorbed on oral and intraperitoneal administration and subsequently metabolized into carbon dioxide chloride ion, phosgene and other unidentified metabolites in test animals. The most toxic substance in the metabolism of chloroform seems to be phosgene (Cotruvo, 1981). Cotruvo also stated in the same year that in his a study, which measured chloroform levels in blood among groups of individuals drinking chlorinated water and non-chlorinated water, the group consuming chlorinated water showed significantly higher chloroform. And the human health effect observed in accidental, habitual and occupational exposures to chloroform are similar to those found in the experimental animals. These include effects on the central nervous system, liver and kidneys.

The studies above indicated that THMs have potential health effects on experimental animals in high doses, but the health effects of THMs in low concentration as present in drinking water are still not yet clear. It should be noted that those effects shown in animals might be having the same effect to mankind.

The EPA computed U.S. human uptakes levels of THMs in milligrams per year from air, food and drinking water employing as number of assumption as shown in the Table 2.6.

**Table 2.6** Human uptakes of chloroform and trihalomethanes from drinking water, food and air.

Chemical	Exposure level mg/l, mean and (range)		
	Drinking Water	Food	Air
Chloroform	64 (0.73-343)	9 (2-15.97)	20 (0.41-204)
Trihalomethanes	85 (0.73-572)	-	-

The acute toxicity, LD<sub>50</sub> of trihalomethanes is shown in Table 2.7. Acute chloroform exposure may result in health by respiratory arrest. The primary toxic response at low levels of exposure is hepatotoxicity leading to a fatty liver and

centrilobular necrosis. Kidney damage may also occur in animal after acute poisoning in the convoluted tubules, but it may also affect the epithelium of Henles's loops (NEB, 1984).

**Table 2.7** Acute toxicity of trihalomethanes

Compound	No. of rats Lethal time			LD <sub>50</sub> mg/l p = 0.05	
	M	F	day	M	F
<b>Chloroform</b>	90	90	1-9	1120 (789-1590)	1400 (1120-1680)
<b>Bromodichloromethanes</b>	70	90	1-6	450 (326-621)	900 (811-990)
<b>Dibromodichloromethanes</b>	80	80	1-5	800 (667-960)	1200 (945-1524)
<b>Bromofrom</b>	80	70	1-9	1400 (1205-1595)	1550 (1165-2062)

## 2.2 Natural Organic Matter Surrogates

Natural Organic Matter (NOM) is the term used to describe the complex metric of organic material in natural water. NOM can react with chlorine in the chlorination process to form disinfection by-product (DBPs). NOM consists of humic substances, amino acids, sugars aliphatic acids, and a large number of organic molecules (Malcolm Pirnie Inc., 1993). Humic substances include humic and fulvic acids; while non-humic substances include hydrophilic acids, proteins, carbohydrates, carboxylic acids, amino acids, and hydrocarbons (Thurman, 1985; Amy, 1993). NOM can be separate into humic and non-humic fraction. The humic fraction has a more hydrophobic character than the non-humic fraction. The humic fraction consists of humic and fuvic acids. The non-humic consists of hydrophilic acids, proteins, amino acids and carbohydrate. However, in terms of their chemical properties and implication for water treatment, the humic substance is the most important (Owen, 1995). NOM which consist of humic and fuvic acid (aquatic humic) that cause natural color, is the most important (Edzwald, 1993).

NOM plays a role in many aspects of water treatment. NOM can impart color to water and is capable of forming complexes with metals such as iron. It can serve as a substrate for microbial growth and can exert significant oxidant demand, thereby interfering with both oxidation and disinfection during drinking water treatment. Depending on the concentration and type of NOM, the acidity of water can also be affected.

Humic acids have a molecular weight greater than 2,000 a.m.u., but are usually less than 100,000 a.m.u. The SUVA of humic acids range from 4.8 to 7.4 L/mg-m (Reckhow et al., 1990). The molecular weights of fulvic acids typically range from 500 to 2,000 a.m.u. (Thurman, 1985, Amy et al., 1992). Fulvic acids have a higher charge density and are less amenable to coagulation by charge neutralization (Amy et al., 1992). Fulvic acids are also more prevalent and more soluble than humic acids. In most surface waters, the concentration of humic substances ranges from 100 µg/L to 4 mg/L (Thurman, 1985).

Non-humic substances, such as algae and their extracellular products, have been shown to be precursors to THMs (Morris and Baum, 1978; Oliver and Shindler, 1980). Oliver and Shindler (1980) observed faster reaction kinetics between chlorine and algae than between chlorine and aquatic humic materials. Their results suggest that algae in surface waters may be a major contributor to THM production.

Humic acids have generally been found to be more reactive with chlorine than fulvic acids. There is also evidence that the humic fraction produces greater concentrations of HAAs and THMs than the non-humic fraction.

Leenheer et al., (1982), Leenheer and Noyes, (1984) and Reckhow et al., (1992), proposed natural organic matter fraction and chemical group, which will be shown in Table 2.8.

**Table 2.8** Natural organic matter fraction and chemical group

Fraction	Chemical groups
<b>Hydrophobic</b>	
Acids	
Strong	Humic and fuvic acid, high MW alkyl monocarboxylic and dicarboxylic acids, aromatic acids,
Weak	Phenols, tannins, intermediate MW alkyl monocarboxylic and dicarboxylic acids, aromatic acids
Bases	Proteins, aromatic amines, high MW alkyl Amines
Neutrals	Hydrocarbon, aldehydes, high MW methyl ketones and alkyl alcohols, ethers, furan, pyrrole
<b>Hydrophilic</b>	
Acids	Hydroxy acids, sugars, sulfonics, low MW alkyl monocarboxylic and dicarboxylic acids
Bases	Amino acids, purines, pyrimidines, low MW alkyl amines Polysaccharides; low MW alkyl alcohols, aldehydes and
Neutrals	ketones

(Sources: Leenheer et al., 1982; Leenheer and Noyes, 1984; and Reckhow et al., 1992)

Samorn Muttamara (1995) illustrated the effect of humic acid on THM formation. Humic acid concentration of 3, 5, and 10 mg/L at chlorine doses 3, 5, and 10 mg/L were utilized in his study. It could be concluded that due to the same initial chlorine dosage, higher THM formation will form at higher concentration of humic acid.

Marhaba and Washington (1998) presented that NOM contains precursors for disinfection by-product formation during water treatment disinfection operation. Furthermore, humic substances were characterized by non specific parameters, which are based on their organic carbon content (i.e., TOC), their ability to absorb UV light at 254 nm (i.e., UV 254), and their potential to form trihalomethanes (i.e., THMFP) have become a useful technique to characterize NOM.

To describe the characteristics of NOM, surrogate parameters must be used because no single analytical technique is capable of measuring the widely varied characteristics of NOM. Commonly used NOM surrogates include total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet absorbance at wavelength of 254 nm (UV- 254) and THMFP. Moreover, THMFP removal is also presented to highlight any difference between TOC and THMFP removal (USEPA, 1999). Edzwald, Becker and Wattier, (1985) demonstrated surrogate measurements of water quality for potable water treatment, which is shown in Table 2.9

**Table 2.9** Surrogate measurements of water quality for potable water treatment

<b>Surrogate Parameters</b>	<b>Measurements</b>
<b>Turbidity</b>	Surrogate measure of suspended particles; standard of 1 ntu; traditional parameter to measure water plant performance.
<b>Color</b>	Surrogate measure of humic matter; secondary standard of 15 Pt-co units; no standard instrument method of measurement; traditional aesthetic parameter.
<b>Coliform</b>	Indicator or surrogate measure of pathogenic microorganisms.
<b>TOC</b>	Collective or group measure of organic matter; no standard or criterion.
<b>TTHMFP</b>	Indirect measure of THM precursors; no standard on precursors; standard on THMs formed.
<b>UV(254nm) absorbance</b>	Surrogate measure of TOC and THM precursors.

(Source: Edzwald, Becker and Wattier, 1985)

### 2.2.1 THMs Precursors

THM precursors consist primarily of NOM. Limnologists refer to precursors and nutrients in natural waters as either allochthonous (derived from the surrounding watershed, including land and sub-surface waterways) or autochthonous (derived from within the water body). Watershed run-off is a major contributor to allochthonous humic materials; dissolved and particulate organic substances are transported to a



water body during run-off events (Cooke and Carlson, 1989). Algae and macrophytes are sources of organics within surface water bodies (Cooke and Carson, 1989).

Young and Singer (1979) showed that quantity of chloroform produced is depend upon TOC concentration in raw water. Chloroform formation increased as non-volatile TOC increased. The removal of TOC is a conservative indicator of the removal of the precursors of trihalomethanes (Milter, Nolan and Summers, 1994).

THMFP was found to be directly related with the dissolved organic carbon (DOC) content. However when different source waters were compared, poor relationships between DOC and THMFP have been observed (EPA, 1981). This suggests that factors such as chemical functional groups in the DOC play an important role in the formation of THMs.

Reckhow et al. (1990) measured the UVA and THM formations of the humic and fulvic fractions of five different sources. Humic acids had greater UVA, more aromatic rings, and a higher molecular weight than fulvic acids. As the aromatic content increased (as in humic acids) the percentage of chlorine incorporation (i.e., THM formation) also increased.

The molecular weight of precursors has also been correlated with THM formation potential (THMFP). Bell et al. (1996) indicated that organic molecules with molecular weights greater than 1 kilo Dalton (kd) contributed more THMFP than did the organics having molecular weights of less than 1 kd.

### **2.2.2 Total Organic Carbon (TOC)**

TOC measures the amount of organically bound carbon in water samples. The organic carbon in water and wastewater is composed of a variety of organic compounds in various oxidation states. TOC is independent of the oxidation state of organic matter and dose not measure other organically bound elements such as hydrogen and nitrogen (APHA, AWWA, and WEF, 1995).

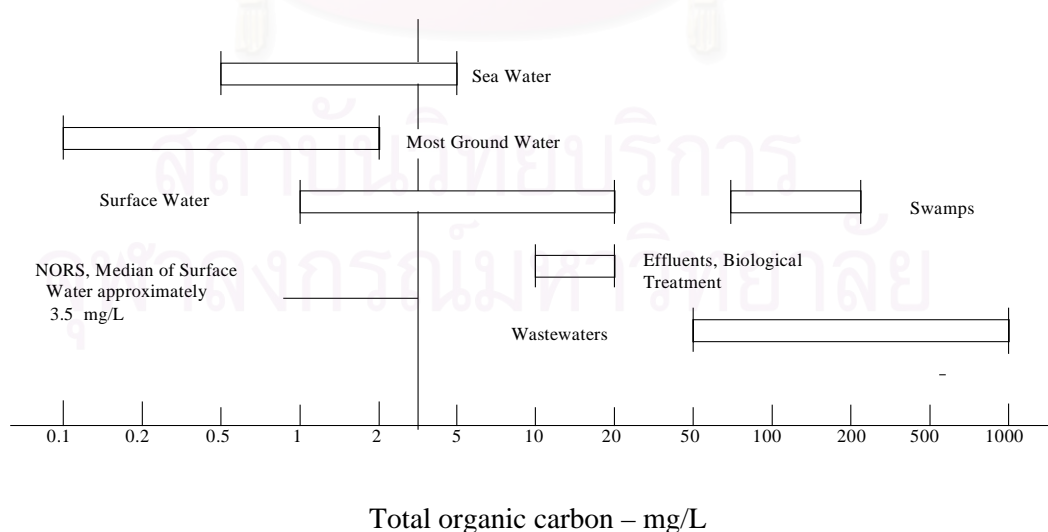
The removal of TOC is a conservation indicator of the removal of the precursors of trihalomethane and haloacetic acids, the most common DBPs (Miltner, Nolan, and Summers, 1994). Therefore, the percent removal of TOC is correlation to the percent removal of DBPs. The USEPA proposed the percentage TOC required for enhanced coagulation and softening. It will depend upon the TOC and alkaline concentration in raw water. The details are shown in Table 2.10 (USEPA, 1999).

**Table 2.10** Percent removal of TOC requirements for enhanced coagulation and softening

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as CaCO <sub>3</sub> )		
	0 - 60	>60 - 120	>120*
2.0 - 4.0	35	25	15
4.0 - 8.0	45	35	25
>8.0	50	40	30

(Source: USEPA 1999)

Kavanaugh (1978) demonstrated range of TOC for a variety of natural water, shown in Figure 2.5



**Figure 2.5** Range of TOC reported for a variety of natural water

### **2.2.3 Dissolve Organic Carbon (DOC)**

Dissolved organic carbons are defined as the fraction of TOC that passes through a 0.45- $\mu\text{m}$ -pore-diam filter (Standard method, 1995). DOC is the independent of the oxidation state of the organic matter. Organic carbon in natural water can be composed in two fractions, particulate organic carbon (POC) and dissolve organic carbon (DOC). In surface water, between 50 and 60 % of humic substances are DOC (Thurman, 1985).

### **2.2.4 UV Absorbance at Wavelength 254 nm (UV- 254)**

Ultra-violet (UV) absorption at a wavelength of 253.7 nm is used to provide an indication of the aggregate concentration of UV-absorbing organic constituents, such as humic substances and various aromatic compounds (APHA, AWWA, WEF, 1995). As noted by Edzwald et al. (1985), humic aromatic compounds and molecules with conjugated double bonds absorb UV light, whereas simple aliphatic acids, alcohol, and sugars do not absorb UV light.

Organic compounds that are aromatic or that have conjugated double bonds absorb light in the ultraviolet (UV) wavelength region. Therefore, UV absorbance is a well-known technique for measuring the presence of naturally occurring organic matter such as humic substances. UV analysis is also affected by pH and turbidity (Edzwald, Becker and Wattier, 1985). UV absorption is a useful surrogate measure for NOM or precursor of THMs because humic substrates strongly absorb ultraviolet (UV) radiation (Eaton, 1995)

### **2.2.5 Specific Ultraviolet Absorbance**

The ratio between UVA absorbance to DOC, referred to as specific absorbance (SUVA) ( $\text{cm}^{-1}\text{mg}^{-1}\text{L}$ ) demonstrates a relative index of humic content (Edzwald, 1993 and Owen et al., 1993). Specific absorbance could suggest the nature of NOM and its consequent THM formation (Krasner et al., 1996). Higher specific

absorbance values tend to indicate higher humic content. Specific absorbance of a humic sample depends upon the molecular weight of the substances. (Pettersen et al., 1995)

SUVA can be used as an indicator of its coagulation (or softening) ability to remove THM precursors. Water having a high SUVA ( $SUVA > 3 \text{ L/mg-m}$ ) have been found to contain organic matter that is more humic-like in character, higher in apparent molecular weight (AMW), and more readily removed by coagulation (Edzwald, 1993) whereas lower SUVA values ( $< 3 \text{ L/mg-m}$ ) indicate the presence of organic matter of lower AMW that is more fulvic-like in character and more difficult to remove.

## **2.3 Removal of THMs and NOM Surrogate Parameters by Coagulation**

### **2.3.1 Approach for THMs and NOM Surrogate Parameters Removal**

Researchers are working to find new methods that could control the by-products caused by current methods. Some alternatives to the complex situation of reactions are good and others produce unwanted compounds.

Rook (1979) stated that the use of macroreticular anion exchange resin followed by coagulation, sedimentation and filtration that is very effective but it is an expensive way of removing the organic precursors. The aim of experiment is to minimize the haloform reaction by lowering the concentrations of the precursors by a combination of ozone and chlorine are feasible, but it is not the most cost effective method. The study of Rook in the same year found that the removal of THMs by activated carbon breakthrough after 2-3 weeks, even though the carbon is still effective in removing larger chlorinated compounds.

Olive and Lawrence (1979) demonstrated that alum treatment followed by sand filtration can remove about two-thirds of precursor. Chlorination of this treated water yields quite low haloform concentration.

Amy and Chadik (1983) studied four cationic polymers (low-molecular-weight quaternary ammonium polymer, low-molecular-weight polyalkyl polyamine, medium-molecular-weight quaternary ammonium polymer, and ultralow-molecular-weight quaternary polyamine) as sole coagulants for removing THM precursors from synthetic and natural waters. Waters synthesized from humic acid were more amenable to polymer coagulation than those synthesized from fulvic acid. For natural waters, the ambient pH of the water appeared to influence polymer performance. The polymer itself can make a modest contribution to the THMFP if a significant residual remains in the solution after coagulation.

Hubel and Edzwald (1987) described that the removal of trihalomethane precursors by coagulation using alum, high-molecular-weight polymers, cationic polymers and various combinations of these coagulants. High-charge-density cationic polymers with alum as a coagulant aid provided good precursor removal at low alum dosages.

Bolto et al. (1999) concluded that the more hydrophobic NOM fractions were the most easily removed by polymer, and the performance of cationic polymers improved significantly with increasing charge density and molecular weight.

Bolto et al. (1999) investigated the treatability of the various fractions for very hydrophobic compounds (nominally humic acid) and less hydrophobic compounds (nominally fulvic acid) where alum was used as the most effective reagent. In reaction with charged hydrophobic compounds (nominally proteins and anionic polysaccharides) polymer could be as effective on this fraction as alum. And for neutral hydrophobic compounds (nominally carbohydrates), very minor component, alum was by far the most effective.

Randtke and Hoehn (1999) examined DBP precursor removal by enhanced coagulation and softening. The results showed precursor removal by coagulation can be maximized by increasing the coagulant dosage and optimizing pH. The addition of acid can significantly reduce the required coagulant dose.

Bell-Ajy et al. (2000) studied bench- and full-scale experiments which were conducted to evaluate the optimal coagulation condition for removal of total organic carbon and disinfection by-product precursors. Jar test and full-scale results indicated that optimized coagulation depends on the pH (between 5.5-6.5) of coagulation and can enhance the removal of organic carbon and DBP precursors.

Exall and Vanloon (2000) examined the removal of organic matter by coagulation. Tannic, humic, lignosulfonic, and salicylic were used as model organic compounds in water and their removal by alum, PACl, and PAHS (Polyaluminum hydroxysulfate) was studied at warm and cold temperatures. In warm water, alum and PACl were the more efficient coagulants. Organic matter had approximately the same effect on alum at both temperatures, but its effect on PACl was somewhat increased in warm water. PAHS effectively reduced turbidity in the absence of organic matter.

Kornegay (2000) concluded that the major constituents of NOM are humic and non-humic substances, and the effective treatment techniques for these materials are vastly different. Humic materials are effectively removed by coagulation while advanced treatment techniques are required to remove the non-humic fraction.

Precursor removal by MF and UF alone is typically less than 20 percent. Scanlan et al. (1997) reported that MF without coagulant addition achieved 6.5 percent TOC removal from surface water supply in Wyoming (average raw water TOC and turbidity near 4.5 mg/L and 3.1 NTU, respectively). The UF system achieved 19 percent TOC removal. Jacangelo et al. (1995) reported that TOC removal by UF from three different surface water supplies was less than 22 percent. Memcor MF and Aqua source UF systems achieved only 11 to 12 percent TOC removal in studies at Tempe, AZ. In general, the sizes of MF and UF membranes do not reject the majority of precursors in surface water (Carollo Engineers, 2000).

Potassium Permanganate can be used as a THM control. Potassium Permanganate ( $\text{KMnO}_4$ ) is a very strong oxidant. It is especially effective with taste and odor problems. When added to water it turns purple, and the color changes to

clear as the oxidation reaction goes to completion. There are side effects to the color characteristics. If the concentration is not carefully monitored so that the reaction goes to completion, then there could be residual color in the finished water. Sometimes the  $\text{KMnO}_4$  will react with substances differently than chlorine and control conditions that chlorine is unable to. By using  $\text{KMnO}_4$  at the beginning of the water treatment process, you can delay the addition of chlorine till later and therefore reduce the time in which THMs can form. The  $\text{KMnO}_4$  is known to oxidize iron and manganese, and is used to control THM precursors.

Enhanced coagulation is a hot research topic. Researchers hope to find a solution to THM formation during disinfection processes. "Enhanced coagulation" refers to a modification in the conventional coagulation process to gain better rates of removal of Natural Organic Matter (NOM). The enhanced coagulation process changes the parameters of water treatment such as pH and coagulant dose. Because most water treatment plants that exist today are working with old technology, it is hard to expect them to be able to comply with the regulations without some extra help in the treatment process. Enhanced coagulation is being tested to see how effective it is at removing particles and THM precursors. Tests are done on the raw water as well as the filtered water to measure turbidity, TOC levels, UV-254 absorbance, and THM formation potential. Testing the characteristics of these two types of water can predict the TOC removal rate. This can forecast whether or not the changes in water treatment will be in compliance with the newer, stricter regulations. Many of the results depend on the raw water. Samples with higher starting TOC levels tend to have better remove rates. To ensure that the extra work being performed to remove TOC does not add more particles to the water and deteriorate the turbidity, close monitoring of the turbidity must continue.

Some NOM take the form of precursors for the formation of trihalomethanes via reactions with chlorine. Subsequently, these discoveries motivated several additional studies on the removal of this precursor by coagulation.

In addition to the formation of THMs and other halogenated organics during disinfection, NOM is indicative of the presence of color in the water; it utilizes the adsorption capacity of activated carbon beds, exerts an oxidant demand, and may transport other contaminants via complexes through the water treatment plant. A summary is given below of the most recent and relevant research on the chemical coagulation of NOM that is applicable to water treatment plant practice.

The study of Young and Singer in 1979 showed that the quantity of chloroform produced depends upon the total organic carbon concentration in raw water. The higher the raw water non-volatile TOC concentration, the greater chloroform formation potential. Chloroform formation decreases more than 60 percent by chlorination of the coagulated water compared with raw water. The laboratory investigation indicated that chloroform formation can be reduced by adding chlorine after pretreatment with alum. They also suggested that in practice, modification of the point of chlorine addition could similarly result in a significant reduction in finished water concentration of chloroform. They demonstrated that chlorination following coagulation and settling is a cost effective means of achieving a significant reduction in chloroform.

Shorney et al. (1996) found that DOC removal was significantly higher for source waters having SUVA values greater than 4 L/mg-m. Coagulation and softening are expected to result in a lowering of the SUVA value for any given water, since the less removable organic matter remaining in the water should exhibit a lower SUVA than the material that is removed.

Many investigators have studied the addition of powdered activated carbon (PAC) or coagulant upstream of MF or UF membranes for improved organic removal and the results have been mixed. The addition of a modest coagulant dosage (15 to 35 ml/L alum or ferric-salt coagulant) improved TOC removal from 6.5 percent to 38 percent in studies by Scanlan et al. (1997) and Freeman et al. (1997). PAC addition (20 mg/L) upstream of MF, however, achieved only 11 percent TOC removal in one



trial, and 0 percent TOC removal in another trial. Both the coagulant and PAC additions shortened the duration of water production between cleanings.

The ability of commonly used coagulants to remove TOC is discussed below:

1. *Precursor Removal by Aluminum Sulfate Coagulation.* It is well known that TOC removal by  $\text{Al}_2(\text{SO}_4)_3$  coagulation is superior when the solution pH values is around 5.5 to 6. The TOC removal achieved within this pH range can be substantial; TOC removals of greater than 50 percent have been widely reported in the literature. Alum coagulation is also effective for DBPP removal. Cheng et al. (1995) observed approximately a 30 percent removal of THM precursors and a 30 percent removal of HAA precursors removal with 20 mg/L  $\text{Al}_2(\text{SO}_4)_3$  at a pH of 5.5 to 6.3 in their work for the State Project on the Colorado River water in Southern California.

2. *Precursor Removal by Ferric Sulfate Coagulation.* Ferric sulfate coagulation can effectively reduce TOC, THMFP, and TOXFP. In studies by Sinsabaugh et al. (1986) a 20 mg/L dosage of  $\text{Fe}_2(\text{SO}_4)_3$  removed nearly half of the THMFP and the TOXFP. Increasing the dosage to 50 mg/L  $\text{Fe}_2(\text{SO}_4)_3$  increased these removals to approximately 70 percent. The pH during coagulation was maintained near 5.0.

3. *Precursor Removal by Ferric Chloride Coagulation.* Ferric chloride is also very effective for NOM removal. Dryfuss et al. (1995) optimized TOC removal using bench-scale  $\text{FeCl}_3$  coagulation for three different source waters. The percentage DOC removal ranged from 46 to 71 percent, and the removal of THMFP and HAAFP was slightly greater, ranging from 59 to 90 percent. Ferric chloride coagulation was found to preferentially remove the high molecular weight, humic fraction of organics; non-humics were also removed by  $\text{FeCl}_3$  coagulation, but to a lesser extent. The differences between iron and aluminum-salt coagulants include the optimum pH

values for organics removal, solubility, surface areas, and surface charge. A number of studies comparing alum to iron-based coagulants have found that iron achieved greater precursor removal than alum (e.g. Vilage et al., 1997; Shorney et al., 1998)

4. *Precursor Removal by Polyaluminum Chloride Coagulation.* Polyaluminum chloride is a partially hydrolyzed metal coagulant prepared by adding a base to the coagulant to "pre-form" the polymeric aluminum species that may be more effective in achieving organics removal. Dempsey et al. (1984) reported that PACl outperformed  $\text{Al}_2(\text{SO}_4)_3$  for fulvic acid removal. The PACl coagulant was better at all pH values above and below those for optimum alum coagulation.

### **2.3.2 Process Variables**

#### **2.3.2.1 Coagulant Type**

Various investigators have arrived at the different conclusion when comparing the ability of aluminum- and iron-salt coagulants to remove THMs and NOM Surrogate Parameters. Some have found aluminum salts to be superior, especially at low dosages (Edwards, 1997), while some (Black et al. 1963; Smith et al. 1994 and Bell et al. 1996) have found iron salts to be superior. Other studies (Young and Singer, 1979) have found them are equally capable of reducing inorganic turbidity to an acceptable level. However, they vary significantly in their ability to remove soluble NOM. Al salts are frequently found to be more effective than iron salts, but occasionally the opposite is true. Some organic, for example, have a stronger preference for iron than for aluminum. In any event, the difference in performance is not very great, and the optimum removal is usually about the same for either salt. Selection of a coagulant for NOM removal may be based on the differences in the chemical costs and handling requirements.

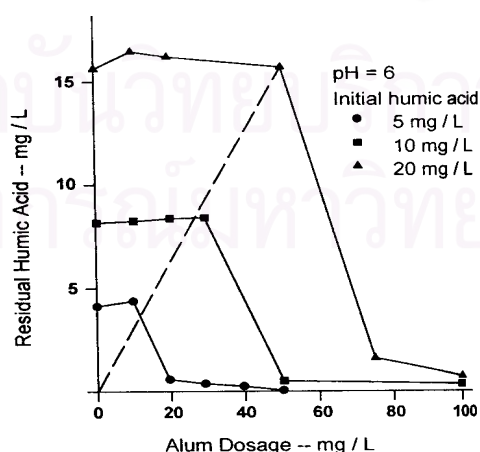
Research on polymerized Al and Fe chloride salts have been conducted to compare the more traditional coagulation to these polycoagulants for the removal

of both turbidity and NOM. For example, it was found that polyaluminum was likely to be a better coagulant than alum for low and moderate concentrations of humic acid and clay-fulvic acid suspensions, especially at pH values  $<5.5$  and  $>7.0$ . On the other hand, no difference was found between polymeric ironchloride over a pH range of 5-8 for the removal of NOM.

Organic, cationic polymers have received considerable investigation for the removal of NOM. In most situations, “good” removal of humic substances and color was achieved. These polymers may be advantageous in the direct filtration of colored, low turbidity waters, but are used more often as coagulant acids in conjunction with metal salts or lime.

### 2.3.2.2 Coagulant Dosage

That there is a stoichiometric relationship between NOM removals is seen in Figure 2.6 for the removal of humic acid by alum. In these situations, stoichiometry is defined as the required initial dosage proportional to the NOM concentration. Of course this is genetic, but it could be established for a given treatment situation. It should be noted that over dosing (exceeding the stoichiometry) might lead to restabilization of the NOM. This is possible where cationic polymers are employed as coagulation acids.



(Source: Faust and Aly, 1998)

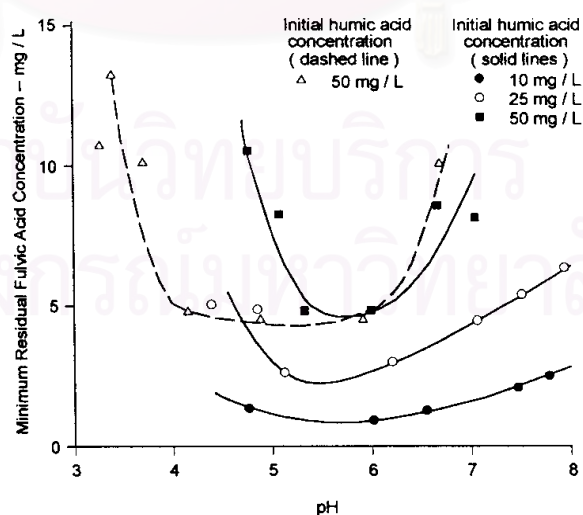
**Figure 2.6** Stoichiometric relationships between alum dosage and humic acid concentration

Another type of “stoichiometry” is conceivable; that is where coagulation is associated with “high” pH, “low” concentrations of NOM, and NOM that may not be of humic origin. Higher coagulant dosages are required as the [NOM] increases, but the relation is not necessarily stoichiometric. Overdosing is not possible, but any increase in NOM removal is marginal at best. This behavior is quite common for surface waters where turbidity and alkalinity are “moderate to high”. Removal of soluble synthetic organic chemicals [SOC] is expected to follow this “stoichiometry” and mechanism of coagulation.

### 2.3.2.3 Influence of pH

The optimum pH range of 5-6 is usually cited for removal of NOM by alum with a slightly lower value for iron salts. The graph in Figure 2.7 is typical for the removal of humic and fulvic acids.

This is an important operational variable, especially where coagulation is used as a pretreatment for the activated carbon processes. Subsequently, the pH value would have to be adjusted upward before AC treatment and discharge into the distribution system.



**Figure 2.7** Influence of pH on the removal of fulvic acid with acid alum and humic acid with ferric chloride

#### **2.3.2.4 Mixing**

Rapid and slow mixing influences the removal of NOM. When the particulates of NOM are removed via the charge neutralization mechanism, the type of rapid mixing greatly influences this reaction. It is imperative that the coagulations be dispersed into the raw water stream as rapidly as possible (<0.1 sec) so that the hydrolysis products, which develop in 0.01 to 1 sec, will destabilize the colloid. On the other hand, rapid mixing should influence the removal of dissolved NOM, since it will influence the charge and distribution of the metal hydrolysis products. Here it is necessary for the metal hydroxide to have a high surface area and an amorphous structure for the co-precipitation of the soluble NOM. Aged or recycled coagulant sludge is not very effective for dissolved organic because these solids will become more crystalline as they age.

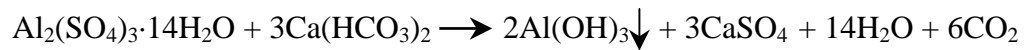
### **2.4 Coagulants**

The most widely used coagulants in water treatment are aluminum and iron salts. Aluminum salts are employed more frequently than iron salts because they are usually cheaper. Iron salts have an advantage over aluminum salts because they are effective over a wider pH range. The principle factors affecting the coagulation and flocculation of water or wastewater are turbidity, suspended solids, temperature, pH, cationic and anionic, compositions and concentrations, duration and degree of agitation during coagulation and flocculation, dosage and nature of the coagulant, and the coagulant aid. The selection of a coagulant requires the use of laboratory or pilot plant coagulation studies since given water or wastewater may show optimum coagulation results for a particular coagulant.

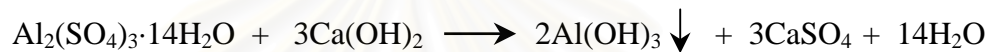
#### **2.4.1 Aluminum Sulfate**

Normally, the water must contain sufficient alkalinity in order for it to react with aluminum sulfate to produce the hydroxide floc. Usually, for the pH ranges

involved, the alkalinity is in the form of a bicarbonate ion. The simplified chemical reaction to produce the floc is



In the case of water that does not have sufficient alkalinity to react with alum, alkalinity must be added. Usually alkalinity in the form of a hydroxide ion is added by the addition of calcium hydroxide (slaked or hydrated lime). The coagulation reaction with calcium hydroxide is as follows:



Alkalinity may also be added in the form of a carbonate ion by the addition of sodium carbonate (soda ash). Most water has sufficient alkalinity, so no chemical needs to be added other than aluminum sulfate. The optimum pH range for alum is from about 4.5 to 8.0. Alum sulfate is available in dry or liquid form; however, the dry form is more common. The dry chemical may be in granular, powdered, or lump form; the granular form being the one most widely used. The granular form, which is 15 to 22 %  $\text{Al}_2\text{O}_3$  contain approximately 14 water of crystallization, a weight from 60 to 63 lb/ft<sup>3</sup> (Reynolds and Richards, 1996)

#### **2.4.2 The Ability of Aluminum Sulfate Coagulants to Remove THMs Precursor**

Oliver and Lawrence (1978) show that THM production of a Canadian river water supply was reduced by 61 percent with alum coagulation and rapid sand filtration.

Young and Singer (1979) demonstrated that coagulation with an alum dosage of 25 mg/L reduced the THMFP of North Carolina water by 60 percent.

Chadik and Amy (1983) removed trihalomethanes precursors from various natural waters by alum and ferric chloride. The experiment was conducted in two pH

condition. First condition was conducted at an ambient pH value (8.5). The others were conducted at a modified pH value (6.0). The results indicated that TOC and THMFP decrease as a function of the coagulation dosage. For Mississippi River water, the untreated THMFP of 313  $\mu\text{g/L}$  was reduced to 131  $\mu\text{g/L}$  by alum coagulation. The indicated coagulant dosage was 15 mg Al/L.

Hubel and Edzwald (1987) determined the optimum alum dosages for coagulation of the Grasse River water. For a pH value of 7.2, the optimum dose was 65 mg/L and it removed turbidity from 24 to 57 percent, soluble UV-254 from 71 to 74 percent, TOC at 53 percent, and TTHMFP at 53 percent. For the pH value of 5.5, the optimum dose was 30 mg/L and it removed turbidity from 50 to 67 percent, soluble UV from 82 to 83 percent, TOC at 73 percent, and TTHMFP at 69 percent.

Suporn Sakornarun (1987) performed the comparative study on THMs content in water as a result of pre-chlorination and post-chlorination and the relationship between TOC and THMs produced. Water samples from Chao Phraya River in Bangkok and Ayudtaya Province, and from Klong Prapa at Samsen and Bangken were collected and treated with chlorine dosages of 3, 5, 7, 10, 15, and 20 ppm and contact times of 1, 3, 6, 12, and 24 hrs. THMs contents were analyzed before and after chlorination. The results showed that THMs contents in treated water as the post-chlorination were significantly less than those treated with pre-chlorination. Coagulation by alum reduced TOC by 34.30 percent and THMs by 47.86 percent in raw water.

Edzwald (1993) demonstrated that the coagulant dosages guidelines for alum; a pH of about 5.5 was used for 0.5 mg of Al per mg of DOC, and a pH value of 7 was used for 1 mg of Al per mg of DOC. From bench, pilot and full-scale studies at an alum dosage about 175 mg/L of water sample from the Grasse River (Canton, NY), 80 percent of UV, 72 percent of TTHMFP and 72 percent of DOC were removed.

Cheng et al. (1995) optimized pH and alum dosages to remove TOC and to reduce THMFP. The results demonstrated two conditions for the purpose. The first

condition was at a pH value of 5.5 and an alum dosage of 20 mg/L. The second condition was at a pH value of 6.3 and an alum dosage 40 mg/L. Those two conditions were effective to remove 20-30 percent of TOC and 30 percent of THMFP.

Crozes et al. (1995) indicated that enhanced coagulation, tested for NOM coagulation, of inorganic coagulants were superior to synthetic organic polymer. Ferric chloride proved to be consistently more effective than alum in removing NOM. Typically, the preadjustment of the pH at a value of 6 increased NOM overall removals to as much as 65 percent and reduced the coagulant dose by as much as 60 percent.

Vrijenhoek et al. (1998) determined the optimum removal of THM precursors from two water sources (the Colorado River water and the California State Project water). The optimum removal of THM precursors was achieved at a pH of 5.5. Particles were effectively removed at alum doses of 20-60 mg/L; further increases in the alum dosage had little effect.

Marhaba and Pipada (2000) determined the maximum removal of NOM in drinking water by coagulation with alum sulfate over a range of pH. Resin adsorption procedures were used to isolate and fractionate NOM into six dissolve organic matter (DOM) fractions: hydrophobic acid (FA), base (FB), neutral (FN), and hydrophilic acid (PA), base (PB), and neutral (PN). The results indicated that the maximum TOC reduction occurred at two different dosages for PA, PB, PN and FN fractions at a pH of 6 and an alum dosage of 60 mg/L. For FA and FB, their fraction maximum reduction occurred at a pH of 6 and an alum dosage of 40 mg/L.

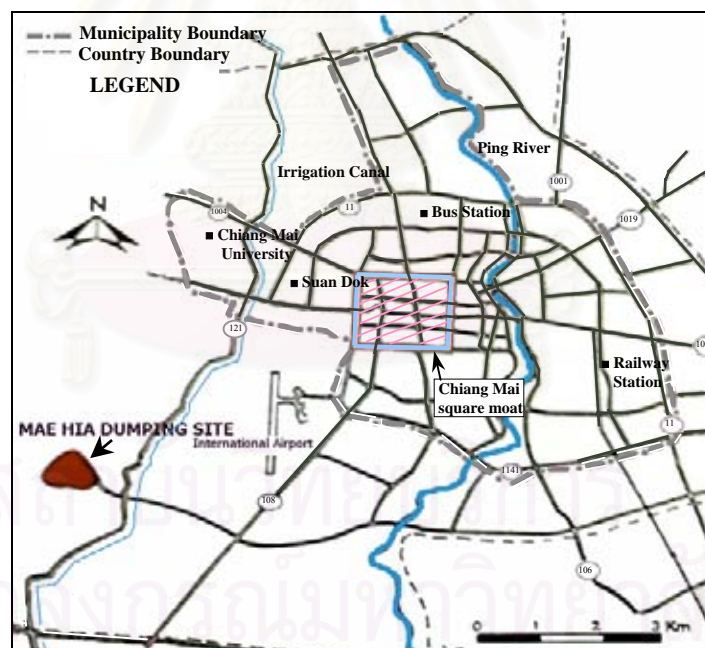


## CHAPTER 3

### METHODOLOGY

#### 3.1 Source of Samples

The Mae-Hia solid waste dumping site is situated about 5 km to the south west of Chiangmai city as shown in Figure 3.1. It lies at a latitude of  $18^{\circ} 44' 37''$  N to  $18^{\circ} 44' 58''$  N, and a longitude of  $98^{\circ} 56' 06''$  E to  $98^{\circ} 56' 43''$  E on a very gentle slope in the range 299 m to 307 m above mean sea level. It covers 75 rai (12 ha). There is a village located 20-300 m east of the dumping site. It has 158 households and a population of about 976 (Wipha Osatharanyakul, 1999).

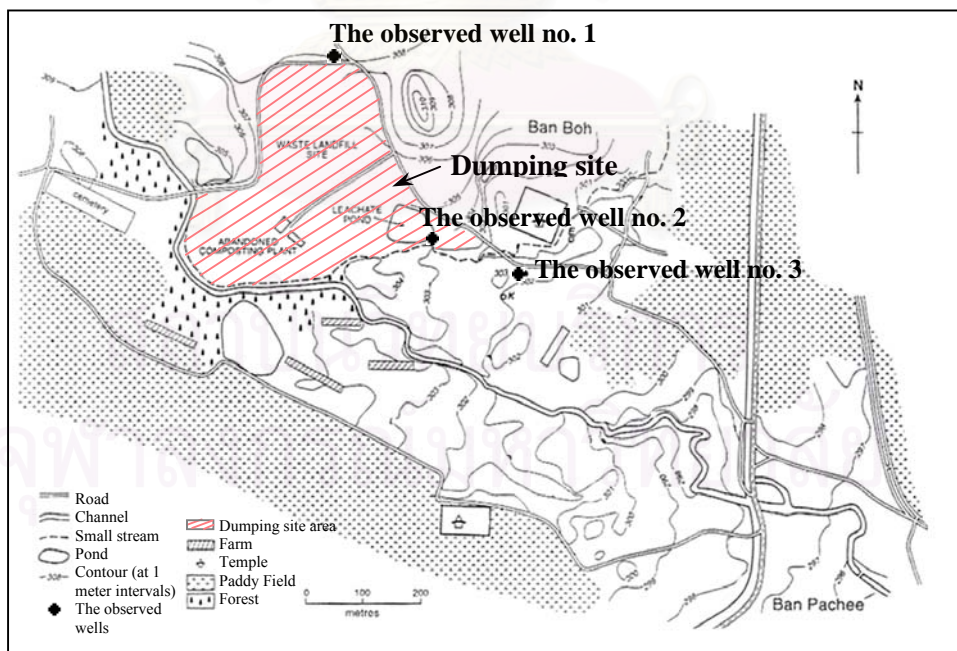


**Figure 3.1** Map of Chiangmai city showing the location of the Mae-Hia solid waste dumping site

From 1958 until 1989, the Mae-Hia solid waste unsanitary dumping site was the only place where solid waste from various sources was open dumped. In May 1989, it was closed because of the protests from the villagers living nearby. Since the

landfill management was not effective enough, the problems of odor and degradation of water sources by leachate occurred in the surrounding areas from time to time.




Mae-Hia solid waste dumping site has a creek which originates from the Doi-Suthep National Park and flow along the western periphery of the dump. Another small stream, diverging from this creek, flows along the southern part of the dumping site and runs through Ban-Boh village. Mae-Hia dumping site is one case of an unsanitary landfill which leads to the flow of organic matter, hazardous chemicals and liquids into surface water, groundwater and soil. More than 100 shallow wells were identified in the vicinity of dumping site. Almost every house has its own shallow well. In this study, water samples were collected from three observed wells which were the shallow well in the area of the dumping site (the observed well no. 2) and the selected shallow wells near the dumping site (the observed wells no. 1 and 3). Raw water were sampled from the observed wells approximately once a month (totally six sampling times) between September 2003 and January 2004. The positions of the observed wells are shown in Figure 3.2.



**Figure 3.2** Map showing the position of the observed wells

The summary description of the observed wells is presented in Table 3.1. In addition, the pictures of the three observed wells are illustrated in Figures 3.3 and 3.4.

**Table 3.1** The observed wells description

The observed well no.	Distance from the edge of the dumping site area (m)	Depth of well <sup>a</sup> (m)	Well water level <sup>b</sup> (m)	Well cover	Water utilization and treatment	Physical information and the picture of raw water color
1	2,000	5.3	1.3	Y	Drinking and miscellaneous purposes, no treatment	 Clear water
2	300	4.6	1.5	N	Agriculture, miscellaneous purposes, no treatment	 Turbid water with floating wooden chips
3	700	5.6	4.1	Y	Miscellaneous purposes, no treatment	 Clear water

Note: a = level at the top of the well – level at the bottom of the well , b = level at the top of the well – level of



(a) The observed well no. 1



(b) The observed well no. 3

**Figure 3.3** The observed shallow wells near the dumping site



(c) The observed well no. 2

**Figure 3.4** The observed shallow well in the area of the dumping site

### 3.2 Experimental Procedure

The following steps are the experimental procedures of the raw water and coagulated water from the observed wells which were analyzed and experimental in the laboratory of the Department of Environmental Engineering, Faculty of Engineering, Chiang Mai University.

1. Determinations of turbidity, pH, temperature, UV-254, alkalinity, TOC, DOC, chlorine demand and  $TTHM_0$  of the raw water from the observed wells no. 1, 2 and 3
2. Experiments of alum coagulation of the water from the observed wells were conducted as briefly described below
  - Coagulation was performed at 100 rpm for 1 minute
  - Flocculation was carried out at 30 rpm for 30 minutes
  - Sedimentation was conducted at a settling time of 1 hour.
  - Filtration was performed using 1.2  $\mu\text{m}$  - glass fiber filter paper

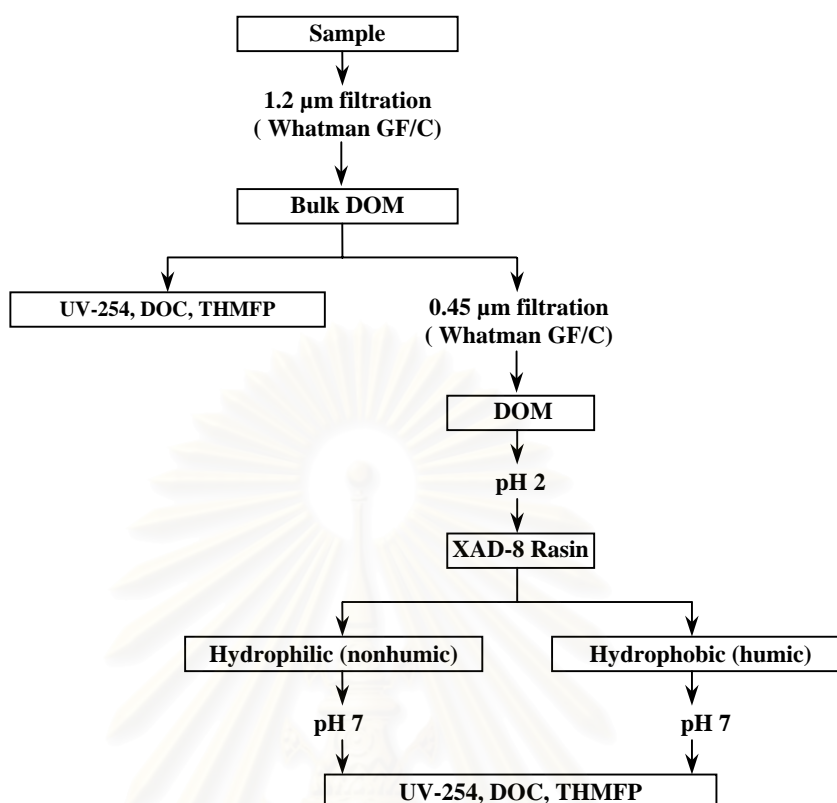
3. Determination of turbidity, pH, temperature, UV 254, alkalinity, TOC, DOC, chlorine demand and TTHM<sub>0</sub> of coagulated waters.
4. The raw waters and coagulated waters were held for 7 days reaction period at standard reaction condition.
5. Determinations of pH, temperature, free chlorine residual and TTHM<sub>7</sub> in shallow well waters and coagulated waters after 7 days reaction.
6. Determinations rate of THMs formation at the varied dosage of chlorine, the chlorine dose at 168 hours was performed using a series of three chlorine dosages based on chlorine demand ( $D_{cl}$ )  $\pm$  2 mg/L of the water samples.

### 3.3 Fractionation procedure

#### 3.3.1 Hydrophobic and hydrophilic fractionation

Raw water from the observed wells was also fractionated into the hydrophobic and hydrophilic fractions as detailed in the following steps and as shown in Figure 3.5.

- The water samples were filtered through Whatman GF/C glass fiber filter and analyzed for DOC, UV-254, and THMFP.
- The remaining filtrates were acidified to pH 2 with 6 N HCl. Acidified water samples were fractionated into hydrophobic (humics) and hydrophilic (nonhumics) substances using the XAD-8.
- The organic substances that passed through the column were operationally defined as hydrophilic DOC while those that were adsorbed on the resin were defined as hydrophobic DOC. Adsorbed organic substances were eluted with 0.10 N NaOH.
- The pH of both fractions was adjusted to 7 prior to further analyses. The neutralized fractions were analyzed for UV-254, DOC, THMFP, COOH, phenolic-OH, and organic nitrogen.



Note: The preparation of the XAD-8 Resin is described in section 3.3.2

**Figure 3.5** Analytical protocol of fractionation procedure

### 3.3.2 Prepare XAD-8 Resin

- The amount of XAD-8 resin was determined according to Leenheer (1981) with a capacity factor of 50 ( $K'=50$ ) and a porosity of 0.60.
- XAD-8 resin was intensively refined with 0.1N NaOH for 24 hours and sequentially extraction with Acetone and Hexane for another 24 hours in a set of Soxhlet extraction apparatus.
- The refined XAD-8 resin was transferred into columns in slurry of Methanol.
- The packed resin was rinsed with two times 2.5 bed volumes of 0.1 N each NaOH first, then HCl, and finished with Mill-Q water until the conductivity and DOC of the effluents were below 10 us/cm and 0.2 mg/L, respectively.

### 3.4 Coagulation Experiment

Since the principal factors affecting the coagulation of water are pH and the coagulant dosages, the selection of pH and coagulant dosage require the use of coagulation studies in a laboratory. The Jar-Test technique is usually used to determine the proper pH value and optimum dosage of coagulant.

#### 3.4.1 Jar-Test Apparatus and Process

The experiment utilized a multi stirrer apparatus, simultaneous tests was conducted on a series of samples covering a range of pH. The samples were coagulant follow the steps: coagulation, flocculation, and sedimentation. After a given time of Jar-Test, the stirring was ceased and the floc that formed was allowed to settle. Then the supernatant samples were filtered by a 1.12  $\mu\text{m}$  GFC prior to determining their turbidity, alkalinity, THMFP and TOC; and the samples were filtered through 0.45  $\mu\text{m}$  cellulose acetate membrane before DOC and UV-254 was measured. All filtered samples were defined as coagulated water. Using the same pH in the second similar set of tests was performed on a series of samples covering a range of alum dosages to determine the optimum alum dosage.

#### 3.4.2 The Jar-Test Conditions

The jar-test experiments were carried out under the conditions of different alum dosages and various controlled pH as depicted in Table 3.2.

**Table 3.2** The experimental jar-test conditions

Coagulant	Coagulant dosage (mg/L)	Controlled pH
Alum (Aluminum sulfate)	10, 20, 30, 40, 50, and 60	5, 6, 7 and 8



### 3.4.3 Coagulant

Regular-grade aluminum sulfate or alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ ) typically in powder form containing approximately 97 percent of  $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$  was used for preparing the 20 mg/mL stock solution in the experiments.

## 3.5 Analytical Methods

### 3.4.1 Alkalinity

The alkalinity of water samples were determined in accordance with standard method 2320 Alkalinity; section 2320 B, Titration Method.

### 3.4.2 pH

The pH of water samples were measured by a Horiba pH meter, Model D-13E with an accuracy of  $\pm 0.01$  pH unit.

### 3.4.3 Turbidity

Turbidity was directly measured by a HACH 2100, Turbidity Meter.

### 3.4.4 Temperature

Temperature of water samples were directly measured by a Thermometer.

### 3.4.5 UV 254 nm

UV 254 of water samples were measured in accordance with standard method 5910 B Ultraviolet Absorption Method. The samples were filtered through a  $0.45 \mu\text{m}$

cellulose acetate membrane prior to measurement by Perkin-Elmer Model Lambda 25, UV/VIS spectrophotometer.

### 3.4.6 TOC and DOC

TOC of water samples were measured in accordance with standard method 5310 Total Organic Carbon (TOC); section 5310 C Persulfate-Ultraviolet Oxidation Method by O.I. analytical 1010 TOC Analyzer.

### 3.4.7 THMs Species

The THMs species detected during the experiment are shown in Table 3.3. In addition to analyzing THMs, three analytical methods were used to analyze the water samples. The details are briefly described below:

**Table 3.3** Detected THMs species during the experiment.

Parameter	Detected THMs Compounds
<b>TTHM<sub>0</sub></b>	Chloroform, Bromodichloroform, Chlorodibromoform and Bromoform
<b>TTHM<sub>7</sub></b>	Chloroform, Bromodichloroform, Chlorodibromoform and Bromoform

#### 3.4.7.1 THMs

THMs were measured in accordance with standard method 5710, Formation of Trihalomethanes and Other Disinfection By-Products. Gas Chromatography was used (Agilent 6890 Series Gas Chromatographic with ECD detector) under the following condition:

##### *Inlet Condition*

Mode: Split, Initial temp: 225°C., Pressure: 31.33 psi, Split ratio: 10:1  
Split flow 15.9 mL/min, Gas Type: Helium and Total flow: 20.5 mL/min

### *Oven Condition*

The temperature programs of oven adjusted for analyzing THMs are shown in Table 3.4.

**Table 3.4** Temperature programs for analyzing THMs

<b>Ramp</b>	<b>Rate (°C/min)</b>	<b>Final temperature (°C)</b>	<b>Holding time of final temperature (min)</b>
1	15	180	1.00*
2	15	130	1.00
3	15	180	1.00

\* Initial temperature: 75°C, Initial temperature holding time: 1.00 min

### *Detector Condition*

Temperature: 300 °C, Mode: Constant make up flow, Makeup flow: 60 mL/min, Makeup Gas Type: Nitrogen

#### **3.4.7.2 Free Chlorine Residual**

Free chlorine residual was measured in accordance with Standard method 4500-Cl G. DPD Colorimetric Method. Due to THMFP analysis, the chlorinated water samples must have 3 mg/L to 5 mg/L free chlorine residual.

#### **3.4.7.3 Liquid-Liquid Extraction**

Water samples were extracted in accordance with standard method 6232 B Liquid-Liquid Extraction Gas Chromatography Method.

The summary of water samples and analytical methods are depicted in Table 3.5 and the conclusive water samples and analytical parameters in term of a schematic diagram are illustrated in Figure 3.6.

**Table 3.5** Summary of water samples and analytical method

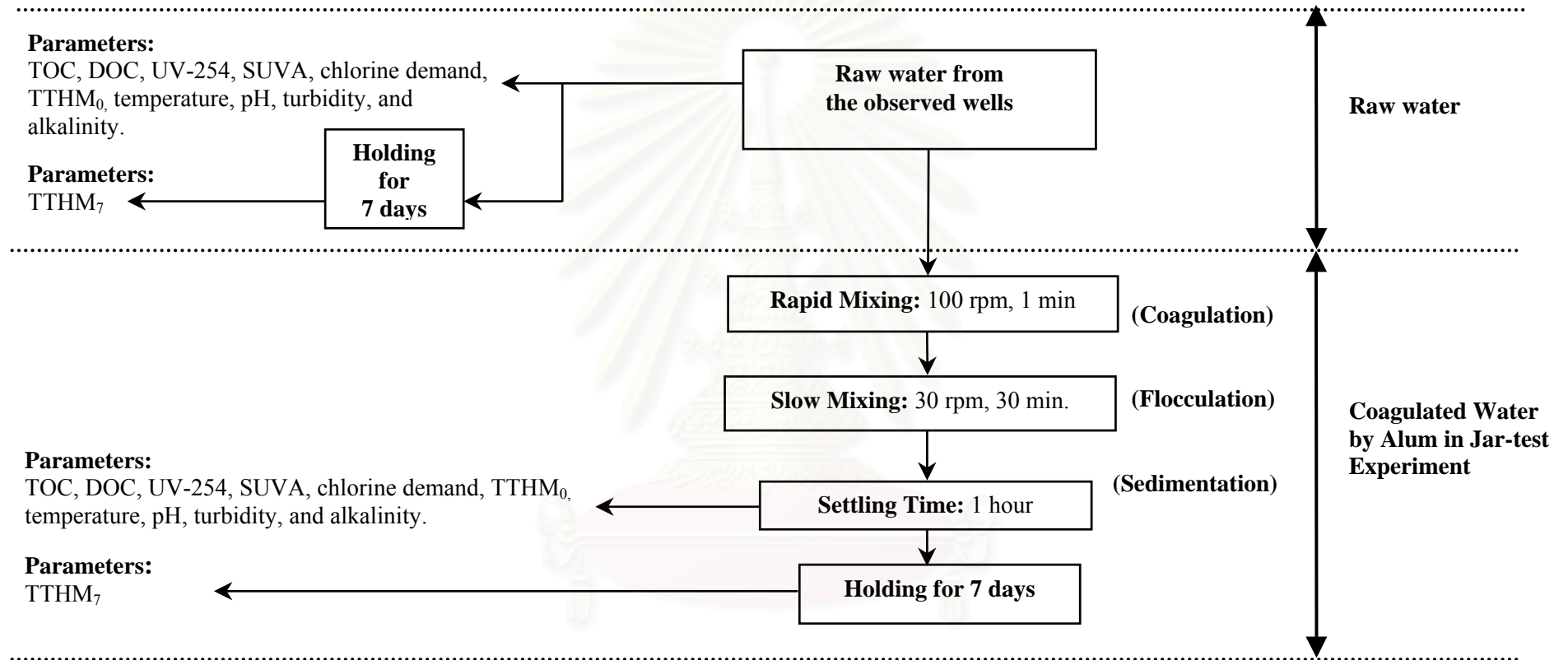
<b>Parameters</b>	<b>Before Coagulation</b>	<b>After Coagulation*</b>	<b>Analytical Method</b>	<b>Standard</b>
<b>pH</b>	√	√	Direct Measurement	-
<b>Turbidity</b>	√	√	Direct Measurement	USEPA method180.1
<b>Alkalinity</b>	√	√	Titration Method	Standard method 2320 B
<b>UV-254</b>	√	√**	Ultraviolet Absorption Method	Standard method 5910 B
<b>TOC</b>	√	√	Persulfate-Ultraviolet Oxidation Method	Standard method 5310 C
<b>DOC</b>	√	√**	Persulfate-Ultraviolet Oxidation Method	Standard method 5310 C
<b>Free chlorine residual</b>	√	√	DPD Colorimetric Method	Standard method 4500 Cl G
<b>TTHM<sub>0</sub>, TTHM<sub>7</sub> and THMFP</b>	√	√	Formation of Trihalomethanes and Other Disinfection By- Products and Liquid-Liquid Extraction Gas Chromatography Method	Standard method 5710 and 6232 B

√ Analyzing in accordance with Standard method or USEPA method

\* Filtered by 1.2 µm GFC

\*\*Filtered by 0.45 µm Cellulose Acetate Membrane

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**Figure 3.6** Water sample parameters and analytical methods in this study

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

The results from the experiments and their analysis for each particular topic are separately presented as following

#### **4.1 Characteristics of Raw Water**

The characteristics of the raw water in the observed wells located near and in the area of the closed solid waste dumping site between September 2003 and January 2004 for the observed wells no.1 and 3, and between October 2003 and January 2004 for the observed well no.2 were analyzed for physical, chemical and NOM surrogate parameters as depicted in Table 4.1.

##### **4.1.1 Physical and Chemical Characteristics**

###### **Temperature**

It is generally accepted that water temperature and the presence of organic precursors are related to seasonal variations. High temperature was more likely to activate the growth of algae and this led to an increase of reactivity rate with chlorine dose (Michael, 2000).

The raw water temperature of the observed wells no. 1, 2 and 3 were in ranged from 21.0 to 27.0 °C, 19.5 to 26.0 °C and 21.0 to 27.5 °C, respectively, as reported in Table 4.1. Figure 4.1 illustrates that the temperature was lower than 23 °C during December 2003 and January 2004 and higher than 23 °C during October 2003 and November 2003. All water samples from the observed wells had a minimum temperature value of about 20 °C in December and a maximum temperature value of about 26 °C in October. Based on this result as previously stated, high temperatures

led to an increase in the water's reactivity rate with chlorine. Therefore, THMs might be higher in October than in December.

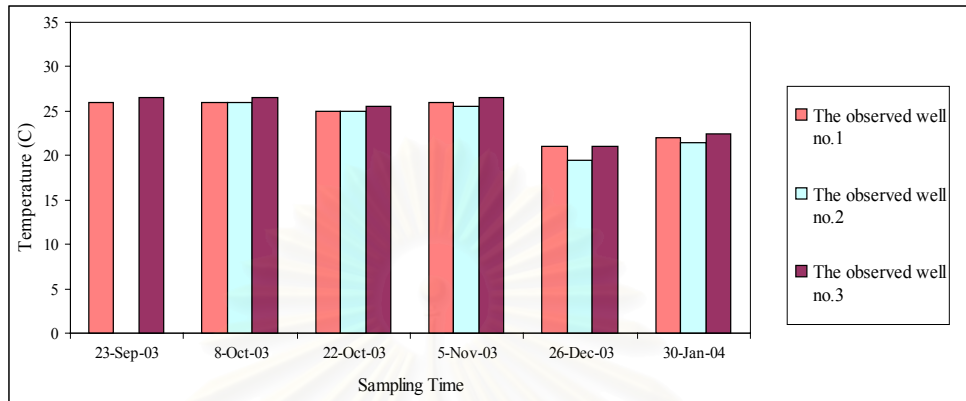
### **pH**

The pH values of the raw water in the observed wells are showed in Table 4.1 and Figure 4.2. In the cases of the observed wells no. 1 and 3, the pH values were mostly acidic to neutral between 6.00 and 6.92. Even though the observed well no. 3 is near the dumping site, the raw water there had not been affected with contaminants due to the depth below the dumping site contaminants. The pH at the observed well no. 2 was basic and ranged from 7.43 to 7.92 which is agreement with Andreottola et al. (1990) who noted that the during 2-3 years of dumping, the pH was acidic because the anaerobic degradation of wastes brought about an increase in the solubilization of chemical substances and a decrease in the sorptive capacity of wastes. Later it became alkaline because the destruction of fatty acids caused the increase in pH and alkalinity. At the time of sampling, the Mae-Hia dumping site had already been closed for 13 years. It can be seen that the raw water in the observed well no. 2 was slightly basic due to the conversion of the fatty acid in the intermediate anaerobiosis and strats with slow growth of methanogenic bacteria, which causes increase pH values and alkalinity.

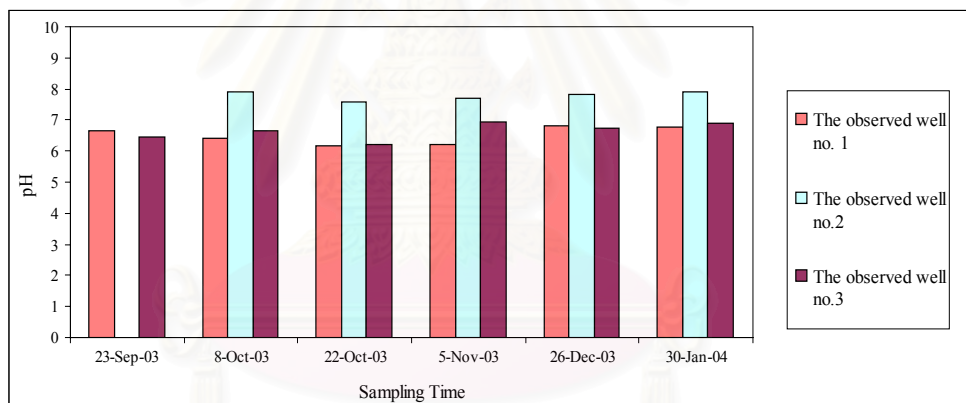
### **Turbidity**

Turbidity, or the cloudiness of water, was caused by multiple numbers of factors such as clay, silt, fine organic and inorganic matter, soluble colored organic compounds, plankton, and other microscopic organisms. It demonstrated the visible impurities present in contaminated water. The average values of turbidity were 3.64, 5.96 and 1.85 NTU in the raw water from the observed wells no. 1, 2 and 3, respectively. The results indicate that turbidity of the groundwater from the observed well no. 2 was slightly higher than Ground Water Quality Standard of 5 NTU. Meanwhile, the turbidity of groundwater from the observed wells no. 1 and 3 were clear enough under current Ground Water Quality Standards, (Notification of the Ministry of Industrial of Industry, No. 332, B.E, 2521), the low turbidity values of the

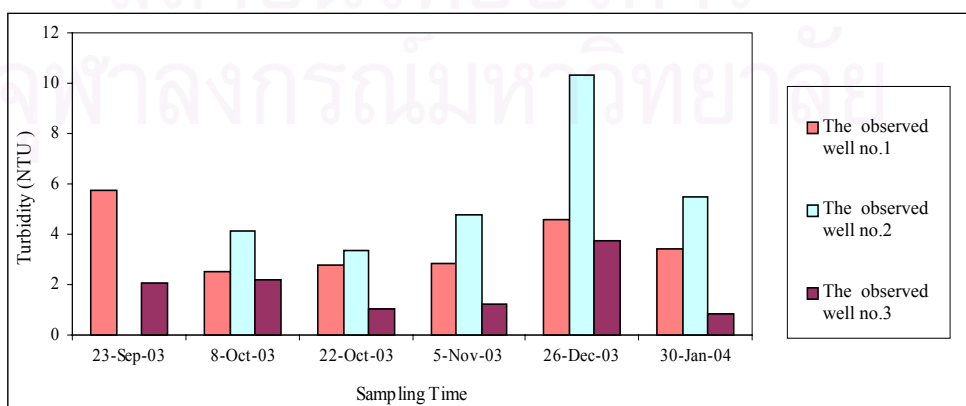
raw water from these sources were good enough for direct utilization in household water supplies.



**Figure 4.1** The temperature values of the raw water in the observed wells



**Figure 4.2** The pH values of the raw water in the observed wells



**Figure 4.3** The turbidity values of the raw water in the observed wells



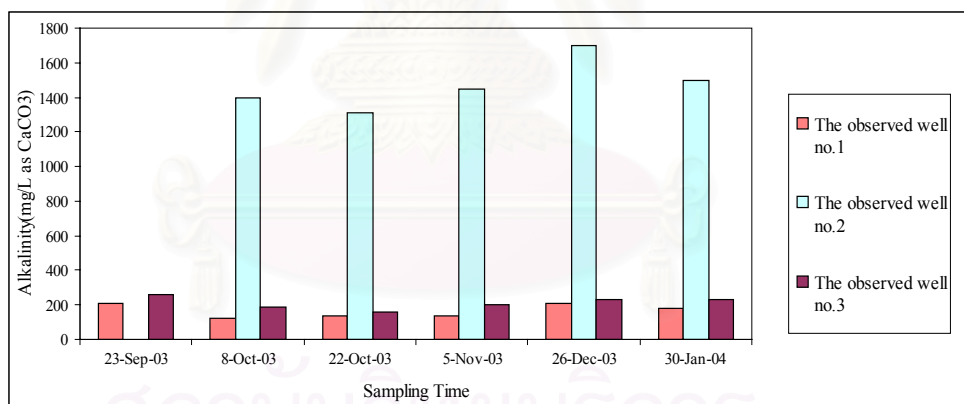
**Table 4.1** Physical, chemical and NOM surrogate parameters of the raw water collected from the observed wells

Parameters	The observed well no. 1		The observed well no. 2		The observed well no. 3	
	Range values	Average values	Range values	Average values	Range values	Average values
<b>pH</b>	6.16 - 6.82	6.50 ± 0.29	7.57 - 7.92	7.78 ± 0.14	6.19 - 6.92	6.64 ± 0.28
<b>Temperature (°C)</b>	21.0 - 26.0	24.3 ± 2.25	19.5 - 26.0	23.5 ± 2.85	21.0 - 26.5	24.75 ± 2.40
<b>Turbidity (NTU)</b>	2.50 - 5.76	3.64 ± 1.28	3.38 - 10.32	5.61 ± 2.74	0.87 - 3.72	1.85 ± 1.07
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	120 - 210	165.67 ± 38.95	1310 - 1700	1475 ± 145.49	160 - 260	212.83 ± 35.86
<b>TOC (mg/L)</b>	1.140 - 5.386	2.58 ± 1.53	5.900 - 18.470	12.22 ± 5.37	1.281 - 5.793	3.03 ± 1.81
<b>DOC (mg/L)</b>	0.791 - 3.469	1.78 ± 0.89	2.807 - 16.236	9.24 ± 6.09	0.774 - 4.126	2.57 ± 1.40
<b>UV-254 (cm-1)</b>	0.202 - 0.283	0.25 ± 0.04	14.970 - 16.236	15.65 ± 0.49	0.271 - 0.418	0.32 ± 0.06
<b>SUVA (L/mg-m)</b>	8.16 - 25.54	15.51 ± 6.55	96.47 - 546.33	251.78 ± 182.99	8.882 - 35.03	16.24 ± 10.03
<b>Chloride (mg/L)</b>	58.63 - 64.97	57.86 ± 7.53	561.49 - 579.82	570.60 ± 9.16	204.93 - 254.92	223.43 ± 27.41
<b>Chlorine Demand (mg/L)</b>	14.18 - 34.60	24.47 ± 6.92	63.69 - 74.45	68.66 ± 3.88	18.60 - 33.05	27.07 ± 5.88
<b>THM<sub>0</sub> (µg/L)</b>	ND	ND	ND	ND	ND	ND
<b>THM<sub>7</sub> (µg/L)</b>	108.901 - 187.813	139.08 ± 32.68	170.511 - 241.938	209.91 ± 26.26	149.372 - 262.613	191.02 ± 38.89
<b>THMFP (µg/L)</b>	108.901 - 187.813	139.08 ± 32.68	170.511 - 241.938	209.91 ± 26.26	149.372 - 262.613	191.02 ± 38.89

ND = Not Detected

### Alkalinity

The alkalinity level indicates the capacity for solutes such as a carbonate, bicarbonate and a hydroxide that contained in natural water to react with acid. Most natural waters contain bicarbonate as a major dissolved anion and the principle source of alkalinity (Hem, 1985). As can be seen from Figure 4.3, it shows that high alkalinity values in the range of 1300 to 1700 mg/L as CaCO<sub>3</sub> were observed in the raw water from the observed well no. 2 between October 2003 and January 2004. At the observed wells no. 1 and 3, alkalinity ranged from 102 to 210 mg/L as CaCO<sub>3</sub> and from 167 to 260 mg/L as CaCO<sub>3</sub>, respectively, which were extremely low when compared with the observed well no. 2. The relatively high alkalinity in the raw water from the observed wells indicated that amount of alkalinities in water during coagulation were enough for coagulation since alkalinity must be destroyed in the reaction with aluminum sulfate to produce the hydroxide floc in the coagulation reaction (1 mg/L of alum  $\equiv$  0.45 mg/L alkalinity as CaCO<sub>3</sub>).

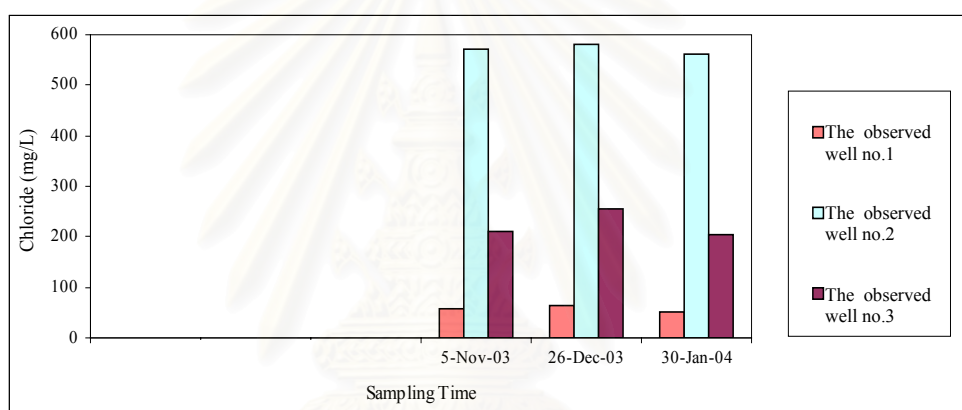


**Figure 4.4** The alkalinity values of the raw water in the observed wells

### Chloride

Chloride played an important role of major ionized substances dissolved in well water. The concentration of chloride can not be reduced by any soil type and chloride is slowly dispersed under all conditions (Polkowski and Boyle, 1970). Table 4.1 and Figure 4.5 shows that the raw water from the observed well no. 2 had a chloride concentration range of 561.49 to 579.82 mg/L which is higher than Ground

Water Quality Standard limit of 250 mg/L because it might be contaminated from dumping site. Chloride in the raw water from the observed well no. 3 ranged from 204.93 to 254.92 mg/L, which is higher than that of the observed well no. 1 which ranged from 58.63 to 64.97 mg/L. It might be a resulted of the washout effect of the pollutants that have migrated. However, the chloride in the raw water from the observed wells no. 1 and 3 were suitable enough compared with Ground Water Quality Standards, (Notification of the Ministry of Industrial of Industry, No. 332, B.E, 2521); hence, the raw water from these sources are good enough for direct utilization such as household water supplies.



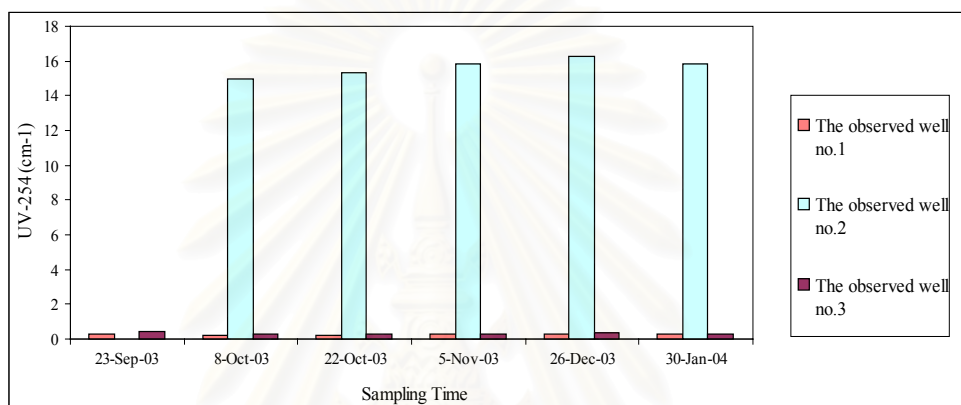
**Figure 4.5** The chloride values of the raw water in the observed wells

#### 4.1.2 NOM Surrogate Parameters

##### UV absorbance at wavelength 254 nm (UV-254)

The use of UV-254 as a NOM surrogate has been shown to have the advantage of probing the state and reactions of aromatic functional groups in NOM (APHA, AWWA and WEF, 1995). Although the NOM from different origins may have different elemental compositions and other chemical properties, their spectra are similar. In general, light absorbance of humic substances in the water will increase with the degree of aromatic rings in the humic substances, the ratio of carbon in aromatic nuclei to carbon in aliphatic or alicyclic side chains, the total carbon contents in the water, and the molecular weight of the humic acids. However, the value of UV-254 strongly depends on the concentrations of humic acids in water. Figure 4.5

showed UV-254 of the raw water in the observed wells over the period of the study. From the graph, it was found that the average values of UV-254 of 0.25 1/cm, 15.73 1/cm and 0.32 1/cm were also detected from the raw water in the observed wells no. 1, 2 and 3, respectively. UV-254 values in the raw water from the observed well no. 2, may be extremely high due the fact that the concentration of aromatic rings in the obtained raw water may be high due to the contaminants from the dumping site.

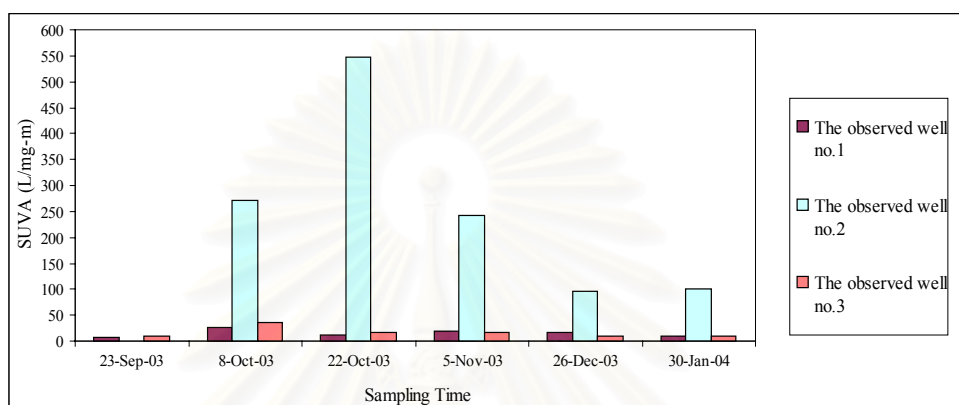


**Figure 4.6** UV-254 values of the raw water in the observed wells

### Specific ultraviolet absorbance (SUVA)

Recently, the specific UV-254 (defined as UV-254 per milligram of organic carbon, also known as SUVA) has also been used as another surrogate for NOM and the DBP precursors. SUVA is defined as a surrogate parameter used to estimate hydrophobic NOM; a higher SUVA means that the water is enriched in hydrophobic such as humic substance. Humic molecules contain aromatic, barboxyl, caobonyl, methoxyl and aliphatic units (Stevenson, 1982 and Christman et al., 1983). In drinking water treatments, SUVA can be utilized to predict the reactivity of humic acids with coagulants and disinfectants (Edzwald, 1993). From the obtained data in Figure 4.6, it can be seen that the raw water at the observed well no. 2 had enormously high SUVA values, from 96.47 to 546.33 L/mg-m. In cases of the observed wells no. 1 and 3, the raw water also had high SUVA values ranged from 8.16 to 25.54 L/mg-m and from 8.75 to 35.03 L/mg-m, respectively. From this point, it can be stated that the raw water may comprise of a high humic content and also have the ability for using coagulation or softening process to remove THM

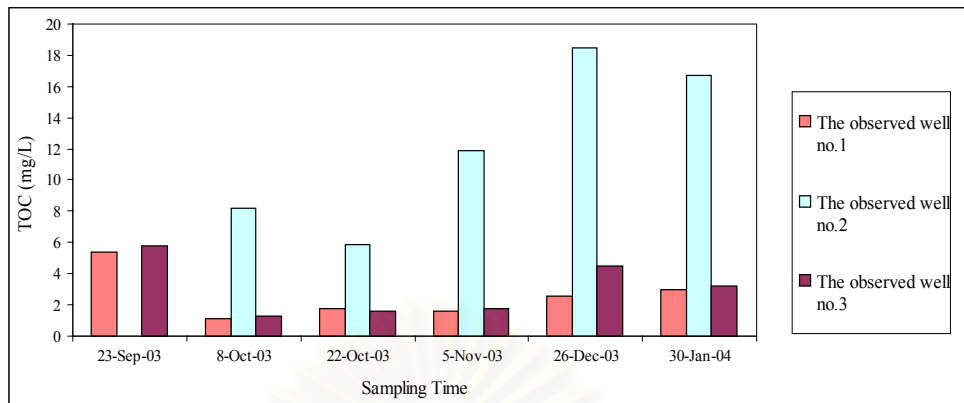
precursors. Correspondingly, it was established by many researchers that water having high SUVA values ( $SUVA > 3 \text{ L/mg-m}$ ) has been found to contain organic matter that is more humic-like in character, higher in apparent molecular weight, and more readily removed by coagulation.



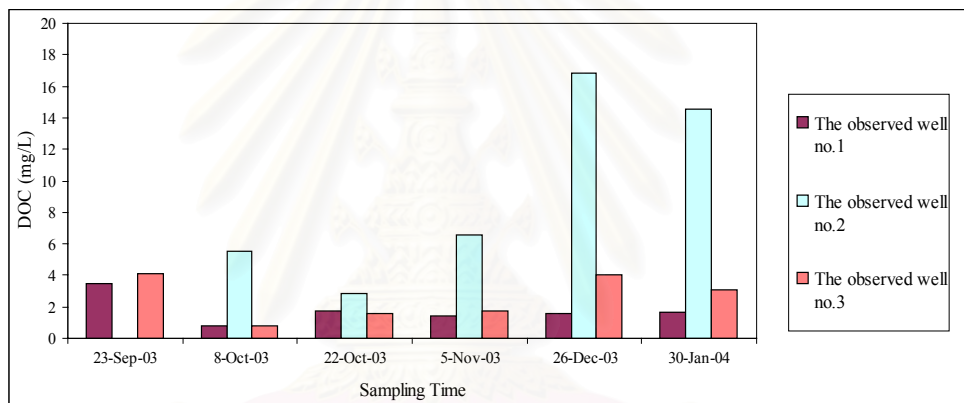
**Figure 4.7** SUVA values of the raw water in the observed wells

### Organic Carbon

Total organic carbon (TOC) and dissolved organic carbon (DOC) were analyzed in this study. TOC in the raw water from the observed wells no. 1, 2 and 3 ranged from 0.940 to 5.386 mg/L, from 5.900 to 18.470 mg/L and from 0.781 to 5.793 mg/L, respectively whereas those of DOC ranged from 0.791 to 3.469 mg/L, from 2.807 to 16.830 mg/L and from 0.774 to 4.126 mg/L, respectively. More than 10 mg/L of TOC and DOC were recorded at the observed well no. 2 during December 2003 - January 2004. Except this time above, TOC and DOC remained at less than 10 mg/L. As the results of such TOC which is mainly NOM surrogate parameters was found in water samples, it could be stated that high level of natural organic compounds may be contain in the raw water from the observed wells .



**Figure 4.8** TOC values of the raw water in the observed wells



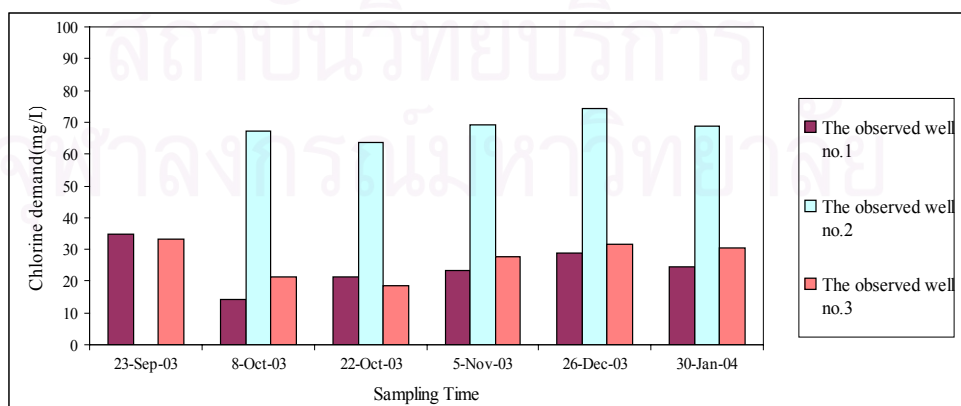
**Figure 4.9** DOC values of the raw water in the observed wells

### **Chlorine Demand and Trihalomethanes Formation Potential (THMFP)**

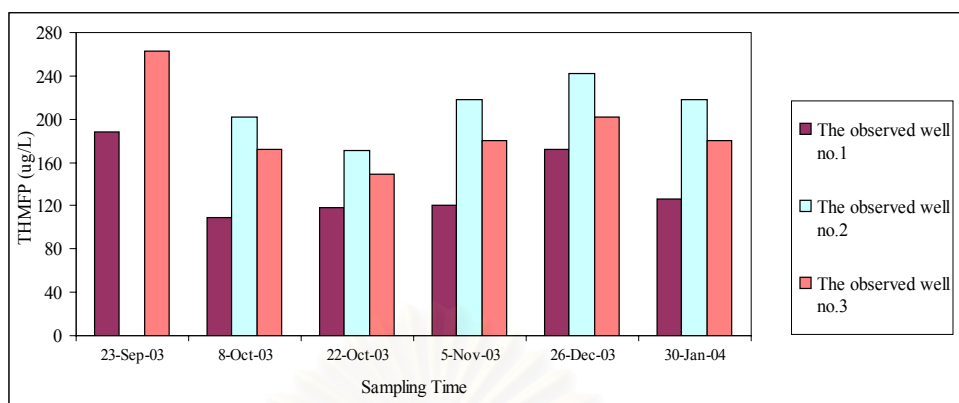
Chlorine dosages are the most important factors influencing THM formation. The level of trihalomethanes formed upon chlorination of natural waters depends upon several operational conditions such as chlorine dosages and chlorine contact time. Normally, the chlorine demand of all samples was required to measure in order to know exact chlorine dosage that nearly complete interacted with substance in water samples. Muttamara et al. (1995) showed the relationship between THM concentrations and chlorine dosage. THM concentrations increased as the chlorine dosage increased. These chlorine dosages ensured that the free chlorine residual at the end of the incubation period of 7 days reaction was required to be within a range between 3 and 5 mg/L to present THMFP.

Many studies have been carried out on the reactivity of humic substances with chlorine and some model on the reaction pathways that result in the formation of various degradation products including THMs (Christman et al., 1978; Morris and Baum, 1978; Reckhow et al., 1990; and Hureiki et al., 1994). THMFP were found under the conditions of a 7 days reaction time with an excess chlorine demand of about 3-5 mg/L. In this study, chlorine demand range between 14.18 and 78.11 mg/L, between 63.69 and 74.45 mg/L and between 18.60 and 75.85 mg/L, were detected from the raw water in the observed wells no. 1, 2 and 3, respectively. While THMFP in the raw water from the observed wells no. 1, 2 and 3 ranged from 108.90 to 187.81  $\mu\text{g/L}$ , from 170.51 to 241.94  $\mu\text{g/L}$  and from 149.37 to 201.45  $\mu\text{g/L}$ , respectively. The obtained results above could conclusive that the increase in THMFP might be due to the increase of chlorine demand for the reaction.

The results lead to the conclusion that the raw water from the observed wells had a moderately high THMFP according to the US Environmental Protection Agency (USEPA) that has set a maximum contaminant level (MCL) of 100  $\mu\text{g/L}$  for total trihalomethanes and has set a new MCL of 80  $\mu\text{g/L}$  in stage 1 of the disinfection by product rule (D/DBP Rule; USEPA 1998). It must be noted that THMFP is also NOM surrogate parameter and are potentially carcinogenic substances. Hence, it is important to reduce THMFP by coagulation in order to mitigate the health risks for people who generally utilize the water from the observed wells in this area.



**Figure 4.10** The chlorine demand values of the raw water in the observed wells



**Figure 4.11** THMFP values of the raw water in the observed wells

The high values of NOM surrogate parameters found in this study implicated the importance of finding remedies for reducing NOM surrogate parameters. Because NOM surrogate parameters might cause a long term health effect, cancer. Therefore, the coagulation experiment was set to reduce NOM surrogate parameters from shallow well water in order to provide a strategy for solving the problem in this study.

#### 4.1.3 Fraction of Raw Water

Thrumman (1985) expands on the characteristics of each fraction. The hydrophobic fractions, which are more aromatic carbon than the hydrophilic products and are low organically bound nutrients, contained the acidic products. Those acidic products came from the degradation of the contaminants from the dumping site. Hydrophilic fractions mainly consist of proteins, carbohydrates, carboxylic acids, amino acids and amino sugar (Marhaba and Van, 2000). The variation of hydrophobic and hydrophilic materials in different water may diverge depending on the source of materials, geology, biological process etc. but in the same source water, its component should be the same. From the results in Tables 4.2 to 4.4, it demonstrated that in the observed wells, its component were the same, except for the amounts of the components differed. Hydrophobic components were the major fraction in the water.

Raw water from the observed wells was fractionated into hydrophobic and hydrophilic fractions. The sum of the hydrophobic and hydrophilic DOC was compared with the values of the respective bulk samples to check possible losses in



the organic material during fractionation. In this research, the hydrophobic group fractionated by XAD-8 resins was more commonly observed than the hydrophilic group. Tables 4.2 to 4.4 illustrates the value of THMFP of each hydrophilic–hydrophobic fraction of the observed well no. 1, which implies that most of THMFP is concentrated in the hydrophobic group at 99.934  $\mu\text{g/L}$ , and least of them is in the hydrophilic fractionation 16.497  $\mu\text{g/L}$ . Similar observations were also noted for the observed wells no. 2 and 3, THMFP concentration in the hydrophobic group were 164.711  $\mu\text{g/L}$  and 136.535  $\mu\text{g/L}$ , respectively, less of them is in the hydrophilic fractionation of 47.170  $\mu\text{g/L}$  and 49.824  $\mu\text{g/L}$ , respectively. The sums of the hydrophilic and hydrophobic DOC in the observed wells were close to the DOC of the bulk sample. This indicates that almost all of the organic carbon adsorbed on the resin during the fractionation step was eluted with NaOH. Moreover, the small loss in DOC is attributed to the hydrophobic-neutral fraction that was not desorbed by the NaOH eluant (Leenheer, 1981).

This result was consistent with the previous study of Thruman (1985), which stated that humic species (hydrophobic fraction) typically dominant in NOM contributing from 50 to 90 percent of the DOC in most natural waters. The hydrophobic fraction was slightly more abundant in reservoir water (51 to 62 percent) than in the river water (41 to 50 percent) (Martin-Mousset et al., 1997). Tadanier et al. (1999) analyzed the source water from Drummond Lake and Chickahominy River (Virginia), and reported that the hydrophobic acid dissolved material matrix (DMM) fraction dominated the dissolved organic matter (DOM) distributions, followed by the hydrophilic neutral fraction. In Taiwan, Huang and Yeh (1997) reported that hydrophobic organics from the Feng-San Stream yielded a higher halogenated organics formation potential because of its higher aromatic content, phenolic acidity, and ultraviolet absorbance. On the other hand, Marhaba and Van (2000) found that hydrophilic acid was a dominant fraction in the water treatment plant in Northern New Jersey, USA. Owen et al. (1995) also found that hydrophilic fraction accounted for about half of the DOC (44 to 58%) meanwhile, 42 to 56% of hydrophobic.

**Table 4.2** NOM surrogate parameters in the hydrophilic and hydrophobic fractions of the raw water at the observed well no. 1

Parameter	The observed well no. 1					
	Raw water	Hydrophilic	Hydrophobic	Sum of fraction	%Fraction	
					Hydrophilic	Hydrophobic
UV-254 (1/cm)	0.27	0.06	0.08	0.15	42.83	57.17
DOC (mg/L)	1.66	0.48	0.60	1.08	44.21	55.79
SUVA (L/mg-m)	10.27	13.14	13.90	27.05	48.60	51.40
<b>Chlorine Demand (mg/L)</b>	24.44	4.13	18.65	22.78	18.13	81.87
THMFP (µg/L)	126.72	16.50	99.93	116.43	14.17	85.83

**Table 4.3** NOM surrogate parameters in the hydrophilic and hydrophobic fractions of the raw water at the observed well no. 2

Parameter	The observed well no. 2					
	Raw water	Hydrophilic	Hydrophobic	Sum of fraction	%Fraction	
					Hydrophilic	Hydrophobic
UV-254 (1/cm)	15.84	2.14	12.77	14.91	14.37	85.63
DOC (mg/L)	14.53	5.75	7.10	12.85	44.75	55.25
SUVA (L/mg-m)	102.00	37.27	179.90	217.17	17.16	82.84
<b>Chlorine Demand (mg/L)</b>	68.70	15.86	54.16	70.02	22.65	77.35
THMFP (µg/L)	217.56	47.17	164.71	211.88	22.26	77.74

**Table 4.4** NOM surrogate parameters in the hydrophilic and hydrophobic fractions of the raw water at the observed well no. 3

Parameter	The observed well no. 3					
	Raw water	Hydrophilic	Hydrophobic	Sum of fraction	%Fraction	
					Hydrophilic	Hydrophobic
UV-254 (1/cm)	0.28	0.07	0.11	0.18	37.92	62.08
DOC (mg/L)	3.10	1.19	1.62	2.82	42.40	57.60
SUVA (L/mg-m)	8.89	5.63	6.78	12.41	45.35	54.65
<b>Chlorine Demand (mg/L)</b>	30.45	7.96	22.31	30.28	26.30	73.70
THMFP (µg/L)	180.63	49.82	136.53	186.36	26.74	73.26

## 4.2 Characteristics of Coagulated Water

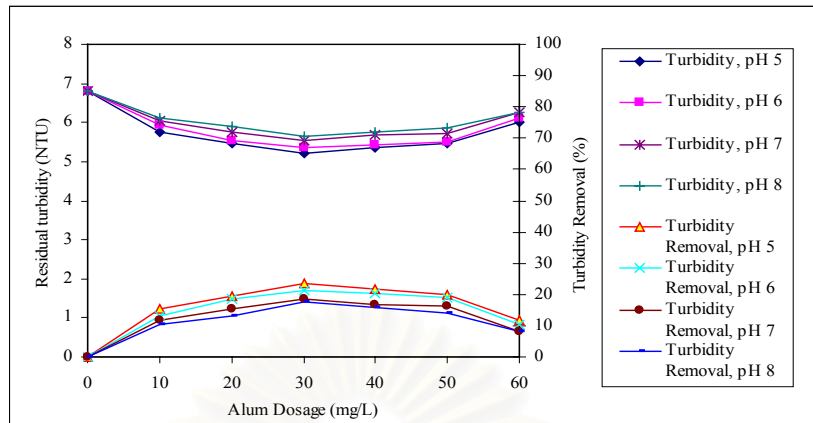
In this experimental series, the raw water samples from the observed wells were conducted in Jar-Test apparatus under the conditions of controlled pH values between 5 and 8 and at various alum dosages from 10 to 50 mg/L.

### 4.2.1 Physical and Chemical Characteristics

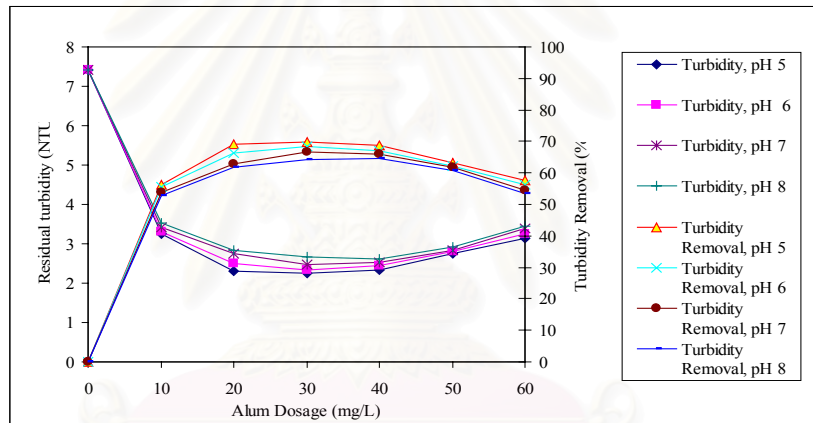
This section will mainly discuss about the physical and chemical characteristics, which are turbidity, pH and alkalinity.

As can be seen from Figures 4.11, 4.12 and 4.13 show residual turbidity and percentage of turbidity removal by alum coagulation of the observed wells no. 1, 2 and 3, respectively. It was found that in case of the observed wells no. 1 and 2, at controlled pH values of 5 and dosage about 30 mg/L. It shows the most decreasing of turbidity are approximately 20 and 70 percent, at the observed wells no.1 and 2, respectively. However, in case of variation on alum dosages from 10 mg/L to 60 mg/L, percentage of turbidity removal is slightly different. In case of the observed well no. 3, at controlled pH values of 6 and dosage about 40 mg/L, the highest percentage of turbidity removal approximately 60 percent was observed. Regarding the results that mention above, it can be concluded that turbidity in the raw water from the observed wells can be optimally removed by alum coagulation at low alum dosage approximately 30-40 mg/L with controlled pH values between 5 and 6.

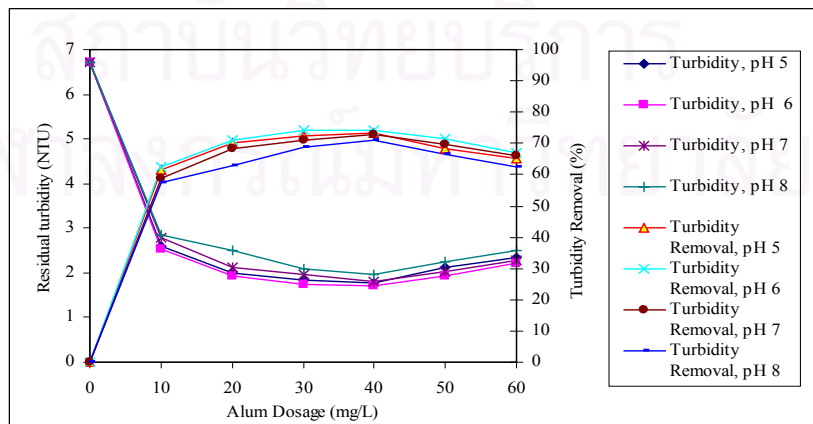
As can be seen from Figures 4.14, 4.15 and 4.16, it shows that in almost all cases of variation on controlled pH values, at alum dosage of 10 mg/L alkalinity of water samples from the observed wells no. 1, 2 and 3 sharply decreased from 110 to 20 from 1700 to 600, and from 230 to 30 mg/L as  $\text{CaCO}_3$ , respectively. Accordingly, after increment in dosage from 20 to 60 mg/L alkalinity was nearly constant, because sufficient alkalinity must be present in the water to react with alum so the hydroxide floc is produced and alkalinity is destroyed during the reaction. NaOH and  $\text{H}_2\text{SO}_4$  were utilized for controlling pH of water sample during coagulation.



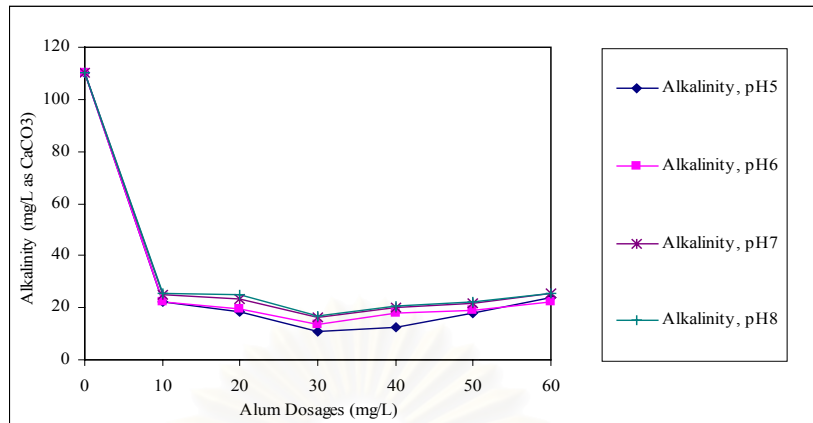
**Figure 4.12** Residual turbidity and percentage of turbidity removal in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



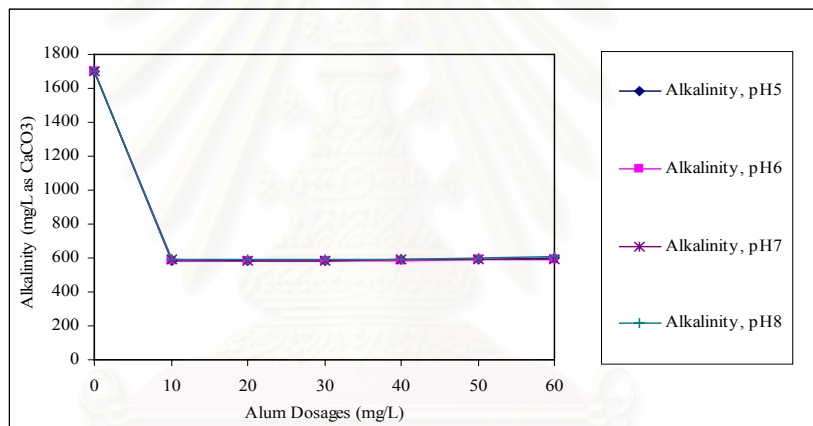
**Figure 4.13** Residual turbidity and percentage of turbidity removal in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



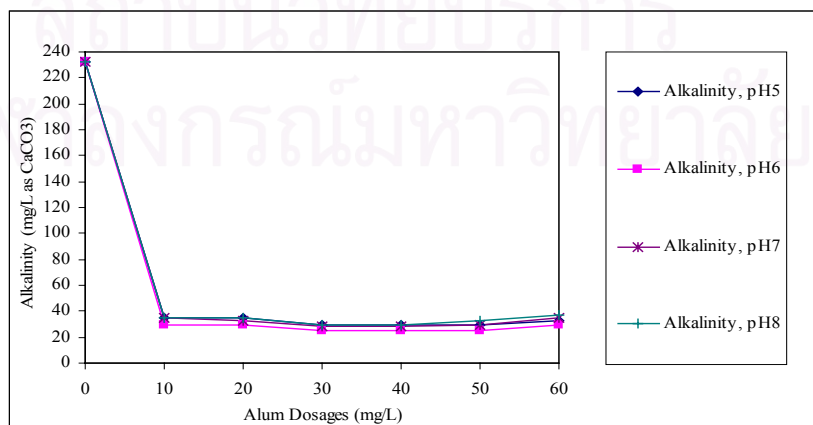
**Figure 4.14** Residual turbidity and percentage of turbidity removal in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments



**Figure 4.15** Alkalinity in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



**Figure 4.16** Alkalinity in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



**Figure 4.17** Alkalinity in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments

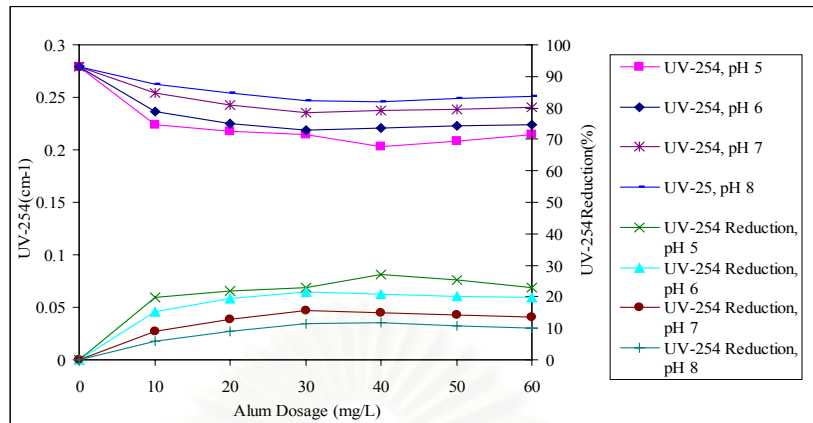
#### 4.2.2 NOM Surrogate Parameters

##### UV absorbance at wavelength 254 nm (UV-254)

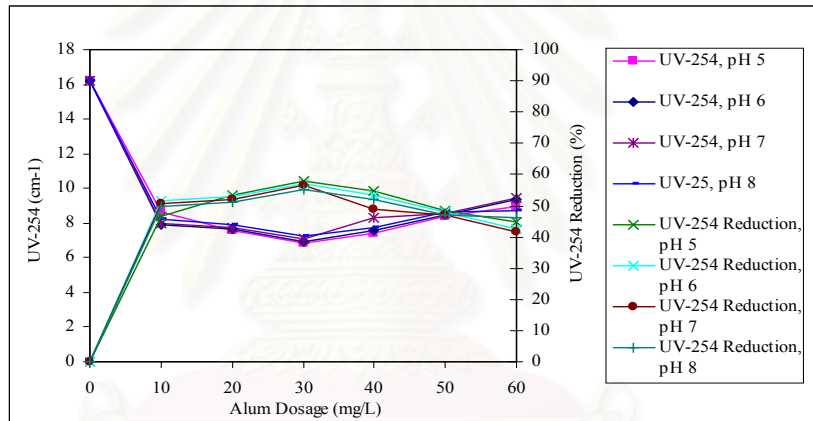
As can be seen from Figure 4.17, which presents the UV-254 reduction as a function of alum dosage at controlled pH from 5 to 8 of the water sample from the observed well no. 1, it shows that in almost all cases of controlled pH the alum dosage at 10 mg/L gradually decreased UV-254 values from 0.27 1/cm to about 0.24 1/cm; whereas the maximum UV-254 removal of approximately 30 percent was observed at the controlled pH of 5 and alum dosage of 40 mg/L. The data from Figure 4.18 indicates that the maximum UV-254 removal of the raw water from the observed well no. 2 approximately 60 percent was observed at controlled pH of 5 and alum dosage of 40 mg/L. At this dosage, it decreased UV-254 from the values of 16 to about 8 1/cm. Meanwhile, Figure 4.19 shows the reduction of UV-254 at the observed well no. 3, at 40 mg/L and pH value of 6 which indicates that the best reduction could decrease UV-254 from 0.36 to 0.27 1/cm., approximately 30 percent. Interestingly, in almost all case after an alum dosage of 10 mg/L, the percent reduction of UV-254 was nearly constant.

##### Specific ultraviolet absorbance (SUVA)

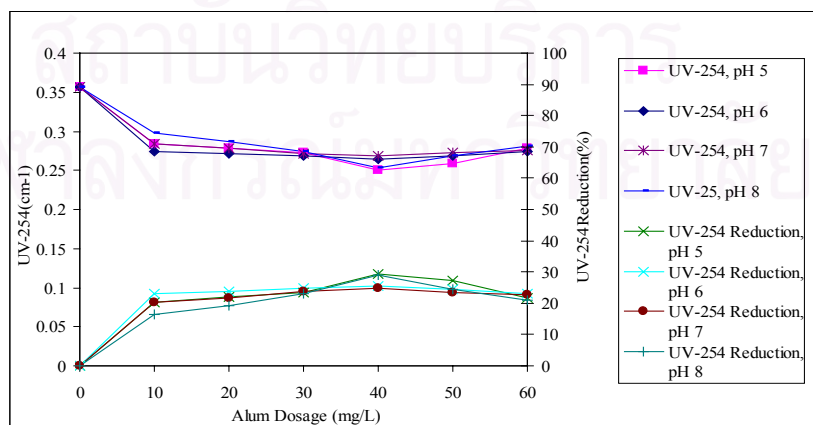
From the obtained data in Figure 4.20, a study of the observed well no. 1 shows that in almost all cases of controlled pH, and an alum dosage of 10 mg/L, SUVA gradually decreased from 18 L/mg-m to 14 L/mg-m; whereas maximum SUVA removal was approximately 23 percent at the controlled pH of 5 and alum dosage of 40 mg/L. As can be seen in Figure 4.21, which presents the SUVA of the observed well no. 2, at an alum dosage of about 20 mg/L and a controlled pH value of 8, the SUVA maximum reduction of approximately 30 percent occurred. In case of the observed well no. 3 from Figure 4.22, which shows that at the controlled pH of 8, SUVA was decreased from 8.9 L/mg-m to about 8 L/mg-m at the alum dosage of 40 mg/L. This reduction of SUVA was approximately 10 percent.



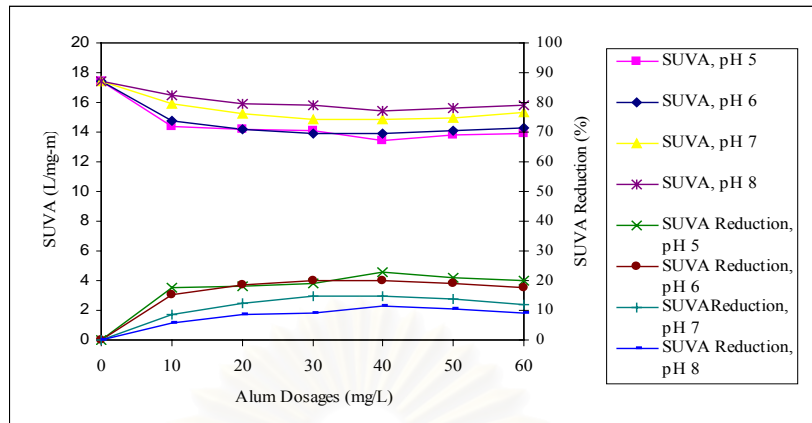
**Figure 4.18** UV-254 and percentage of UV-254 reduction in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



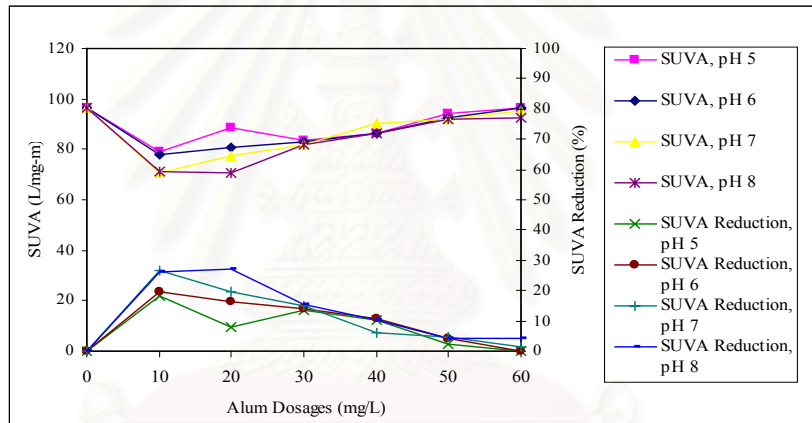
**Figure 4.19** UV-254 and percentage of UV-254 reduction in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



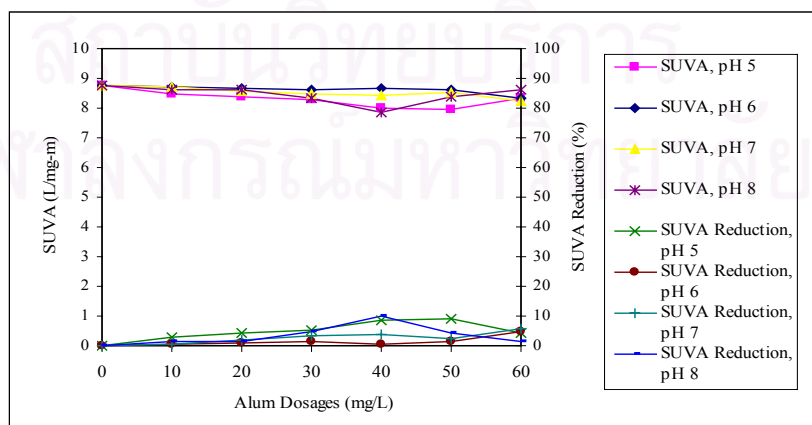
**Figure 4.20** UV-254 and percentage of UV-254 reduction in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments



**Figure 4.21** SUVA and percentage of SUVA reduction in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



**Figure 4.22** SUVA and percentage of SUVA reduction in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



**Figure 4.23** SUVA and percentage of SUVA reduction in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments



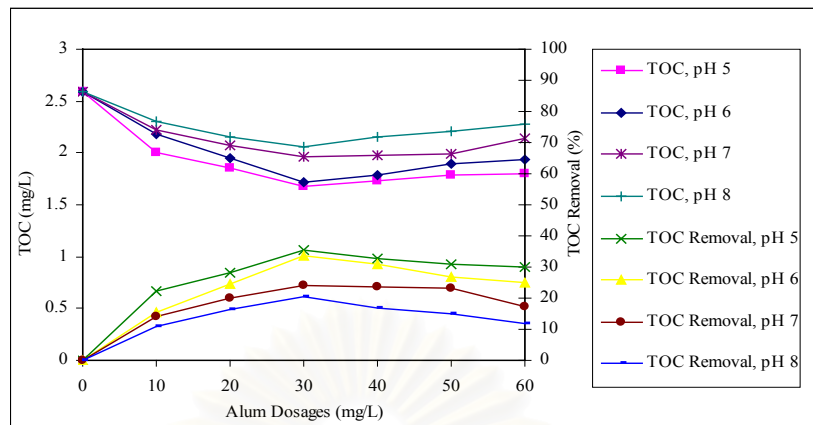
### Organic Carbon

Figure 4.20 presents TOC and the percent removal of the TOC at the observed well no. 1. It was found that in almost all case of controlled pH, TOC of coagulated waters were gradually reduced by variation on dosage from 10 to 30 mg/L. However, increment in dosage from 30 to 50 mg/L resulted in a slightly increase in TOC. The maximum removal of TOC, approximately 35 percent, was observed at the alum dosage of about 30 mg/L and a controlled pH of 5.

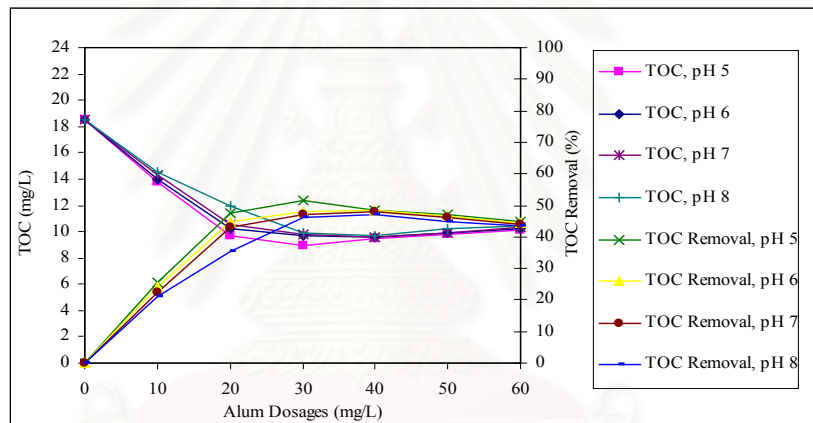
Base on data from Figure 4.21 which demonstrate TOC and the percent removal of the TOC at the observed well no. 2, it exhibits that in almost all case of controlled pH, TOC sharply decreased from a value of about 18.5 mg/L to a value of about 9.8 mg/L at alum dosage of 20 mg/L. And increase the alum dosage from 20 to 60 mg/L resulted in constant of TOC values. The maximum removal of TOC approximately 50 percent occurred at a 30 mg/L dosage and controlled pH of 5. As can be seen in Figure 4.22, which presents the TOC removal as a function of alum dosage at a controlled pH from 5 to 8 of water sample from the observed well no. 3, at the alum dosage of about 40 mg/L and controlled pH value of 6, the maximum removal of TOC, approximately 25 percent occurred.

Figure 4.23 showed DOC and the percent removal of the DOC at the observed well no. 1. It is found that in almost all case of controlled pH, DOC of coagulated waters were from 10 to 60 mg/L was nearly constant. However, the maximum removal of DOC, approximately 0.1 mg/L, was observed at an alum dosage of about 40 mg/L and a controlled pH of 5.

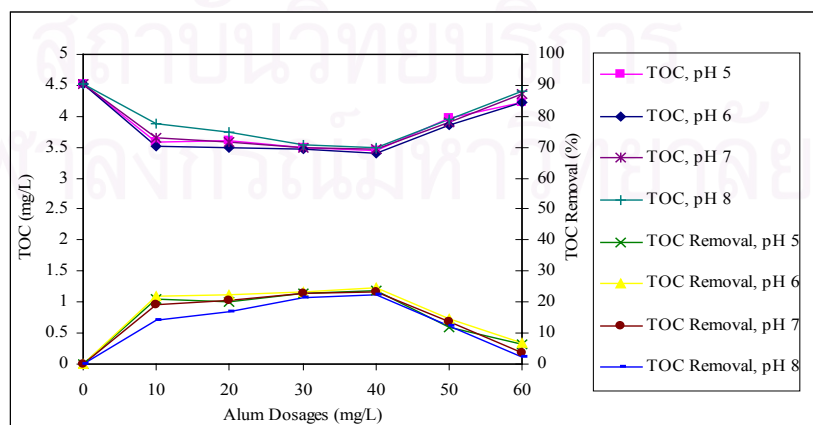
Consequently, at the observed wells no. 2 and 3 (Figures 4.24 and 4.25), DOC was sharply decrease at 10 mg/L of alum dosage but after that the percent removal of the DOC was consistent. The removal of DOC approximately 50 percent, at controlled a pH value of 5 and alum doses of 30 mg/L at the observed well no. 2 and approximately 25 percent at a controlled pH value 6 and alum doses of 40 mg/L at the observed well no. 3.



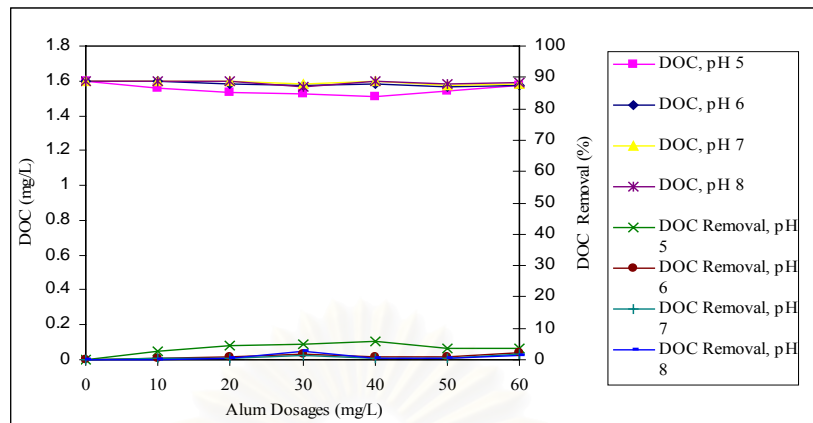
**Figure 4.24** TOC and percentage of TOC removal in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



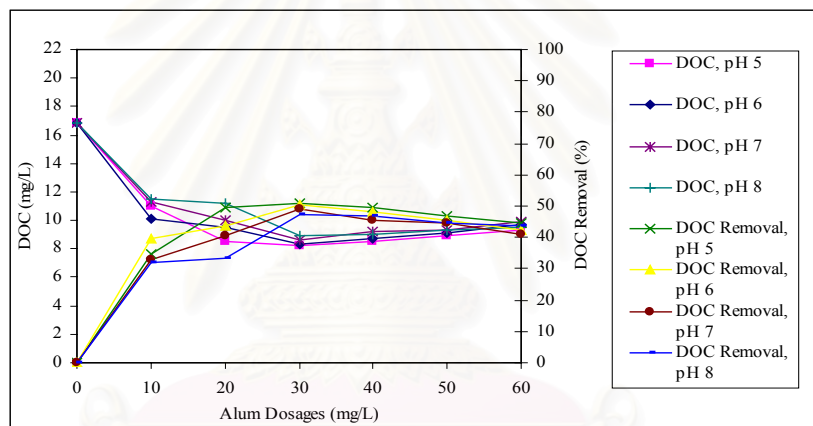
**Figure 4.25** TOC and percentage of TOC removal in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



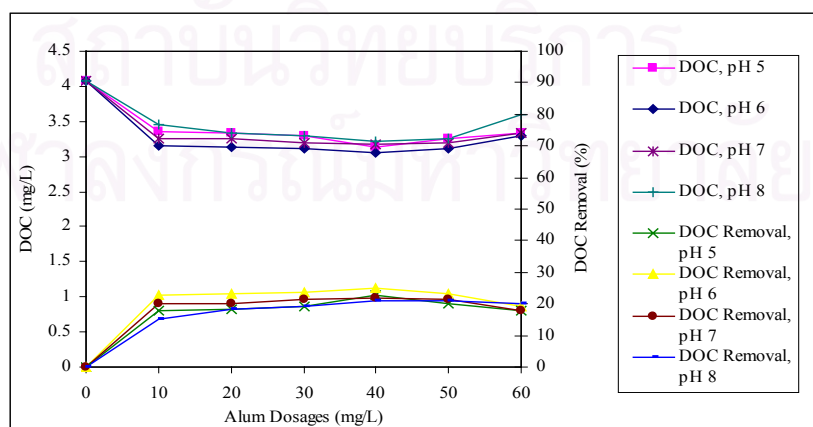
**Figure 4.26** TOC and percentage of TOC removal in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments



**Figure 4.27** DOC and percentage of DOC removal in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



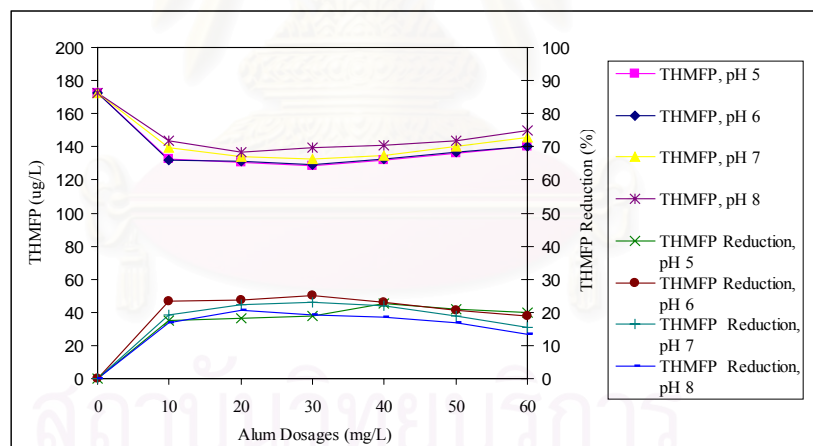
**Figure 4.28** DOC and percentage of DOC removal in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



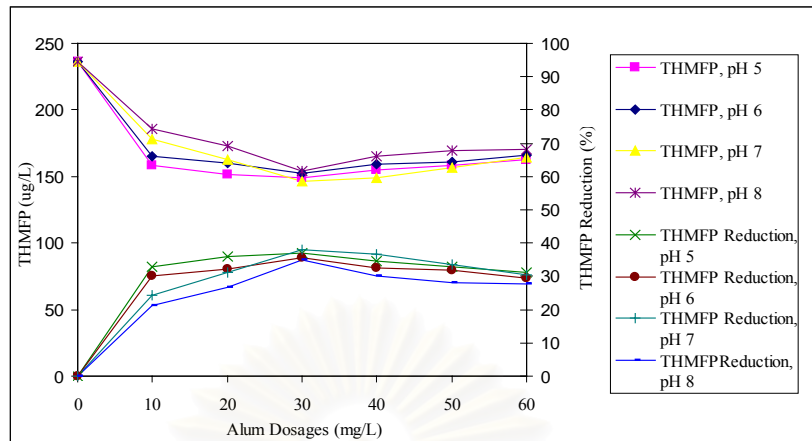
**Figure 4.29** DOC and percentage of DOC removal in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments

### Trihalomethanes formation potential

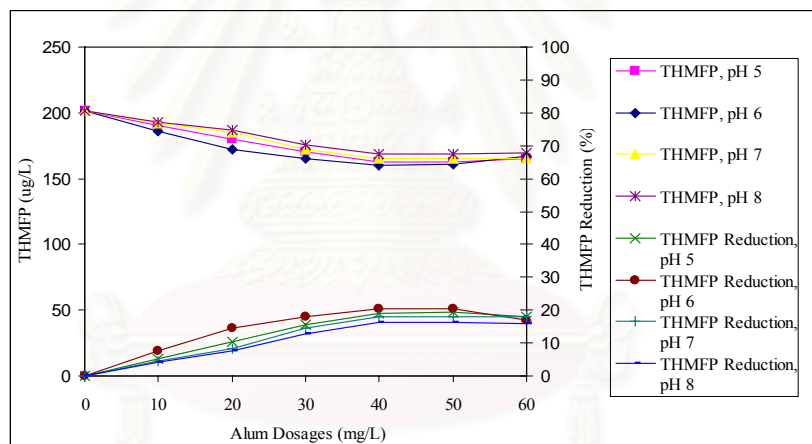
Figures 4.26, 4.27 and 4.28 present the investigation on THMFP reduction in coagulated water by many different dosages of alum and at the variation of controlled pH values at the observed wells no. 1, 2 and 3, respectively. The results obtained shows that at the controlled pH of 5 and alum dosage of 30 mg/L the maximum THMFP reductions of about 25% and 37% for the observed wells no. 1 and 2 were observed, respectively. In the case of the observed well no. 3, THMFP gradually reduced approximately 20 percent by variation on alum dosage from 10 to 40 mg/L, whereas the maximum THMFP reduction approximately 22 percent was observed at the alum dosage of 40 mg/L and controlled pH of 6. Interestingly, in almost all cases at the observed wells no. 1, 2 and 3, an alum dosage of about 10 mg/L can reduce THMFP in the raw water by approximately 15 percent. It may be due to the fact that at the mentioned dosage it can mainly remove NOM fraction, hydrophobic fraction, which is subject to THMFP.



**Figure 4.30** THMFP and percentage of THMFP reduction in the coagulated water of the observed well no.1 as a function of alum dosages at the different controlled pH experiments



**Figure 4.31** THMFP and percentage of THMFP reduction in the coagulated water of the observed well no.2 as a function of alum dosages at the different controlled pH experiments



**Figure 4.32** THMFP and percentage of THMFP reduction in the coagulated water of the observed well no.3 as a function of alum dosages at the different controlled pH experiments

### 4.3 THMFP and THMFP Species of Raw Water and Coagulated Water

With regard to the species of Trihalomethanes, including Chloroform ( $\text{CHCl}_3$ ) and Dichlorobromoform ( $\text{CHCl}_2\text{Br}$ ) and Dibromochloroform ( $\text{CHClBr}_2$ ) and Bromoform ( $\text{CHBr}_3$ ), they usually could be occurred in water due to disinfection which is

accomplished almost solely by chlorination. Therefore, the above-mentioned four forms of THMs were also expected to be observed in this study.

The main THMFP species in the observed wells raw water was Chloroform ( $\text{CHCl}_3$ ) of about 50-80 percent while and Dichlorobromoform ( $\text{CHCl}_2\text{Br}$ ) and Dibromochloroform ( $\text{CHClBr}_2$ ), which were found as few as approximately 10-30 percent and 5-20 percent. Bromoform were found only a few percent in the observed wells no. 1 and 2. The reason used to explain this phenomenon is that halogen atom of disinfectant compound used in this study was Cl (without Br, F and I). It was assumed that only a small amount of Br atom (without F and I) was present in the raw water.

In addition, the concentrations in terms of  $\mu\text{g/L}$  of each THMFP species in the raw water and coagulated water were also presented in Tables 4.5 to 4.7 and Figures 4.33 to 4.34 . It found that as can seen its outset in case of the observed well no. 1 maximum reduction of THMFP was observed at alum dosage 30 mg/L and controlled pH of 5. Due to this condition, Chloroform, Dichlorobromoform and Bromoform were approximately 31.03, 4.26 and 100 percent, respectively. In the observed well no. 2, alum coagulation can reduce Chloroform, Dichlorobromoform , Dibromochloroform and Bromoform were approximately 30.80, 19.15, 77.02 and 100 percent, respectively at alum dosage 30 mg/L and controlled pH of 5. Chloroform, Dichlorobromoform and Dibromochloroform were reduced by alum coagulation at alum dosage 40 mg/L and controlled pH of 6 approximately 21.90, 2.44 and 43.39 percent, respectively in the observed well no. 3.

The results of THMFP were also significantly similar to those of other NOM surrogates and THMs, which were discussed earlier. Consequently, the all above - mentioned results could be used to state that there were the correlation among TOC, DOC, UV-254 and THMFP for representing as NOMs surrogates. Moreover, regarding the complex process for analyzing THMFP, it is advantageous to use one simply analyzing parameter such as TOC, DOC and UV-254for representing the THMFP which will be presented in a next part.

**Table 4.5** The THMFP and THMFP species in the raw water and coagulated water from the observed well no. 1

THMs Species	Alum Dosage (mg/L)	Type of Water	Concentration ( $\mu\text{g/L}$ )	%Reduction
<b>THMFP</b>	<b>0</b>	Raw water	172.48	0.00
	<b>10</b>	Coagulated water	132.56	23.14
	<b>20</b>	Coagulated water	130.42	24.39
	<b>30</b>	Coagulated water	128.73	25.37
	<b>40</b>	Coagulated water	131.69	23.65
	<b>50</b>	Coagulated water	135.98	21.16
	<b>60</b>	Coagulated water	140.16	18.74
<b>Chloroform (CHCl<sub>3</sub>)</b>	<b>0</b>	Raw water	141.3	0.00
	<b>10</b>	Coagulated water	100.53	28.85
	<b>20</b>	Coagulated water	98.95	29.97
	<b>30</b>	Coagulated water	97.45	31.03
	<b>40</b>	Coagulated water	98.22	30.49
	<b>50</b>	Coagulated water	98.16	30.53
	<b>60</b>	Coagulated water	99.49	29.59
<b>Dichlorobromoform (CHCl<sub>2</sub>Br)</b>	<b>0</b>	Raw water	21.6	0.00
	<b>10</b>	Coagulated water	22.35	0.00*
	<b>20</b>	Coagulated water	21.55	0.23
	<b>30</b>	Coagulated water	21.94	0.00*
	<b>40</b>	Coagulated water	20.68	4.26
	<b>50</b>	Coagulated water	20.9	3.24
	<b>60</b>	Coagulated water	21.22	1.76
<b>Dibromochloroform (CHClBr<sub>2</sub>)</b>	<b>0</b>	Raw water	8.33	0.00
	<b>10</b>	Coagulated water	8.73	0.00*
	<b>20</b>	Coagulated water	9.93	0.00*
	<b>30</b>	Coagulated water	9.34	0.00*
	<b>40</b>	Coagulated water	12.79	0.00*
	<b>50</b>	Coagulated water	16.92	0.00*
	<b>60</b>	Coagulated water	19.44	0.00*
<b>Bromoform (CHBr<sub>3</sub>)</b>	<b>0</b>	Raw water	1.24	0.00
	<b>10</b>	Coagulated water	0.95	1.49
	<b>20</b>	Coagulated water	0	0.00
	<b>30</b>	Coagulated water	0	0.00
	<b>40</b>	Coagulated water	0	0.00
	<b>50</b>	Coagulated water	0	0.00
	<b>60</b>	Coagulated water	0.57	3.45

\* Result was not performed for % Reduction < 0

**Table 4.6** The THMFP and THMFP species in the raw water and coagulated water from the observed well no. 2

THMs Species	Alum Dosage (mg/L)	Type of Water	Concentration ( $\mu\text{g/L}$ )	%Reduction
<b>THMFP</b>	<b>0</b>	Raw water	236.27	0.00
	<b>10</b>	Coagulated water	158.48	32.92
	<b>20</b>	Coagulated water	151.35	35.94
	<b>30</b>	Coagulated water	148.96	36.95
	<b>40</b>	Coagulated water	154.62	34.56
	<b>50</b>	Coagulated water	158.37	32.97
	<b>60</b>	Coagulated water	162.48	31.23
<b>Chloroform (CHCl<sub>3</sub>)</b>	<b>0</b>	Raw water	122.19	0.00
	<b>10</b>	Coagulated water	85.79	29.79
	<b>20</b>	Coagulated water	84.91	30.51
	<b>30</b>	Coagulated water	84.56	30.80
	<b>40</b>	Coagulated water	84.61	30.76
	<b>50</b>	Coagulated water	85.82	29.77
	<b>60</b>	Coagulated water	84.73	30.66
<b>Dichlorobromoform (CHCl<sub>2</sub>Br)</b>	<b>0</b>	Raw water	64.24	0.00
	<b>10</b>	Coagulated water	53.13	17.29
	<b>20</b>	Coagulated water	53.26	17.09
	<b>30</b>	Coagulated water	52.95	17.57
	<b>40</b>	Coagulated water	52.56	18.18
	<b>50</b>	Coagulated water	51.94	19.15
	<b>60</b>	Coagulated water	52.54	18.21
<b>Dibromochloroform (CHClBr<sub>2</sub>)</b>	<b>0</b>	Raw water	49.79	0.00
	<b>10</b>	Coagulated water	17.61	64.63
	<b>20</b>	Coagulated water	16.18	67.50
	<b>30</b>	Coagulated water	11.44	77.02
	<b>40</b>	Coagulated water	17.45	64.95
	<b>50</b>	Coagulated water	20.36	59.11
	<b>60</b>	Coagulated water	24.52	50.75
<b>Bromoform (CHBr<sub>3</sub>)</b>	<b>0</b>	Raw water	2.28	0.00
	<b>10</b>	Coagulated water	1.95	14.47
	<b>20</b>	Coagulated water	0.34	85.09
	<b>30</b>	Coagulated water	0	0.00
	<b>40</b>	Coagulated water	0	0.00
	<b>50</b>	Coagulated water	0.25	89.04
	<b>60</b>	Coagulated water	0.69	69.74

\* Result was not performed for % Reduction < 0



**Table 4.7** The THMFP and THMFP species in the raw water and coagulated water from the observed well no. 3

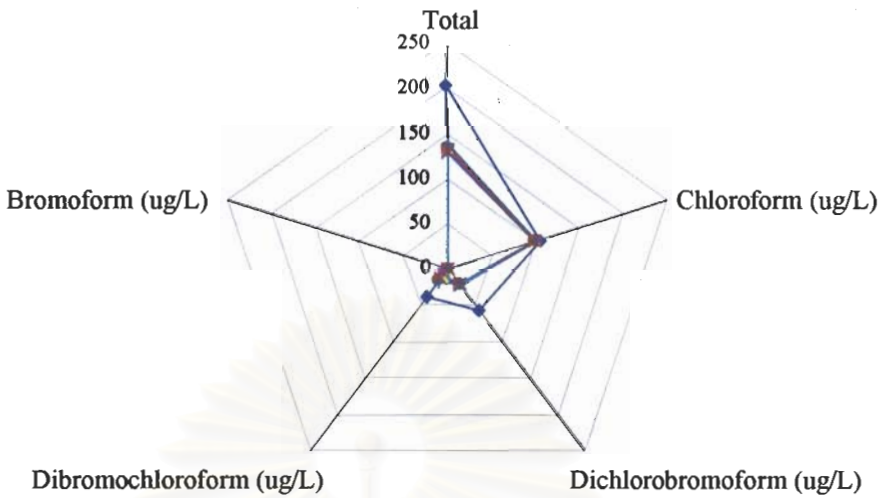
THMs Species	Alum Dosage (mg/L)	Type of Water	Concentration (µg/L)	%Reduction
<b>THMFP</b>	0	Raw water	201.45	0.00
	10	Coagulated water	186.23	7.56
	20	Coagulated water	172.47	14.39
	30	Coagulated water	165.36	17.92
	40	Coagulated water	159.98	20.59
	50	Coagulated water	160.65	20.25
	60	Coagulated water	167.34	16.93
<b>Chloroform (CHCl<sub>3</sub>)</b>	0	Raw water	104.68	0.00
	10	Coagulated water	82.45	21.24
	20	Coagulated water	82.4	21.28
	30	Coagulated water	81.76	21.90
	40	Coagulated water	81.91	21.75
	50	Coagulated water	82.16	21.51
	60	Coagulated water	82	21.67
<b>Dichlorobromoform (CHCl<sub>2</sub>Br)</b>	0	Raw water	56.88	0.00
	10	Coagulated water	57.01	0.00*
	20	Coagulated water	55.95	1.64
	30	Coagulated water	56.01	1.53
	40	Coagulated water	55.49	2.44
	50	Coagulated water	55.76	1.97
	60	Coagulated water	56.13	1.32
<b>Dibromochloroform (CHClBr<sub>2</sub>)</b>	0	Raw water	39.87	0.00
	10	Coagulated water	45.77	0.00*
	20	Coagulated water	34.12	14.42
	30	Coagulated water	27.56	30.88
	40	Coagulated water	22.57	43.39
	50	Coagulated water	22.73	42.99
	60	Coagulated water	29.2	26.76
<b>Bromoform (CHBr<sub>3</sub>)</b>	0	Raw water	0	0.00
	10	Coagulated water	0	0.00
	20	Coagulated water	0	0.00
	30	Coagulated water	0	0.00
	40	Coagulated water	0	0.00
	50	Coagulated water	0	0.00
	60	Coagulated water	0	0.00

\* Result was not performed for % Reduction < 0

**The observed**

**well no. 3**

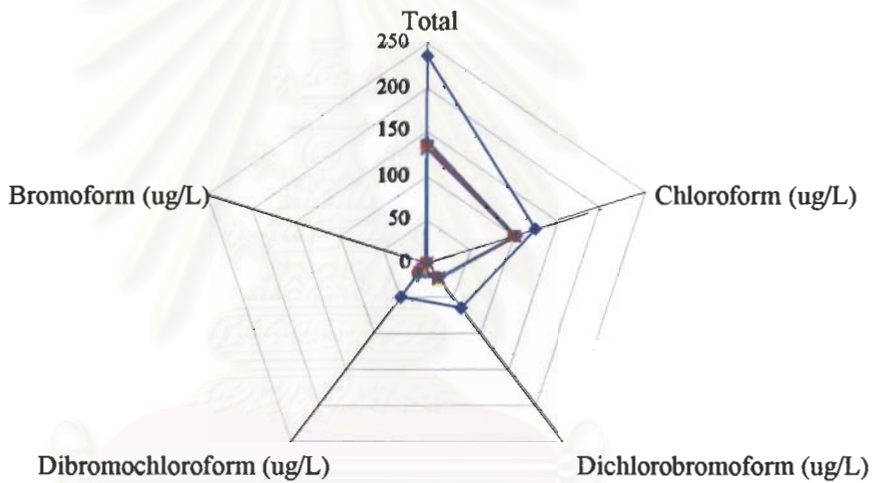
- Raw Water
- alum 10 mg/L
- ▲— alum 20 mg/L
- ×— alum 30 mg/L
- \*— alum 40 mg/L
- alum 50 mg/L
- +— alum 60 mg/L



**The observed**

**well no. 2**

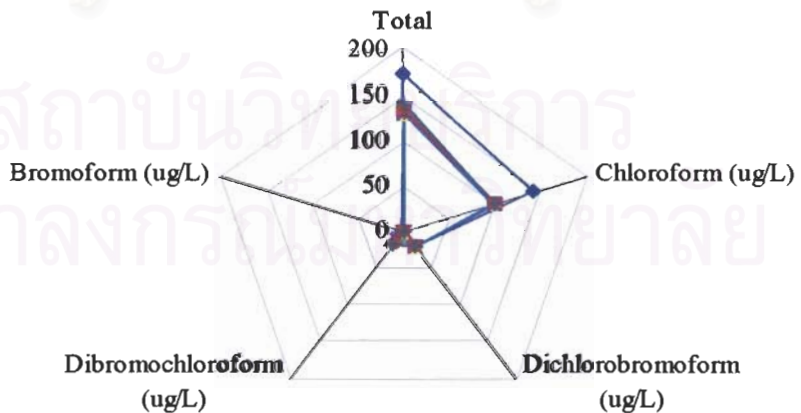
- Raw Water
- alum 10 mg/L
- ▲— alum 20 mg/L
- ×— alum 30 mg/L
- \*— alum 40 mg/L
- alum 50 mg/L
- +— alum 60 mg/L



**The observed**

**well no. 1**

- Raw Water
- alum 10 mg/L
- ▲— alum 20 mg/L
- ×— alum 30 mg/L
- \*— alum 40 mg/L
- alum 50 mg/L
- +— alum 60 mg/L



**Figure 4.33** THMFP species in the raw water and coagulated water

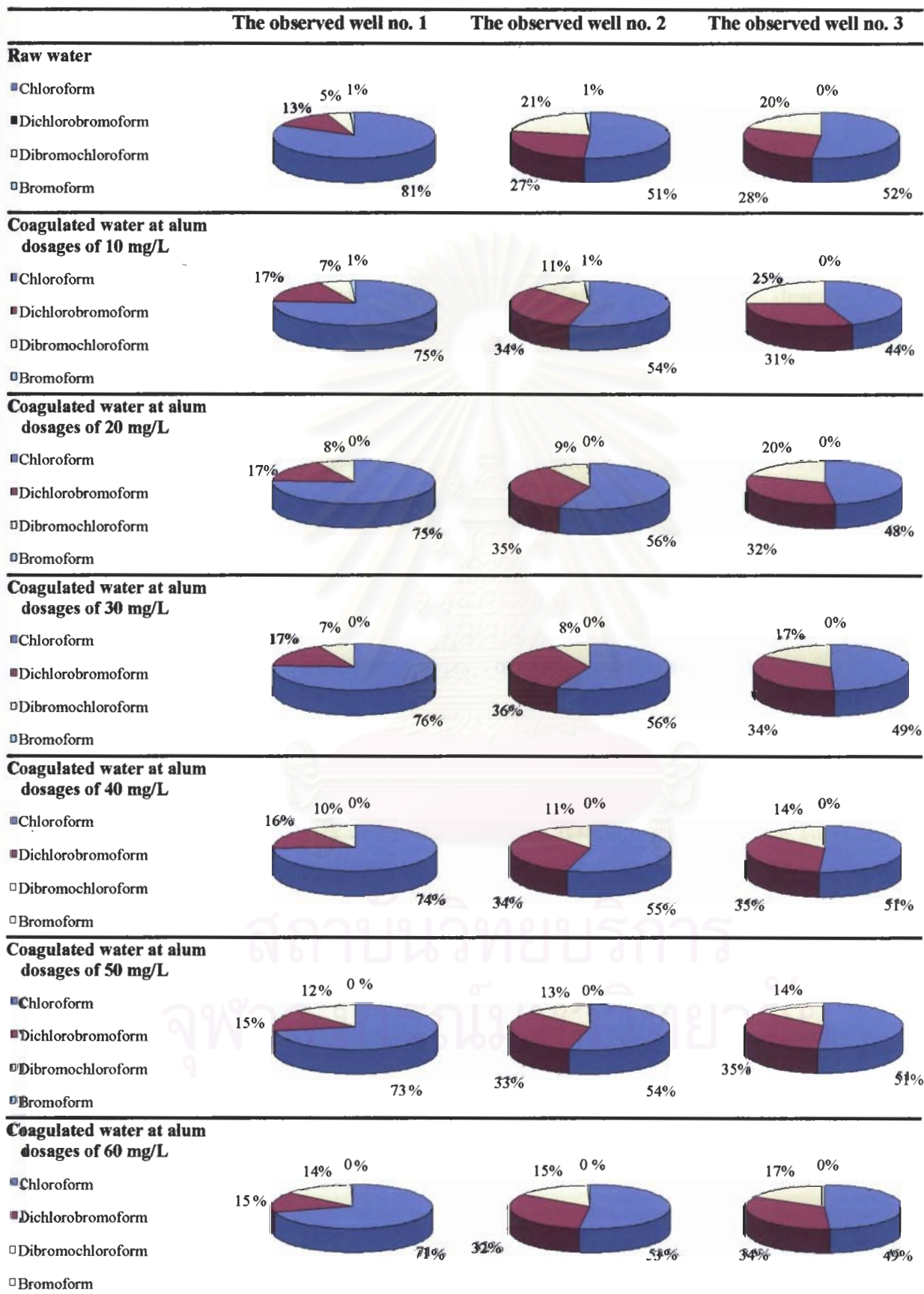


Figure 4.34 THMFP species in the raw water and coagulated water

## 4.4 Correlation between Surrogates for NOM in Raw Water and Coagulated Water of Shallow Wells

### 4.4.1 Correlation between Surrogates for NOM in Raw Water

Generally, natural organic matter (NOM) is the term used to describe the complex metric of organic material in natural water. Because of the difficulties in analyzing NOM, many researchers investigated surrogate parameters for the rapid estimation of NOM. Consequently, NOM may be separated in terms of surrogate parameters including TOC, DOC, UV-254, SUVA, chlorine demand, and THMFP. In this study, a number of surrogate parameters such as TOC, DOC, UV-254, SUVA, chlorine demand and THMFP were utilized to measure the quantity of NOM. Hence, the purpose of this section is to evaluate the correlation and regression among surrogates for NOM. The mentioned results of the raw water and coagulated water were utilized to evaluate the regression and correlation coefficients in this study.

The Pearson correlation coefficient was used to measure the linear association between two variables, while the correlation coefficient indicates the direct relationship (positive or negative). Based on the results obtained in this study, the regression and correlation coefficients determined are depicted in Figures 4.32 to 4.46. In addition, the overall correlations among surrogates for NOM are conclusively presented in Table 4.8. It must be noted that in accordance with AWWA (1993), the correlation levels were divided in four categories as an  $R^2 > 0.9$  was consider a good correlation,  $0.7 < R^2 < 0.9$  a moderate correlation,  $0.5 < R^2 < 0.7$  a fair correlation and  $R^2 < 0.5$  a poor correlation. For considerably poor correlation ( $R^2 < 0.5$ ), regression analyses were not performed; hence, the slope and intercept for the equation were not accepted.

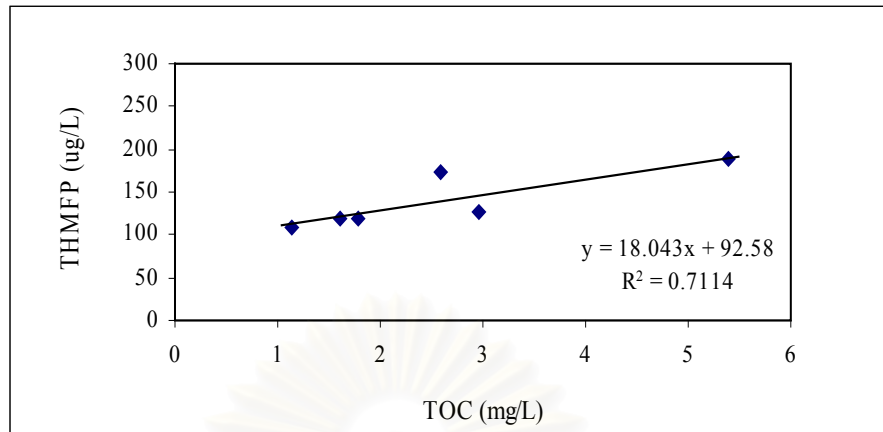
From the results in Table 4.8, it is possible to suggest that TOC was the most suitable NOM surrogate parameter used to describe the quantity of THMFP in the raw

water. In addition, as can be seen from Figures 4.32, 4.33 and 4.34, the regressions and correlations between coefficient between THMFP and TOC were 0.7117, 0.8510 and 0.8091 for the raw water from the observed wells no. 1, 2 and 3, respectively. However, chlorine demand was also markedly acceptable for the raw water from the observed wells as the results show on Table 4.8.

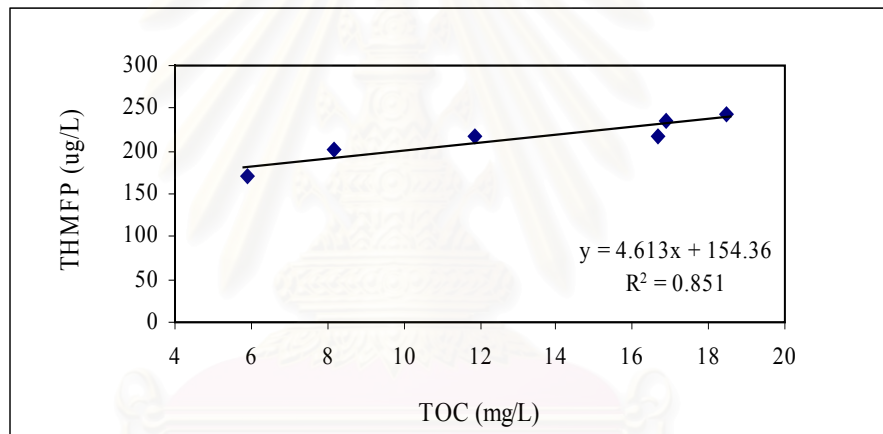
Regarding the relationship between THMFP and NOM surrogates in the raw water, the best correlation of THMFP and TOC was determined. Correspondingly, the equation that could be used to represent such the correlation at the observed wells no. 1, 2 and 3 were  $\text{THMFP} = 92.58 + 18.043 \text{ TOC}$ ,  $\text{THMFP} = 155.57 + 4.4468 \text{ TOC}$ , and  $\text{THMFP} = 132.59 + 19.279 \text{ TOC}$ , respectively.

Not only the relationship between THMFP and NOM surrogates but also the matrix relationship among NOM surrogates was performed and the correlation coefficients of each relationship were also depicted in Table 4.8. In the case of the raw water at the observed wells no. 1, 2 and 3, they were observed that the good correlation coefficient of 0.8797, 0.951 and 0.9142 were obtained for the relationship between TOC and DOC, respectively. In cases of TOC and UV-254, DOC and SUVA, and chlorine demand and DOC, they could be categorized as moderate correlation levels while that of TOC and SUVA, DOC and UV-254, chlorine demand and DOC, chlorine demand and UV-254, and chlorine demand and SUVA were a fair correlation.

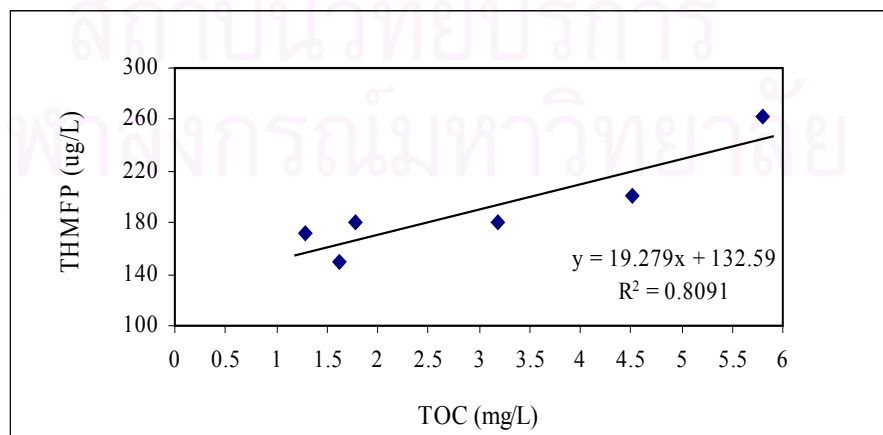
Figures 4.44 to 4.46 show the relationships between THMFP and SUVA in the raw water for the observed wells no. 1, 2 and 3, respectively. SUVA was not a good indicator for THMFP because of the low amount of DOC and the materials differed considerably from source to source.



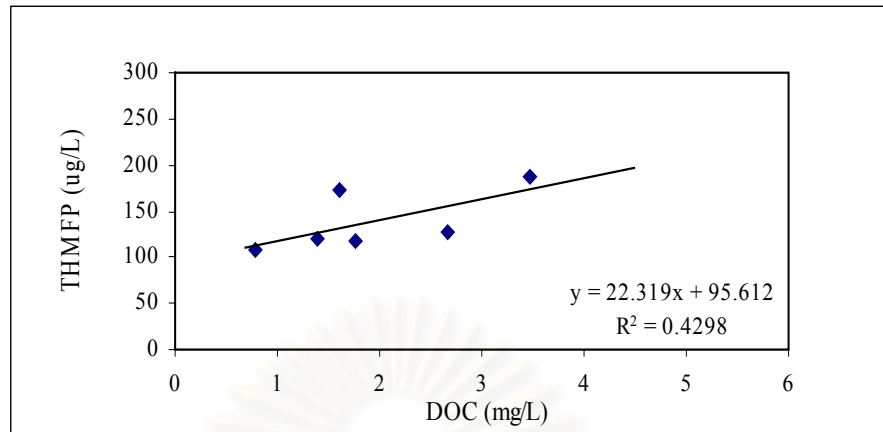
**Figure 4.35** Correlation between THMFP and TOC in the raw water from the observed well no. 1



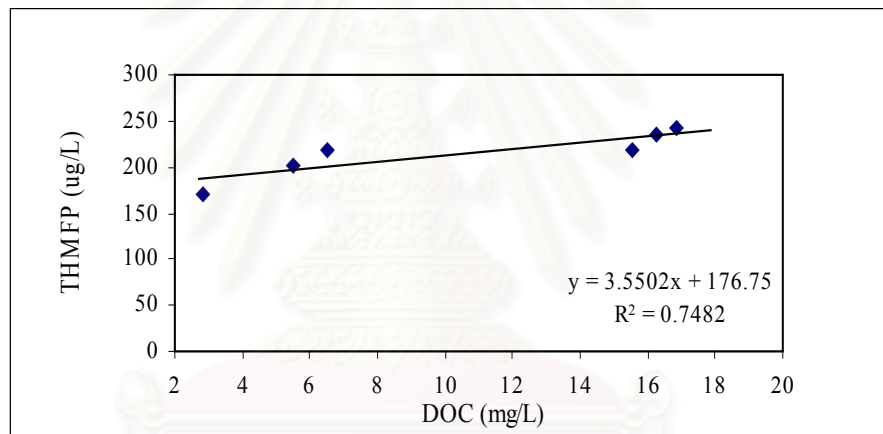
**Figure 4.36** Correlation between THMFP and TOC in the raw water from the observed well no. 2



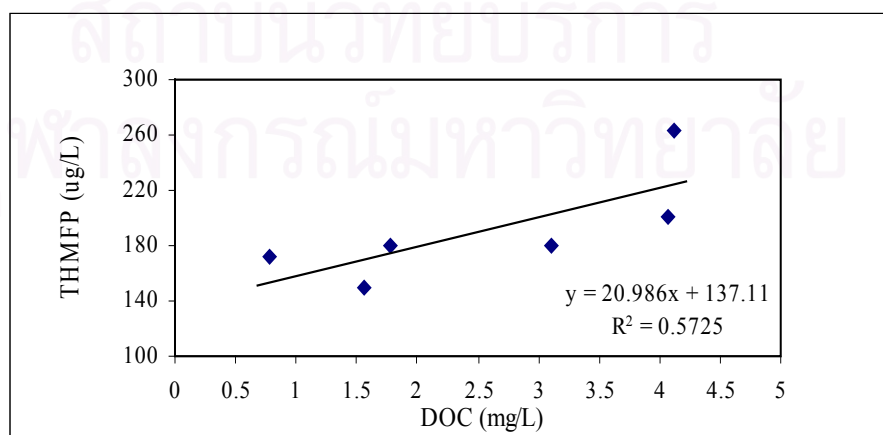
**Figure 4.37** Correlation between THMFP and TOC in the raw water from the observed well no. 3



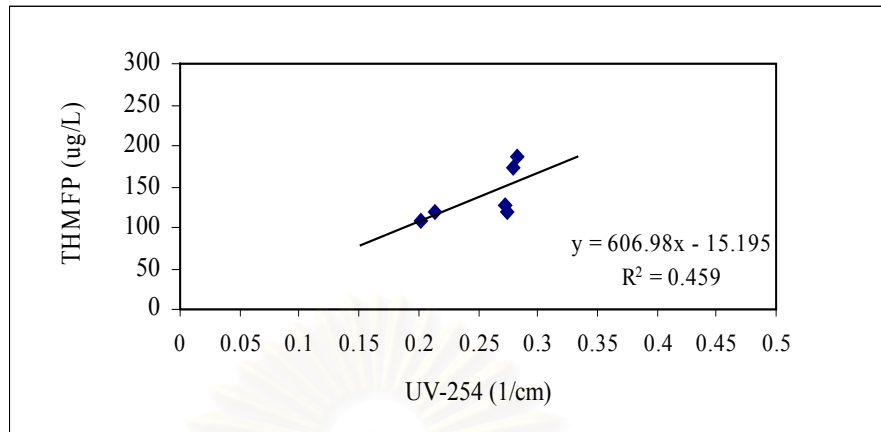
**Figure 4.38** Correlation between THMFP and DOC in the raw water from the observed well no. 1



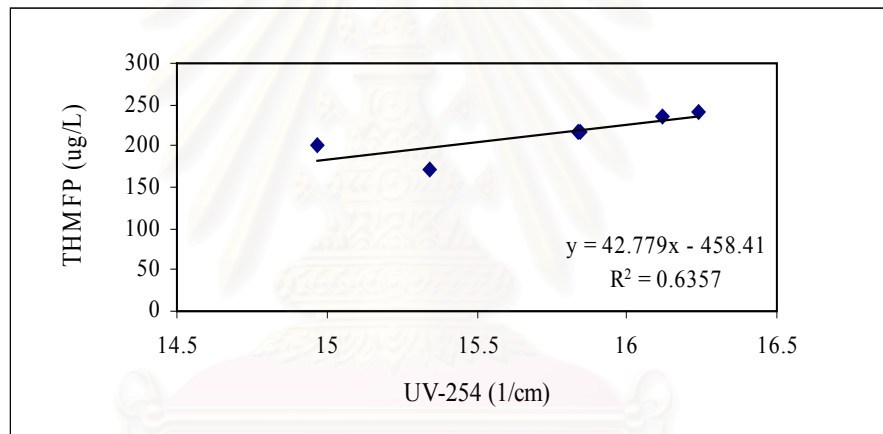
**Figure 4.39** Correlation between THMFP and DOC in the raw water from the observed well no. 2



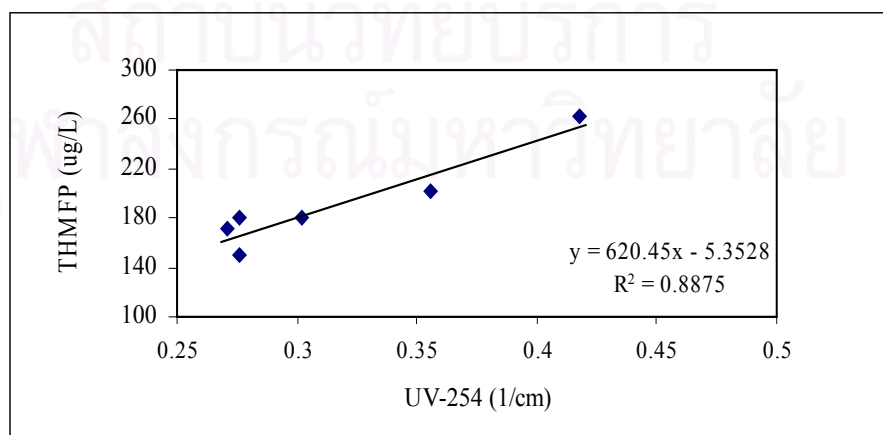
**Figure 4.40** Correlation between THMFP and DOC in the raw water from the observed well no. 3



**Figure 4.41** Correlation between THMFP and UV-254 in the raw water from the observed well no. 1

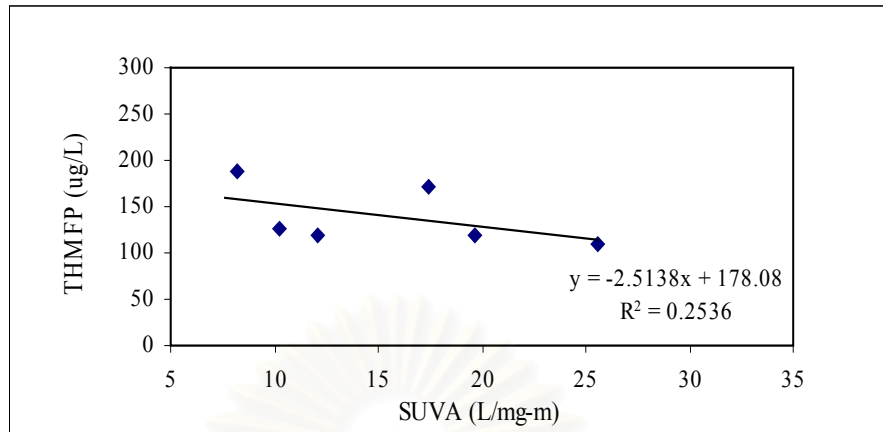


**Figure 4.42** Correlation between THMFP and UV-254 in the raw water from the observed well no. 2

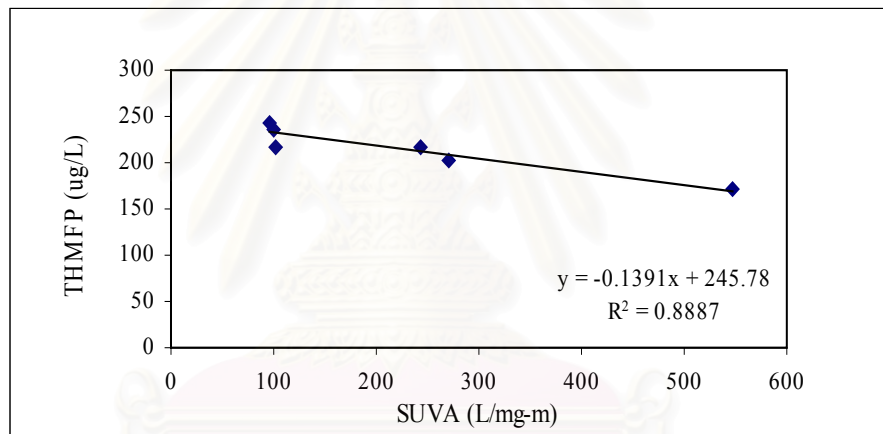


**Figure 4.43** Correlation between THMFP and UV-254 in the raw water from the observed well no. 3

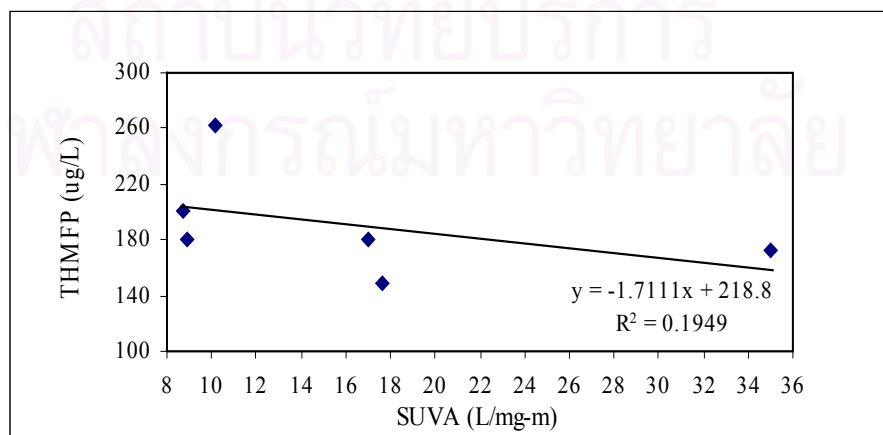




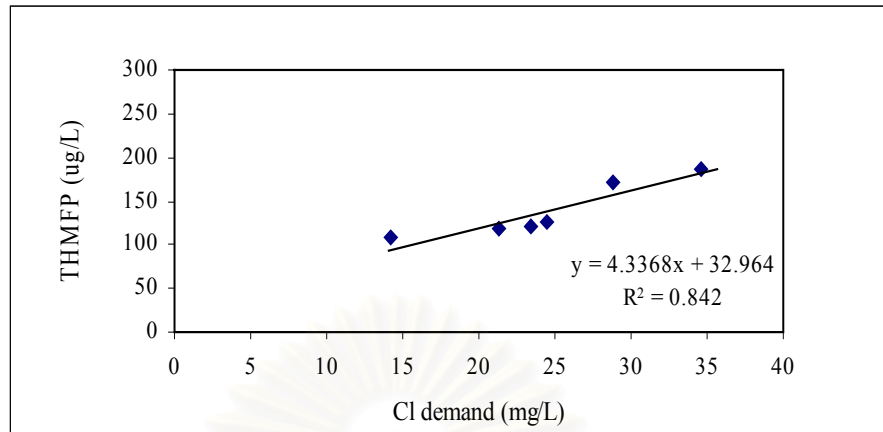
**Figure 4.44** Correlation between THMFP and SUVA in the raw water from the observed well no. 1



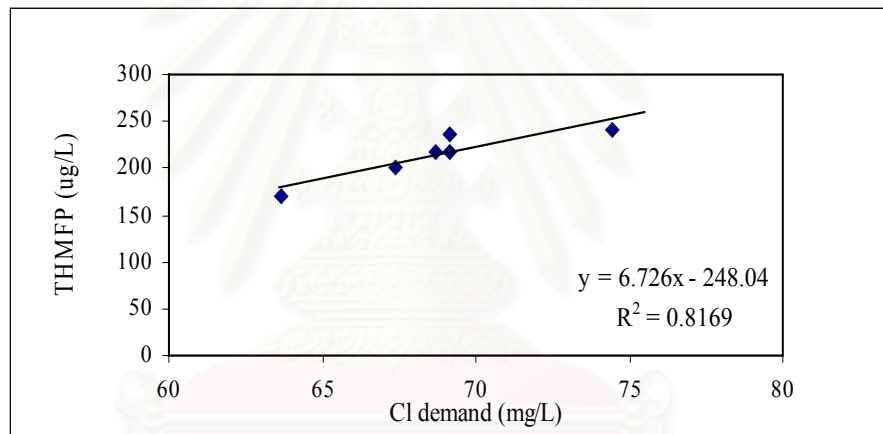
**Figure 4.45** Correlation between THMFP and SUVA in the raw water from the observed well no. 2



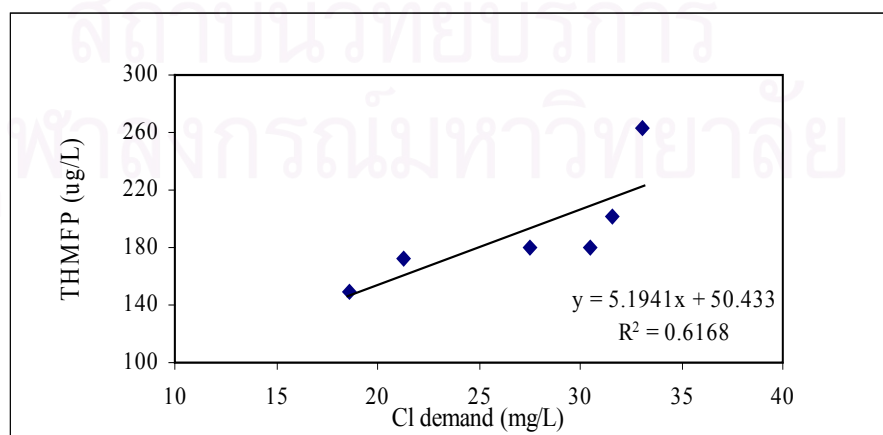
**Figure 4.46** Correlation between THMFP and SUVA in the raw water from the observed well no. 3



**Figure 4.47** Correlation between THMFP and chlorine demand in the raw water from the observed well no. 1



**Figure 4.48** Correlation between THMFP and chlorine demand in the raw water from the observed well no. 2



**Figure 4.49** Correlation between THMFP and chlorine demand in the raw water from the observed well no. 3

**Table 4.8** Regression and correlation coefficients for NOM parameters in the raw water

Dependent Variable	Independent Variable	No. of sample	N	R <sup>2</sup>	b*	a*	Remark
<b>THMFP</b>	<b>UV-254</b>	1	6	<0.5			A poor correlation
		2		0.6357	+42.779	-458.41	A fair correlation
		3		0.8875	+620.45	-5.3528	A moderate correlation
<b>THMFP</b>	<b>TOC</b>	1	6	0.7114	+18.043	+92.58	A moderate correlation
		2		0.8510	+4.613	+154.36	A moderate correlation
		3		0.8091	+19.279	+132.59	A moderate correlation
<b>THMFP</b>	<b>DOC</b>	1	6	<0.5			A poor correlation
		2		0.7428	+3.5502	+176.75	A moderate correlation
		3		0.5725	+20.986	+137.11	A fair correlation
<b>THMFP</b>	<b>SUVA</b>	1	6	<0.5			A poor correlation
		2		0.8887	-0.1391	+245.78	A moderate correlation
		3		<0.5			A poor correlation
<b>THMFP</b>	<b>Cl<sub>2</sub> demand</b>	1	6	0.8420	+4.3368	+32.964	A moderate correlation
		2		0.8169	+6.726	-248.04	A moderate correlation
		3		0.6168	+5.1941	+50.433	A moderate correlation
<b>TOC</b>	<b>DOC</b>	1	6	0.8797	+1.4926	-0.3297	A moderate correlation
		2		0.9510	+0.8004	+4.5278	A good correlation
		3		0.9142	+1.2373	-0.1479	A good correlation
<b>TOC</b>	<b>UV-254</b>	1	6	<0.5			A poor correlation
		2		0.7795	+9.4725	-125.96	A moderate correlation
		3		0.8281	+27.964	-5.8199	A moderate correlation
<b>TOC</b>	<b>SUVA</b>	1	6	0.5851	-0.1785	+5.3458	A fair correlation
		2		0.8495	-0.0272	+19.147	A moderate correlation
		3		0.5093	-0.1291	+5.1262	A fair correlation

Regression analysis was not performed for  $R^2 \leq 0.5$ ; hence the slope (b) and intercept (a) for equation were not computed

**Table 4.8** Regression and correlation coefficients for NOM parameters in the raw water (cont.)

Dependent Variable	Independent Variable	No. of sample	N	R <sup>2</sup>	b*	a*	Remark
<b>DOC</b>	<b>UV-254</b>	1	6	<0.5			A poor correlation
		2		0.6631	+10.645	-156.81	A fair correlation
		3		0.6344	+18.915	-3.4175	A fair correlation
<b>DOC</b>	<b>SUVA</b>	1	6	0.8380	-0.1342	+4.0296	A moderate correlation
		2		0.8000	-0.0321	+17.853	A moderate correlation
		3		0.7384	-0.1201	+4.519	A moderate correlation
<b>SUVA</b>	<b>UV-254</b>	1	6	<0.5			A poor correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation
<b>Cl<sub>2</sub> demand</b>	<b>TOC</b>	1	6	0.7851	+4.0105	+14.131	A moderate correlation
		2		0.6926	+0.5592	+61.473	A fair correlation
		3		0.7202	+2.7503	18.731	A moderate correlation
<b>Cl<sub>2</sub> demand</b>	<b>DOC</b>	1	6	0.6576	+5.8411	+13.093	A fair correlation
		2		0.5677	+0.4156	+64.344	A fair correlation
		3		0.7814	+3.702	+17.543	A moderate correlation
<b>Cl<sub>2</sub> demand</b>	<b>UV-254</b>	1	6	0.6907	+157.53	-15.571	A fair correlation
		2		0.5279	+5.2368	-13.610	A fair correlation
		3		0.5173	+2.7503	+4.396	A fair correlation
<b>Cl<sub>2</sub> demand</b>	<b>SUVA</b>	1	6	0.5139	-0.7571	+36.213	A fair correlation
		2		0.6537	-0.0160	+72.367	A fair correlation
		3		0.5335	-0.4281	34.018	A fair correlation

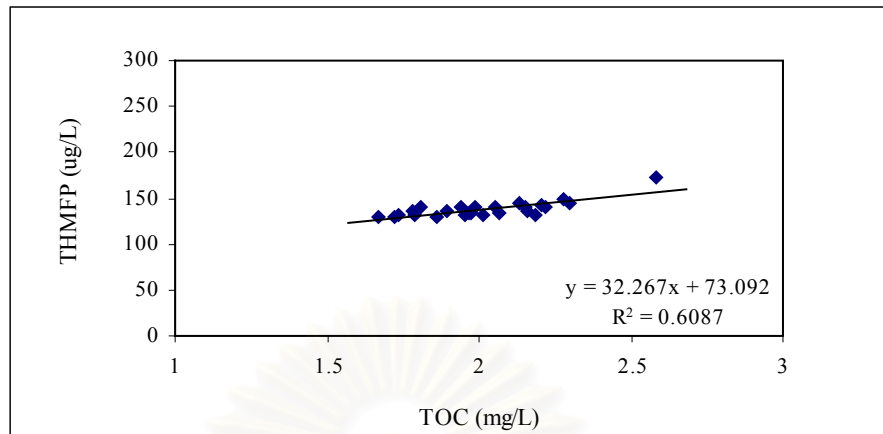
Regression analysis was not performed for  $R^2 \leq 0.5$ ; hence the slope (b) and intercept (a) for equation were not computed

#### 4.4.2 Correlation between Surrogates for NOM in Coagulated Water

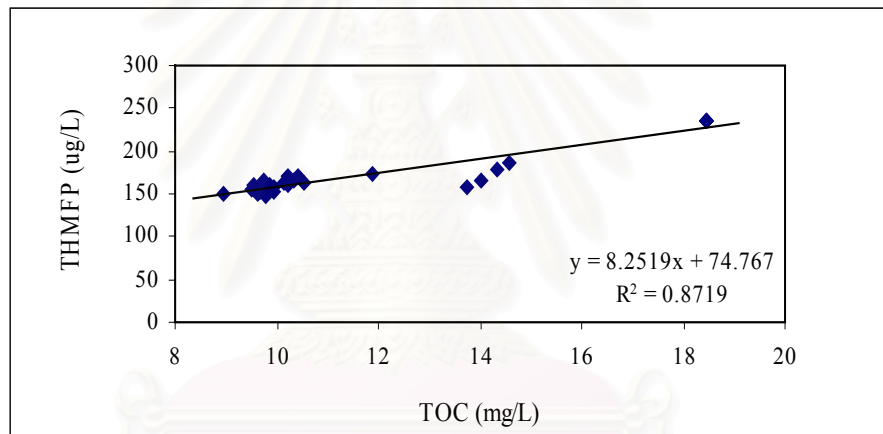
From the results in Table 4.9 in this study, it is possible to suggest that in coagulated water from the observed well no. 1, chlorine demand was the most suitable NOM surrogate parameter used to describe the quantity of THMFP ( $R^2 = 0.7731$ ). In addition, the regression and correlation between coefficient THMFP and chlorine demand was also illustrated in Figures 4.59 to 4.61. However, TOC was also considerably acceptable for the coagulated water at the observed well no. 1. While in the observed well no. 2, DOC had the best correlation for THMFP ( $R^2 = 0.9143$ ), follow by UV-254, chlorine demand and TOC, respectively. At the observed well no. 3, UV-254 was the most suitable NOM surrogate parameter used to describe the quantity of THMFP ( $R^2 = 0.7091$ ). Meanwhile, chlorine demand was also considerably acceptable for the coagulated water in the observed well no. 3.

From the results above and Table 4.9, the conclusion is chlorine demand is the best correlation for THMFP in coagulated water from the observed wells, because it can be used as the surrogate parameters for all the observed wells in this study. Additionally, UV-254, TOC and DOC were also considerably acceptable for coagulated water from the observed wells. Regarding the relationship between THMFP and NOM surrogates from the observed wells no. 1, 2 and 3, can be represented by the equation is  $\text{THMFP} = 69.924 + 3.3201 \text{ Cl}_2$ ,  $\text{THMFP} = 67.15 + 9.9653 \text{ DOC}$ , and  $\text{THMFP} = 68.217 + 381.8 \text{ UV-254}$ .

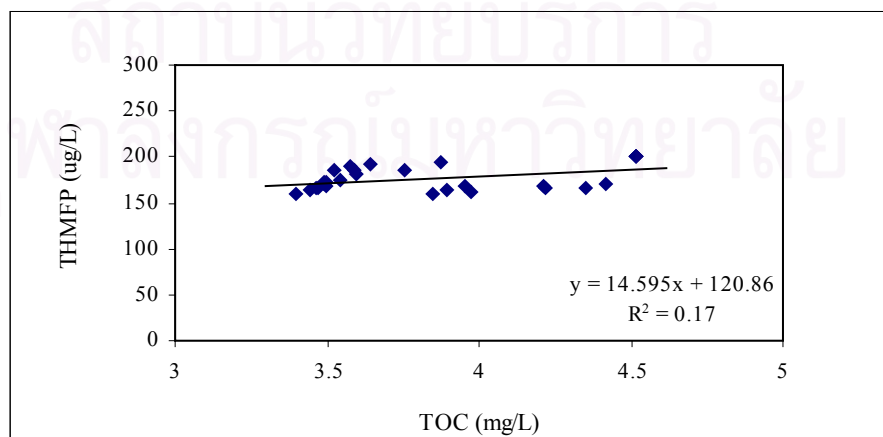
The relationship between the matrix relationships among NOM surrogates was performed, and correlation coefficients of each relationship were also depicted in Table 4.9. In the case of coagulated water, it was observed that the good correlation coefficient ranged from 0.5533 to 0.9173 and from 0.6591 to 0.9306 was obtained for the relationship between DOC and UV-254, and TOC and DOC. In the case of chlorine demand and UV-254, chlorine demand and TOC, chlorine demand and DOC, and TOC and UV-254, it could be categorized as moderate correlation levels while that of DOC and UV-254, UV-254 and SUVA were poor correlations.



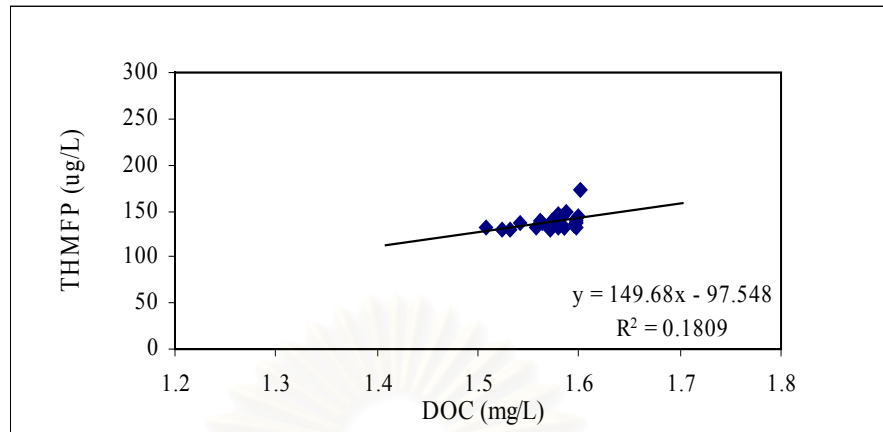
**Figure 4.50** Correlation between THMFP and TOC in the coagulated water from the observed well no. 1



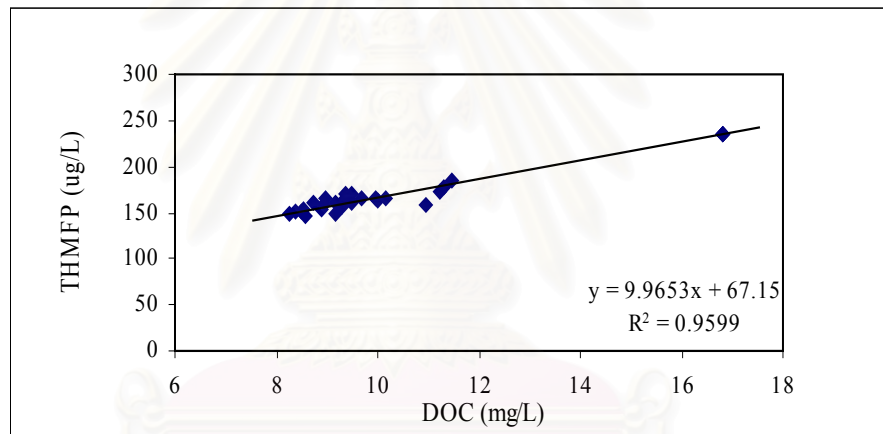
**Figure 4.51** Correlation between THMFP and TOC in the coagulated water from the observed well no. 2



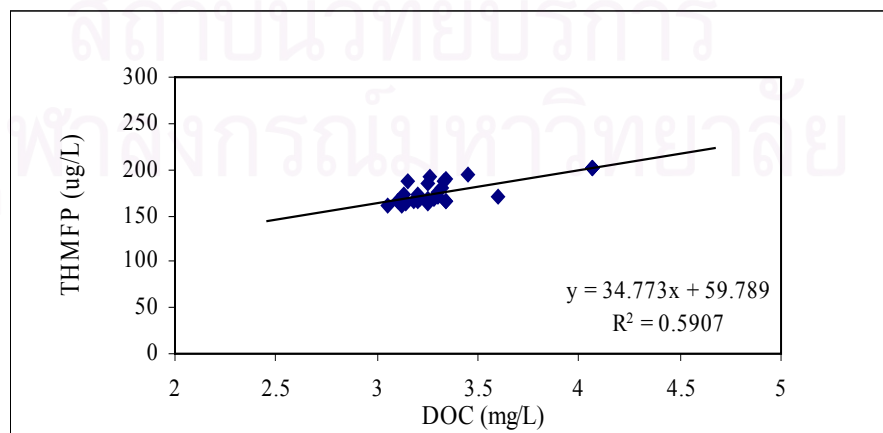
**Figure 4.52** Correlation between THMFP and TOC in the coagulated water from the observed well no. 3



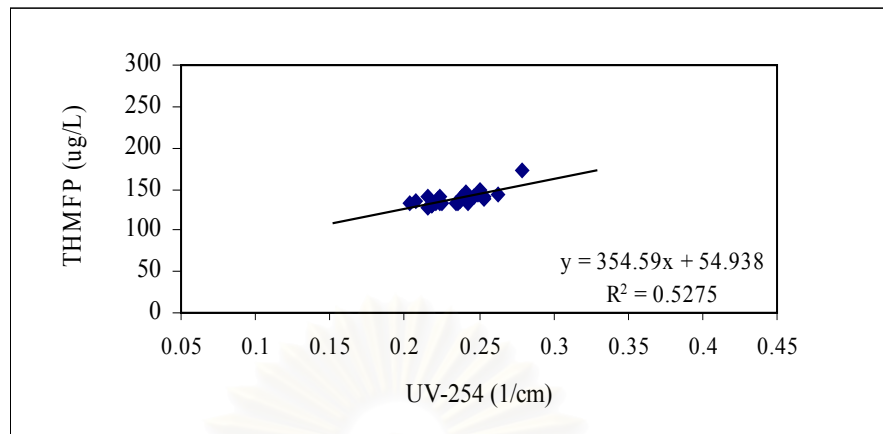
**Figure 4.53** Correlation between THMFP and DOC in the coagulated water from the observed well no. 1



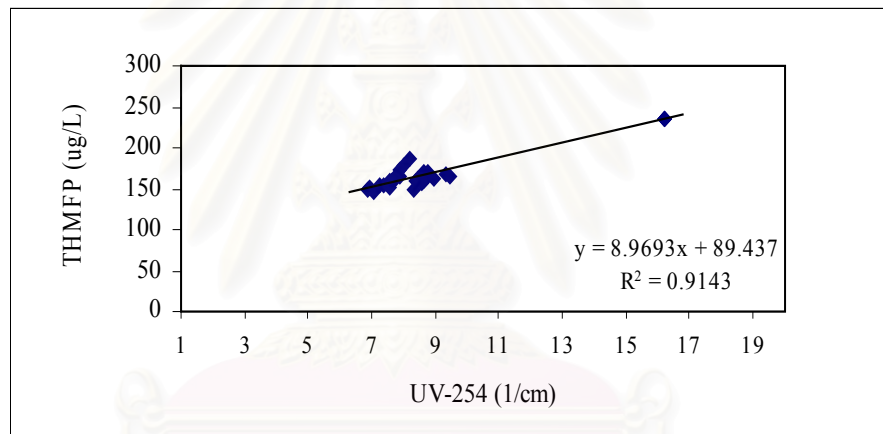
**Figure 4.54** Correlation between THMFP and DOC in the coagulated water from the observed well no. 2



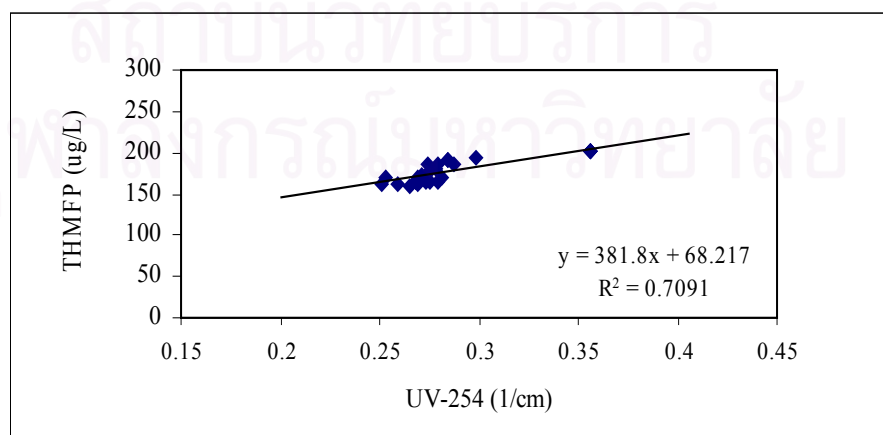
**Figure 4.55** Correlation between THMFP and DOC in the coagulated water from the observed well no. 3



**Figure 4.56** Correlation between THMFP and UV-254 in the coagulated water from the observed well no. 1

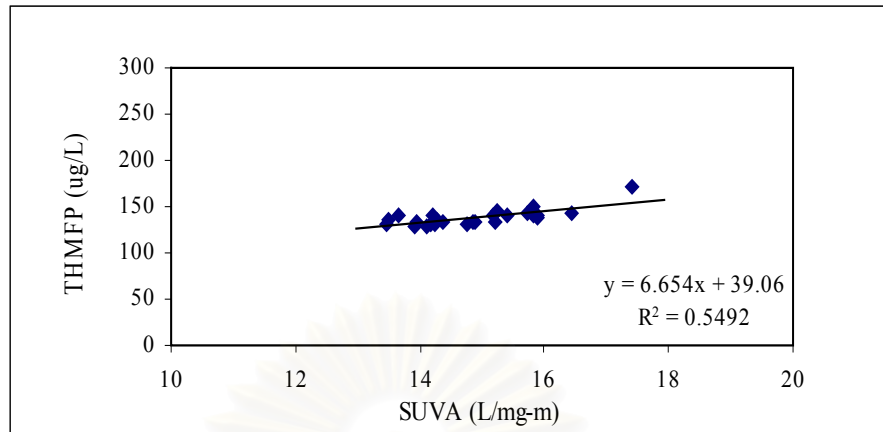


**Figure 4.57** Correlation between THMFP and UV-254 in the coagulated water from the observed well no. 2

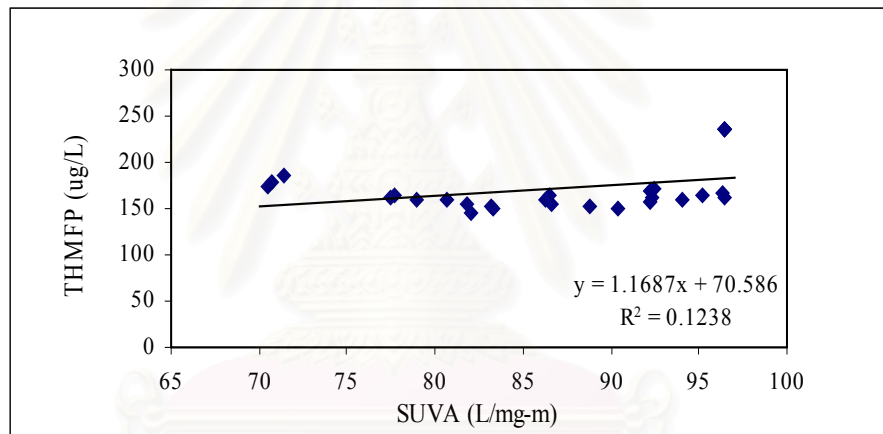


**Figure 4.58** Correlation between THMFP and UV-254 in the coagulated water from the observed well no. 3

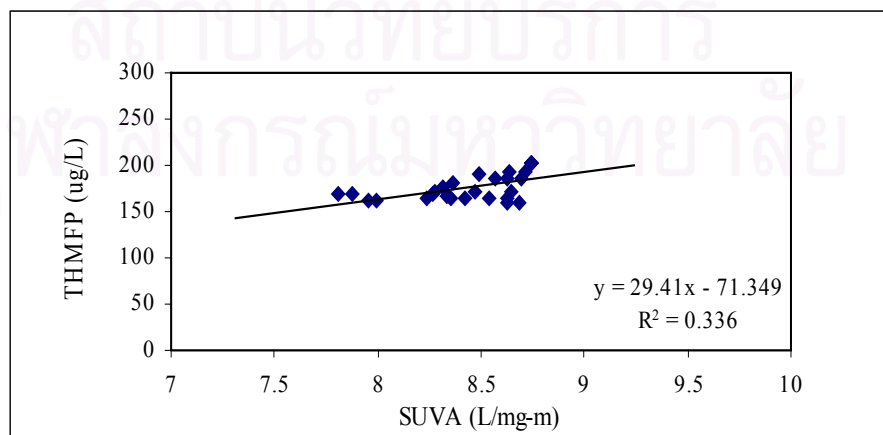




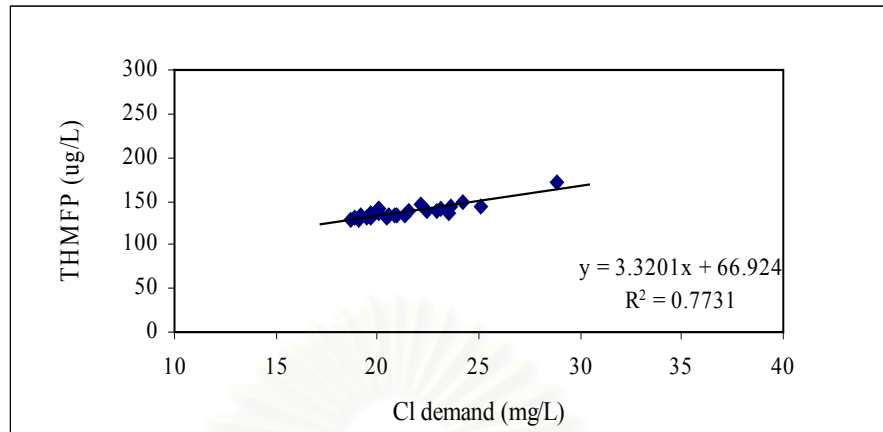
**Figure 4.59** Correlation between THMFP and SUVA in the coagulated water from the observed well no. 1



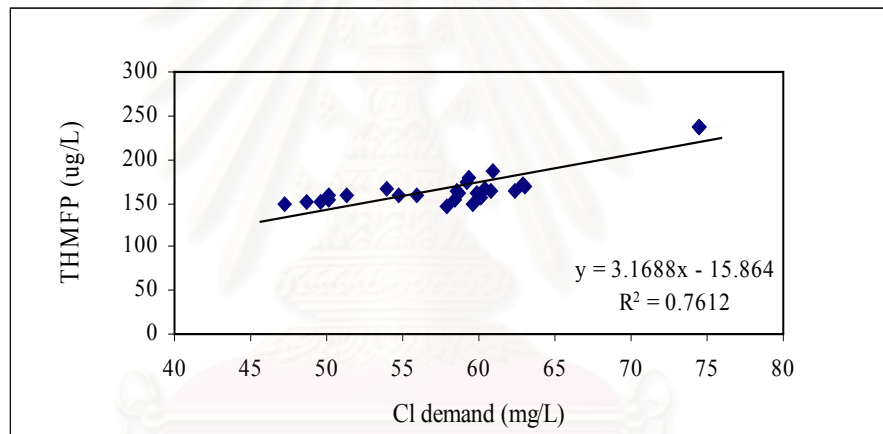
**Figure 4.60** Correlation between THMFP and SUVA in the coagulated water from the observed well no. 2



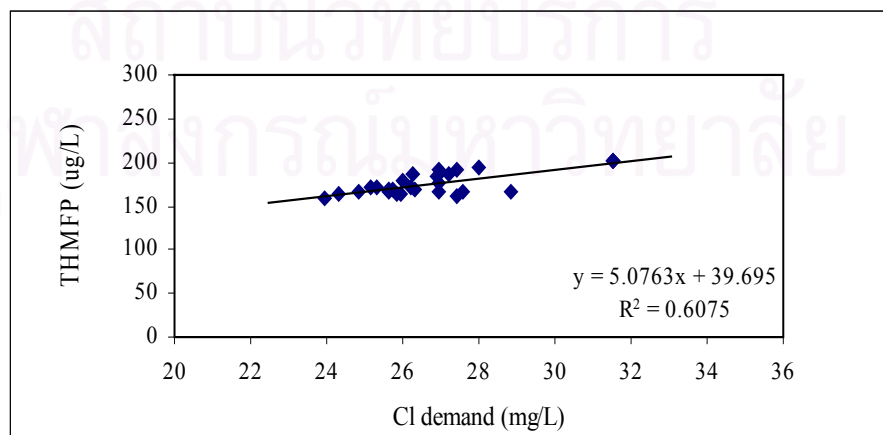
**Figure 4.61** Correlation between THMFP and SUVA in the coagulated water from the observed well no. 3



**Figure 4.62** Correlation between THMFP and chlorine demand in the coagulated water from the observed well no. 1



**Figure 4.63** Correlation between THMFP and chlorine demand in the coagulated water from the observed well no. 2



**Figure 4.64** Correlation between THMFP and chlorine demand in the coagulated water from the observed well no. 3

**Table 4.9** Regression and correlation coefficients for NOM parameters in coagulated water

Dependent Variable	Independent Variable	No. of sample	N	R <sup>2</sup>	b*	a*	Remark
<b>THMFP</b>	<b>UV-254</b>	1	25	0.5275	354.59	54.938	A fair correlation
		2		0.9143	8.9693	89.437	A good correlation
		3		0.7091	381.8	68.217	A moderate correlation
<b>THMFP</b>	<b>TOC</b>	1	25	0.6087	32.267	73.092	A fair correlation
		2		0.8719	8.2519	74.767	A moderate correlation
		3		<0.5			A poor correlation
<b>THMFP</b>	<b>DOC</b>	1	25	<0.5			A poor correlation
		2		0.9599	9.9653	67.15	A good correlation
		3		0.5907	34.773	59.789	A fair correlation
<b>THMFP</b>	<b>SUVA</b>	1	25	0.5492	6.654	39.06	A fair correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation
<b>THMFP</b>	<b>Cl<sub>2</sub> demand</b>	1	25	0.7731	3.3201	69.924	A moderate correlation
		2		0.7612	3.1688	-15.864	A moderate correlation
		3		0.6075	5.0763	39.695	A fair correlation
<b>TOC</b>	<b>DOC</b>	1	25	<0.5			A poor correlation
		2		0.9306	1.1103	0.1028	A good correlation
		3		0.6591	1.0378	0.3499	A fair correlation
<b>TOC</b>	<b>UV-254</b>	1	25	0.8824	11.09	-0.5861	A moderate correlation
		2		0.7595	0.925	3.2708	A moderate correlation
		3		0.5298	9.3233	1.1919	A fair correlation
<b>TOC</b>	<b>SUVA</b>	1	25	0.8593	0.2012	0.9807	A moderate correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation

**Table 4.9** Regression and correlation coefficients for NOM parameters in the coagulated water (cont.)

Dependent Variable	Independent Variable	No. of sample	N	R <sup>2</sup>	b*	a*	Remark
<b>DOC</b>	<b>UV-254</b>	1	25	0.5533	1.0321	1.3326	A fair correlation
		2		0.9094	0.8795	2.4262	A good correlation
		3		0.9173	9.5973	0.6364	A good correlation
<b>DOC</b>	<b>SUVA</b>	1	25	<0.5			A poor correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation
<b>SUVA</b>	<b>UV-254</b>	1	25	0.9764	53.656	2.2986	A good correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation
<b>Cl<sub>2</sub> demand</b>	<b>TOC</b>	1	25	0.8635	10.178	0.9314	A moderate correlation
		2		0.5604	1.8215	37.838	A fair correlation
		3		0.6395	4.3462	10.327	A fair correlation
<b>Cl<sub>2</sub> demand</b>	<b>DOC</b>	1	25	<0.5			A poor correlation
		2		0.7067	2.3542	34.528	A moderate correlation
		3		0.8123	6.2614	5.946	A moderate correlation
<b>Cl<sub>2</sub> demand</b>	<b>UV-254</b>	1	25	0.8754	120.98	-6.9391	A moderate correlation
		2		0.7596	2.251	38.575	A moderate correlation
		3		0.8525	64.276	8.7358	A moderate correlation
<b>Cl<sub>2</sub> demand</b>	<b>SUVA</b>	1	25	0.8996	2.2553	-12.34	A moderate correlation
		2		<0.5			A poor correlation
		3		<0.5			A poor correlation

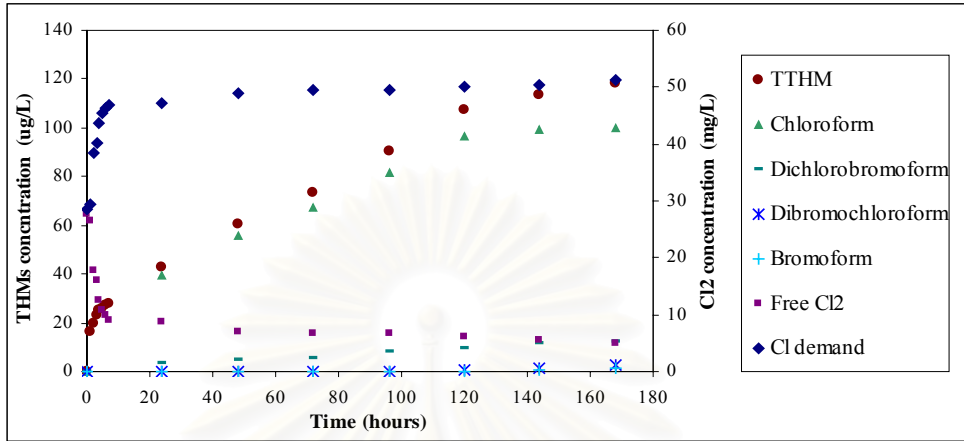
Regression analysis was not performed for  $R^2 \leq 0.5$ ; hence the slope (b) and intercept (a) for equation were not computed

#### 4.5 THMs Formation

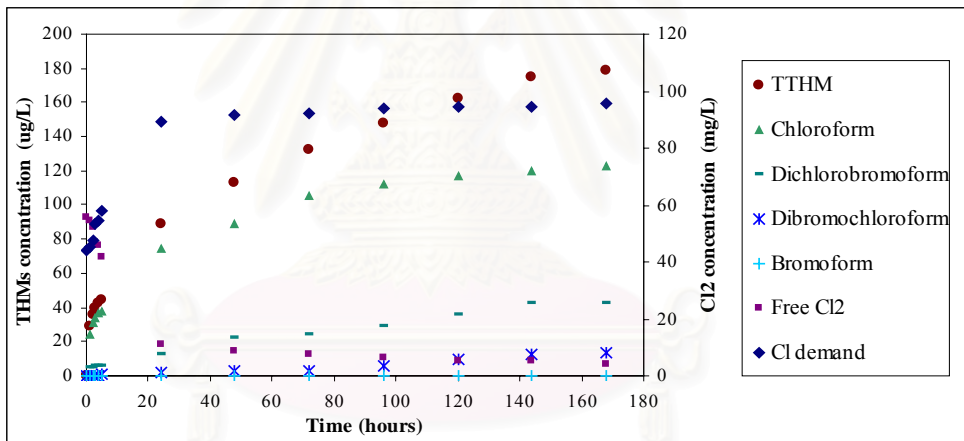
The rate of formation of THMs was measured in the observed well samples taken from the contaminated raw water. THMs formation results showed that the predominant THMs form was chloroform, comprising the largest proportion of the TTHM 40% of all samples. Chloroform was found to be present in all of the samples as was Dichlorobromoform and Dibromochloroform. Bromoform was the least commonly detected THM (Figures 4.62 to 4.64). It can also be seen from Figures 4.62 to 4.64 that THM formation rates were initially rapid corresponding with the rapid consumption of chlorine, followed by declining rate. About 60% of THM was formed within the first 24 h. This indicates that the TTHM formation (in  $\mu\text{g/L}$ ) was a function of chlorine consumption in the raw waters. It can be concluded that chlorine consumption reducing would reduce the THM formation. For instance, decreasing of chlorine demand can reduce THM formation. Sinha (1999) had reported that THM formation was moderately sensitive to the molecular weight of the NOM fraction. Reckhow et al. (1990) also found that the specific by-product formation was related to the activated aromatic content, while activated aromatic content was correlated with chlorine consumption. The results reported herein were based on a single sampling of Mississippi River water at Chester, IL. As the molecular weight of the fractions decreased, TTHM yield coefficients increased.

From Figures 4.68 to 4.70, attempts were made to fit the THMs formation data to chlorine dosages and contact times at the observed wells no. 1, 2 and 3, respectively. This indicates that the THMs formation (in  $\mu\text{g/l}$ ) was a function of chlorine consumption in the raw waters. The THMs formation and chlorine dosages relationships for three different initial chlorine concentrations to make the chlorine residual to be 3-5 mg/ after 168 hours are preformed. The results showed that there are about 15 percent differences among three chlorine dosages. It can be concluded that chlorine doses and contact times of the chlorination process influenced the production of THMs. Therefore, reducing chlorine consumption by removing the NOM surrogate parameter would reduce the THM formation. For instance, alum

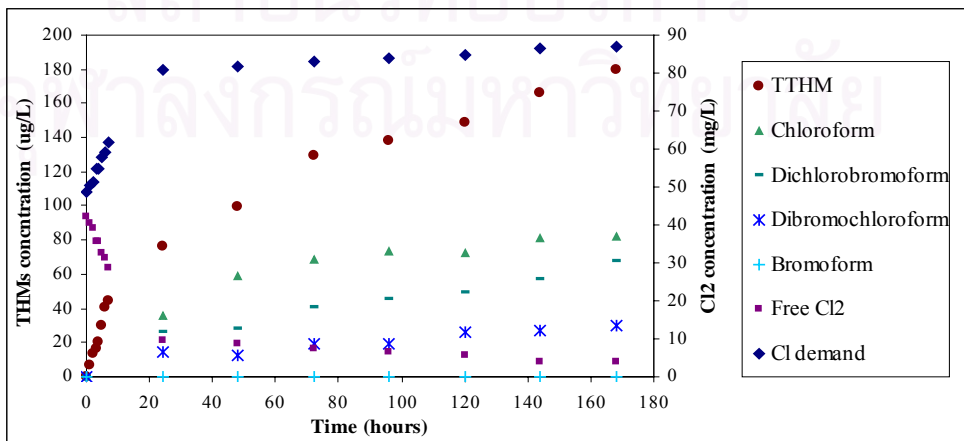
coagulation pretreatment can decrease chlorine demand; therefore, this pretreatment can reduce THM formation.



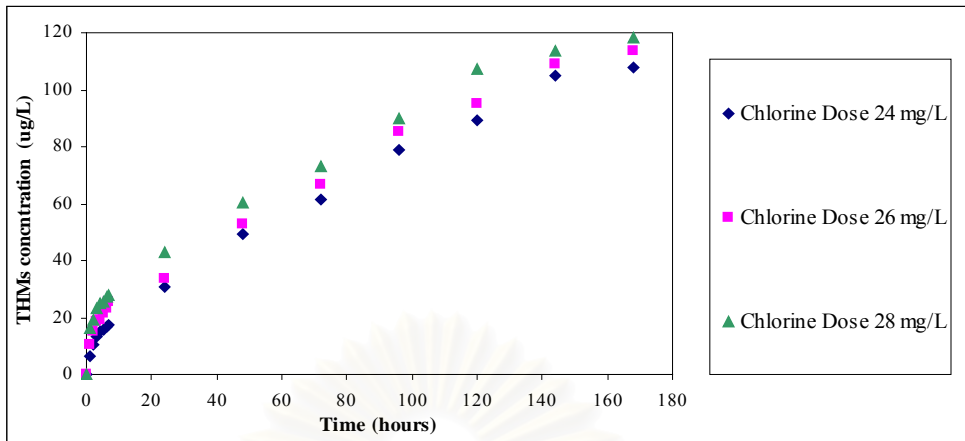
**Figure 4.65** Rate of trihalomethane formation in the observed well no. 1



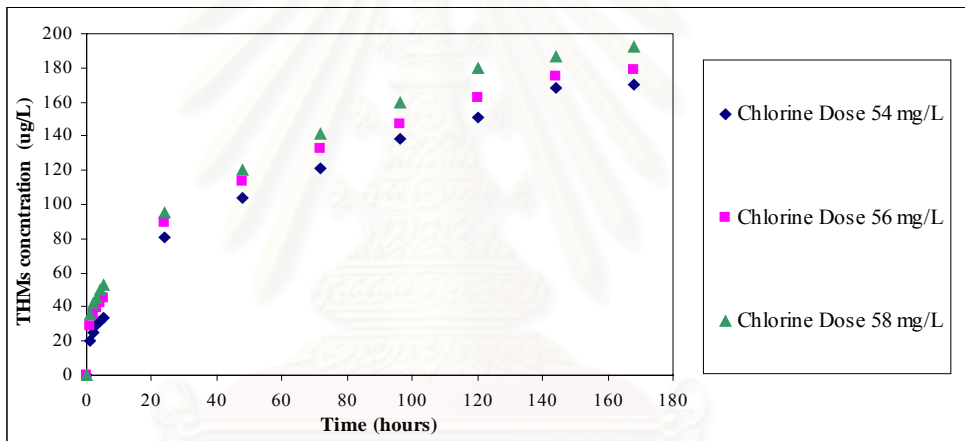
**Figure 4.66** Rate of trihalomethane formation in the observed well no. 2



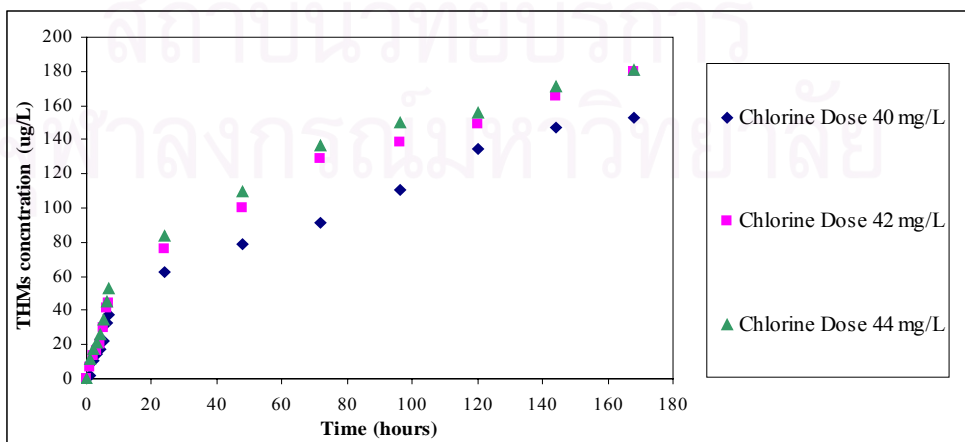
**Figure 4.67** Rate of trihalomethane formation in the observed well no. 3



**Figure 4.68** Effect of chlorine doses and contact times on THMs production in the observed well no. 1



**Figure 4.69** Effect of chlorine doses and contact times on THMs production in the observed well no. 2



**Figure 4.70** Effect of chlorine doses and contact times on THMs production in the observed well no. 3

## CHAPTER 5

### CONCLUSIONS

The major objective of this research was to investigate trihalomethane concentration and trihalomethane formation potential (THMFP) in the raw water and coagulated water from the observed wells located near and in a Mae-Hia closed solid waste dumping site. Base on the experimental results, the following conclusion can be drawn.

1. For shallow wells water, the direction of the movement of contamination by leachates from the dumping site is towards the north and east. All wells pose a high risk for drinking. Raw water from the observed well no. 2 in particular, contains values of physical characteristics (pH, turbidity, alkalinity and chloride) and NOM surrogates parameters (TOC, DOC and UV-254) higher than the limits set by the groundwater quality standards. The water should be treated before drinking.

2. The values of TOC in the observed wells no. 1, 2 and 3 ranged from 1.140 to 5.386 mg/L, from 5.900 to 18.470 mg/L and from 1.281 to 5.793 mg/L; whereas DOC values ranged from 0.791 to 3.469 mg/L, from 2.807 to 16.236 mg/L and from 0.774 to 4.126 mg/L and UV-254 values ranged from 0.202 to 0.283 1/cm, from 14.970 to 16.236 1/cm and from 0.271 to 0.418 1/cm, respectively. THMFP was found in the observed wells no. 1, 2 and 3 were ranged from 108.90 to 187.81  $\mu\text{g/L}$ , from 170.51 to 241.94  $\mu\text{g/L}$  and from 149.37 to 262.60  $\mu\text{g/L}$  in the raw water from the three observed wells.

3. The hydrophobic group fractionated by XAD-8 resins is more commonly observed than the hydrophilic group. And the hydrophobic DOC was found to have a higher potential to form THM than the hydrophilic DOC.



4. With regarding to alum dosages in the observed wells no. 1 and 2, the best conditions for alum coagulation and THMFP reduction were at the pH values of 5 and the alum dosage of 30 mg/L of. Meanwhile, the proper pH value of most alum dosages for well 3 was at the pH value of 6 and the alum dosage of 40 mg/L. Hence, for the three observed wells water states that coagulation by using alum as coagulant for THMFP reduction is recommended under the condition of a proper pH value of 5.

5. The THMFP species in the raw water and coagulated water of in the observed wells no. 1, 2 and 3, alum coagulation can reduce Chloroform, Dichlorobromoform, Dibromochloroform and Bromoform were approximately 30 to 100 percent, at alum dosage 30-40 mg/L and controlled pH of 5-6. In addition, the main THMFP species in the raw water from the observed wells was Chloroform ( $\text{CHCl}_3$ ) at 50-80 percent while and Dichlorobromoform ( $\text{CHCl}_2\text{Br}$ ) and Dibromochloroform ( $\text{CHClBr}_2$ ), were found at 10-30 percent and 5-20 percent. Bromoform were found only a few percent in wells 1 and 2.

6. In the raw water, THMFP and TOC was the moderate and good correlation represented in the observed wells no. 1, 2 and 3 by the equation of  $\text{THMFP} = 92.58 + 18.043 \text{ TOC}$ ;  $R^2$  of 0.7114,  $\text{THMFP} = 155.57 + 4.4468 \text{ TOC}$ ;  $R^2$  of 0.8510 and  $\text{THMFP} = 132.59 + 19.279 \text{ TOC}$ ;  $R^2$  of 0.8091, respectively.

7. In the coagulated water, the correlation for the observed wells no. 1, 2 and 3 can be represented by the equation are  $\text{THMFP} = 69.924 + 3.3201 \text{ Cl}_2$ ;  $R^2$  of 0.7731,  $\text{THMFP} = 67.15 + 9.9653 \text{ DOC}$ ;  $R^2$  of 0.9599, and  $\text{THMFP} = 68.217 + 381.8 \text{ UV-254}$ ;  $R^2$  of 0.7091, respectively.

8. Chlorine doses and contact times of the chlorination process also influenced the production of THMs. THM formation rates (in  $\mu\text{g/L}$ ) were initially rapid corresponding with the rapid consumption of chlorine, followed a decline rate. This indicated that TTHM formation is a function of chlorine consumption in raw water.

## CHAPTER 6

### RECOMMENDATIONS FOR FUTURE WORK

Based on the results of this study, some recommendations for further studies can be proposed.

1. As stated previously, the correlation between UV-254 and other surrogate parameters for NOM in raw water were poor ( $R^2 < 0.5$ ), which is disagreement with others' studies. Thus more studies on the effect of alum coagulation on UV-254 should be carried out.

2. In this study, THMs and THMFP were investigated during the rainy season and the beginning of the winter season. Thus, the comparison of THM and THMFP in the different seasons is interesting for further study.

3. Due to the high level of THMFP that were observed in the raw water, this indicated that other chlorinated DBPs in term of HAAs, HANs and cyanogen halides may be formed; thus, these chlorinated DBPs should be studied.

4. Comparisons between alum and other coagulants such as PACl and ferric chloride should be developed so that their efficiency and cost can be estimated.

## REFERENCES

- Amy, G.L., and Chadik, P.A. 1983. Cationic polyelectrolytes as primary coagulants for removing trihalomethane precursors, J.AWWA. : 527-531.
- Amy, G.L., Sierka, R.A., Bedessem, J., Price, D., and Tan, L. 1992. Molecular size distribution of dissolve organic matter. J.AWWA. 75 (6): 67.
- Andreottola, G., Cannas P., Cossu R. 1990. Overview on landfill leachate quality . CISA, Environmental Sanitary Engineering Centre, Technical Note No. 3.
- APHA, AWWA and WPCF. 1995. Standard Methods for the Examination of Water and Wastewater. 19<sup>th</sup>ed., Washington D.C., U.S.A.
- AWWA. 1999. Removal of DBP Precursors by Enhanced Coagulation and Lime Softening. 1<sup>st</sup>ed., U.S.A.
- Bell-Ajy, K., Abbaszadegan, M., Ibrahim,E., Verges, D., and LeChevallier, M. 2000. Conventional and optimized coagulation for NOM removal. J.AWWA. 92 (10): 44-58.
- Black, A.P. 1963. Characteristics of colored surface waters. J.AWWA. 55(6): 753.
- Bolto, B., Abbt-Braun, G., Dixon, D., Eldridge, R., Frimmel, F., Hesse, S., King, S., and Toifl, M. 1999. Experimental evaluation of cationic polyelectrolytes for removing natural organic matter from water. Wat. Sci. Technol. 40(9): 71-80.
- Carollo Engineers. 2000. Process treatment technology assessment draft-revision 2. Lake pleasant water treatment plant quality testing study-phase 1 Technical memorandum No.2 [Online]. Available from: <http://www.Client\Phoenix PHXW\4900a00\Tecmem\Draft2\TM2Report.wpd>
- Chadik, P.A., and Amy, G.L. 1983. Cationic polyelectrolytes as primary coagulants for removing trihalomethane precursors. J.AWWA. 10: 527-531.
- Cheng, R.C., Krasner, S.W., Green, J.F., and Wattier K.L.1995. Enhanced coagulation: a preliminary evaluation. J.AWWA. 2: 91-103.
- Christman R. F., Johnson J. D., Hass J. R., Pfaender F. K., Liao W. T., Norwood D. L. and Alexander H. J. 1978. Natural and model aquatic humics: reactions with chlorine. In Water Chlorination: Environmental Impact and Health Effects, eds. R. L. Jolley et al., Vol. 2. Ann Arbor Science Publishers, Ann Arbor, MI.

- Christman, R.F., et al. 1983. Identity and yields of major halogenated products of aquatic and fulvic acid chlorination. Environ. Sci. Technol. 17(10):625.
- Collins M. R., Amy G. L. and Steelink C. 1986. Molecular weight distribution, carboxylic acidity, and humic substances content of aquatic organic matter: implication for removal during water treatment. Environ. Sci. Technol. 20: 1028-1032.
- Cooke, G. D. and Carlson, R. E. 1989. Chapter 3: THM production and eutrophication. Reservoir management for water quality and THM precursor control. J.AWWA. Denver, CO: 5-20.
- Cotruvo, J.A. 1981. THMs in drinking water. Environ Sci & Tech. 15(3): 268-274.
- Crozes, G., White, P., and Marshall, M. 1995. Enhanced coagulation: Its effect on NOM removal and chemical costs. J.AWWA. 1: 78-89.
- Dempsey, B.A., Ganho, R. M. and O' Melia, C.R. 1984. The coagulation of humic substances by means of aluminum salts. J.AWWA. 76(4):141.
- Department of Environmental and Labour. Water Resources Management Division. 2000. Trihalomethanes level in public water supplies of Newfoundland and Labrador[Online]. Available from: <http://www.hc-sc.gc.ca>[2001 January 25]
- Dryfuss, M.J., Miltner, R.J., and Summers, R.S. 1995. The removal of molecular size and humic/non-humic fractions of DBP precursors by optimized coagulation. Proceeding of the annual conference of the American water works association, Anaheim, CA:18-22.
- Eaton A. 1995. Measuring UV-absorbing organic: a standard method. J.AWWA. 2: 86-90.
- Edwards, M. 1997 Predicting DOC removal during enhanced coagulation. J.AWWA. 89(5): 78-89.
- Edzwald, J.K., Becker, W.C., and Wattier, K. 1985. Surrogate parameters for monitoring organic matter and THM precursors. J.AWWA. 4: 122-132.
- Edzwald, J.K. 1993. Coagulation in drinking water treatment: particles, organics and coagulants. Water Sci. Technol 27(11):21.
- El-Shahat, M.F., Abdel-Halim, S.H., and Hassan, G.A. 1998. Evaluation of trihalomethanes in water treatment plants' outputs in Cairo, Egypt during 1991-1993, Bull. Environ. Contam. Toxicol 60: 502-506.

- El-Shahat, M.F., Abdel-Halim, S.H., and Hassan, GA. 2001. Factors influencing the formation of trihalomethanes in drinking water treatment plants. Bull. Environ. Contam. Toxicol 67: 549-553.
- Environmental Protection Agency, USA. 1983. National Interim Primary Drinking Water Regulations, Control of Trihalomethanes in drinking water. Federal Register 48: 401.
- Exall, K.N., Vanloon, S.W. 2000. Using coagulants to remove organic matter, J. AWWA. Nov: 93-102
- Faust S.D. and Aly O.M. 1998. Chemistry of Water Treatment. 2<sup>nd</sup> ed. Ann Arbor Press.
- Federal Register 69390 (63). Finalized on December 16,1998 as established in 40 CFR 141.53.
- Federal Register 69390 (63). Finalized on December 16,1998 as established in 40 CFR 141.64.
- Freeman, J.K., Maxwell, M., Pohlman, B., Scanlan, P., Harms. L., Mark, J., and Spillman, B. 1997. Pilot evaluation of microfiltration and ultrafiltration treatment at cheyene, wyoming. Proceedings of the American Water Works Annual Conference, Atlanta, GA, June 15-19.
- Fryters, T. 2001. Tri-Halo Methanes & their treatment/prevention, 2001. Annual Alberta Water and Wastewater Operation Associatio' Seminar Held in Banff, Alberta.
- Ghazali, Zainuddin Bin Md. 1989. Trihalomethane formation in Bangkok Water Treatment Plant, Thailand. Master's Thesis, Asian Institute of Technology Thailand.
- Gould J.P., Fitchorn L.E. and Urheim E. 1983. Formation of brominated trihalomethanes: extent and kinetics. Water Chlorination: Environmental Impact and Health Effects, eds. R. L. Jolley et al., Vol. 4. Ann Arbor Science Publishers, Ann Arbor, MI.
- Hem, J.D. 1985. Study and interpretation of the chemical characteristics of the natural water. U.S. Geological Survey Water Supply Paper 2254.
- Huang, W.J., Yeh, H.H. 1997. The effect of organic characteristics and bromide on disinfection by-products formation by chlorination. J. Environ. Sci. Health A 32(8), 2311–2336.

- Hubel, E.R. and Edwald K.J. 1987. Removing trihalomethanes precursor by coagulation. J.AWWA. 6: 98-106.
- Hureiki L., Croué J. P. and Legube B. 1994. Chlorination studies of free and combined amino acids. Wat. Res. 28:2521-2531.
- Jacangelo, J.G. 1995. Mechanism of Cryptosporidium, Giardia, and MS2 Virus Removal by MF and UF. J. AWWA.
- John Capece, 1998. Trihalomethanes and our water supply [Online]. Available from: <http://www.southerndatastream.com>. Updated on 3/11/2002.
- Karnchanawong, S. et al. 1993. Monitoring and evaluation of shallow well water quality near a waste disposal site. Environmental International. 19: 579-587.
- Karnchanawong, S. et al. 1999. The Mae Hia Landfill, Chiang mai, Thailand : the post closer groundwater contamination legacy. In P. Asnachinda and S. Lerdtusnee, eds., Proceedings of International Conference on Water Resources Management in International Basins, 2-6 February 1999, Chiang Mai University, Chiang Mai, Thailand: 231-245.
- Kavanaugh, M.C. 1978. Modified coagulation for improved removal of trihalomethane precursors. J.AWWA. 70(11): 613-619.
- Kornegay, B.H. 2000. Natural organic matter in drinking water: recommendation to water utilities. AWWARF, [Project#2543].
- Krasner, S.W., Croue, J.P., Buffle, J., and Perdue, E.M.1996. Three approaches for characterizing NOM. J.AWWA. 5: 66-79.
- Leenheer, J. A., and Stuber, H. A. 1981, Migration through soil of organic solutes in an oil shale process water. Environ. Sci. and Technol. v. 15, no. 12: 1467-1475.
- Leenheer, J.A., Noyes, T.I. and Steer, H.A. 1982. Determination of polar organic solute in oil-shale report water. Environ. Sci. Technol. 16(10):714-723
- Leenheer, J.A. and Noyes, T.I. 1984. A filtration and column-adsorption or system for onsite concentration and fractionation of organic substances from large volume of water. U.S. Geological Survey Water Supply Paper 2230, U.S. Govt. Printing Office Washington, D.C.
- Malcolm Pirnie Inc. 1993 . Guidance Manual for Enhanced Coagulation and Enhanced Softening. Manwah, NJ: USEPA.

- Marhaba, T.F., and Washington, M.B. 1998. Drinking water disinfection and by-products: history and current practice. Adv. Environ. Res. 2(1): 103-115.
- Marhaba, T.F., and Pipada, N.S., 2000. Coagulation: effectiveness in removing dissolved organic matter fractions. Environ. Eng. Sci. 17(2): 107-115.
- Marhaba, T.F., and Van, D. 1999. Chlorinated Disinfection By-Product Formation Potential of Dissolved Organic Matter Fractions at an Ozonation Water Treatment Plant. Advances in Environ. Res. 3(3): 255-268.
- Marhaba, T.F., and Van, D. 2000. The variation of mass and disinfection by-product formation potential of dissolved organic matter fractions along a conventional surface water treatment plant. Journal of Hazardous Materials : 1-15.
- Martin-Mousset B., Croue J. P., Lefevbre E. and Legube B. 1997. Distribution et caractérisation de la matière organique dissoute d'eaux naturelles de surface. Water Res. 31:541-553.
- Michael, L.P. et al. 2000. Sources and Haloacetic acid trihalomethane formation potentials of aquatic humic substances in the Wakarusa river and Clinton lake near Lawrence, Kansas. Environ. Sci. Technol 34: 427B-428B.
- Miltner, M.J., Nolan S.A., and Summers R.S. 1994. Evaluation of enhanced coagulation for DBP coagulation. Water and Wastewater Treatment: Proceedings of the 1994 National Conference on Environmental Engineering. Boulder, Co.: ASCE.
- Morris, J.C. and Baum B. 1978. Precursors and mechanisms of haloform formation in the chlorination of water supplies. Water Chlorination: Environmental Impact and Health Effects, eds. R. L. Jolley et al., Vol. 2. Ann Arbor Science Publishers, Ann Arbor, MI.
- Morris, R.D. et al. 1992. Chlorination byproducts and cancers: a meta-analysis. American Journal of Public Health 82 (7): 955-963.
- Muttamara, S., Sales, C.I. and Gazali, Z. 1995. The formation of trihalomethane from chemical disinfectants and humic substances in drinking water. Water Supply 13 (2):105-117.
- Najm, N.I., Patania L.N., Jacangelo, G.J. and Krasner W.S. 1994. Evaluating surrogates for disinfection by-products. J.AWWA. 6: 98-106.
- Norin, H., Renberg, L., 1980. Water Res. 14: 1397-1402.

- National Environment Board Thailand, Environmental Quality Standard Division, Laboratory and Research Section. 1984. Seminar on Trihalomethane in Drinking Water in Bangkok Metropolitan Area. Bangkok.
- National cancer institute.1979. Report on Carcinogenesis Bioassay of Chloroform, Bethesda, MD.
- Notification of the Ministry of Industry, No. 332, B.E. 2521(1978), issued under the industrial Product (1968), published in the Royal Government Gazette, vol.95 Part 68, dated July 4, B.E. 2512(1998).
- Oliver, B. and Lawrence, J. 1979. Haloforms in drinking water: a study of Precursors and precursor removal. J.AWWA. 71:3:161.
- Oliver, B.G., and Shindler, D. B 1980. Trihalomethanes from the Chlorination of Auatic algae. Environ. Sci. Technol. 14 (12):1502.
- Owen, D.M., Amy, G.L., Chowdhury, Z.K. and Viscosil, K. 1995. NOM characterization and treatability. J.AWWA. 75 (10):46-63.
- Owen, D.M., Pirnie, M., Amy, G.L., and Chowdhury, Z.K.1993. Characterization of natural organic matter and its relationship to treatability, AWWARF., order number: 90631.
- Pettersson, C., K. H. Bishop, Y. H. Lee, and B. Allard. 1995. Relations between Organic Carbon and Methylmercury in Humic Rich Surface Waters from Svartberget Catchment in Northern Sweden. Water Air and Soil Pollut. 80:971-979.
- Polkowski, L.B. and Boyle W.C. 1970. Gruondwater Quality Adjacent to Septic Tank Soil Adsorption System. Wisconsin Dept. of Natural Resources, Madison.
- Randtke, S. J., Hoehn, R. C., Hargette, P. H., Knocke, W. R., Dietrich, A. M., and Long, B. W. 1994. The influence of raw water quality on the formation of disinfection by-products during drinking water treatment. Proceedings, 1994 Water Quality Technology Conference; Part II, San Francisco, CA: 1947-1975.
- Reckhow, D.A., and Singer, P.C. 1984. The removal of organic halide precursors by preozonation and alum coagulation. J.AWWA. 76(4): 151-157.



- Reckhow, D.A., and Singer, P.C. 1990. Chlorination by-products in drinking water: from formation potentials to finish water concentration. J.AWWA. 82: 173-180.
- Reckhow D.A., Singer P.C., Malcolm R.L. 1990. Chlorination of humic materials: by product formation and chemical interpretations, Environ. Sci. Technol. 24 (11): 1655.
- Reckhow, D.A., Bose, P., Bezbarua, B., Hesse, E.M. and McKnight, A.P. 1992. Transformations of natural organic material during preozonation. EPA Report. USEPA, Drinking Water Research Division, Cincinnati, Ohio.
- Reynolds, D.T. and Richards, A.P. 1996. Unit Operation and Process in Environmental Engineering. 2<sup>nd</sup> ed., U.S: PWS publishing Company.
- Rook, J.J. 1974. Formation of haloforms during chlorination of natural water. Wtr.Trmt & Exam. 23: 234.
- Rook J.J. 1976. Haloforms in drinking water, J. Am. Water Works Assoc. 68 (3):168.
- Scanlan, P., Pohlman, B., Freeman, S., Spillman, B., and Jerome, M. 1997. Membrane filtration for the removal of color and TOC from surface water. American Water Works Association Membrane Technology Conference Proceedings. February 23-26. New Orleans, LA.
- Shorney, H.L., Randtke, S.J., Hargette, P.H., Mann, P.D., Hoehn, R. C., Knocke, W.R., Dietrich, A. M., and Long, B.W. 1996. The influence of Raw water Quality on Enhanced Coagulation and Softening For the removal of NOM and DBP Formation Potential. J.AWWA. Doctoral Dissertation, Department of Environmental Engineering, University of Kansas, Lawrence, Kansas.
- Shorney, H.L., and Freeman, S. 1998, Control of disinfection by-product precursors [Online]. Available from: <http://www.epa.gov>.
- Sinha S. 1999. Coagulability of NOM and its effects on formation of chlorination DBPs. Ph.D. dissertation, University of Colorado at Boulder, Colorado.
- Sinsabaugh, R.L., Hoehn, R.C., Knocke, W.R., and Linkins, A.E. 1986. Removal of dissolved organic carbon by coagulation with iron sulfate. J.AWWA. 78 (5):74.
- Stevens, A.A., Slocum, C.R., Seeger, D.R., and Robeck, G.G.1976. Chlorination of organics in drinking water. J.AWWA. 615-620.

- Stevenson, F.J. 1982. Humus Chemistry: Genesis, Composition, Reactions. John Wiley and Sons, New York.
- Stuart M.E., Goody D.C., Kinniburgh D.G. Klinch B.A., 2001. Trihalomethanes formation potential: a tool for detecting non-specific organic groundwater contamination. Urban Water. 3: 173-184.
- Suporn Sakornarun. 1987. A Comparative Study of Trihalomethanes Content in Water as a result of Pre-chlorination and Post-Chlorination. Master's Thesis, Faculty of Graduate Study, Mahidol University.
- Symon, J.M. et al. 1975. National organics reconnaissance survey for halogenated organics. J.AWWA. 67(11): 634.
- Tadanier, C.J., Berry, D.F., Knocke, W.R. 1999. Dissolved component recovery following resin exchange based DOM fractionation. J. Environ. Eng. 125 (10), 933–943.
- Thrumann, E.M. 1985. Organic Geochemistry of Natural Waters. Marinus Nijhoff/Dr.W.Junk, Dordrecht. The Netherlands.
- Trussell, R.R., and Umphres, M.D. 1978. The formation of trihalomethanes. J.AWWA. 70 (11): 604-611.
- US.EPA.1994 National Primary Drinking Water Regulation: Disinfectants And Disinfection Byproducts(D/DBP), Notice of Data Availability; Proposed Rule. Fed.Reg. 59:145:38668.
- US.EPA.1997 National Primary Drinking Water Regulation: Disinfectants And Disinfection Byproducts(D/DBP), Notice of Data Availability; Proposed Rule. Fed.Reg. 62:212:59388.
- USEPA. 1998. National Primary Drinking Water Regulation: Disinfectants And Disinfection Byproducts (D/DBP), Final Rule. Fed. Register. 63:69389-69476.
- USEPA.1999. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of water (4607) [Computer file]. Available from: <http://www.epa.gov>[2001 november10]
- Vilge, A., Rose, J., Masion, A., Laine, F., and Bottero, F. 1997. Advanced coagulation of natural organic matter mechanism of interaction between NOM and Al and Fe. Proceeding of the annual conference of the American water works association, Atlanta, GA, June 15-19.

- Wipha Osatharanyakul. 1999. Risk Assessment of Water and Soil Contamination by Mae-Hia Solid Waste Disposal Site in Chiang Mai Province. Master's Thesis, Environmental Science, Graduate School, Chiang Mai University.
- Young, J.S. and Singer, P.C. 1979. Chloroform formation in public water supplies: a case study. J.AWWA. 71(2)87.
- Vrijenhoek, E.M. 1998. Removing particles and THM precursors by enhanced coagulation. J.AWWA. 90(4):139-150.

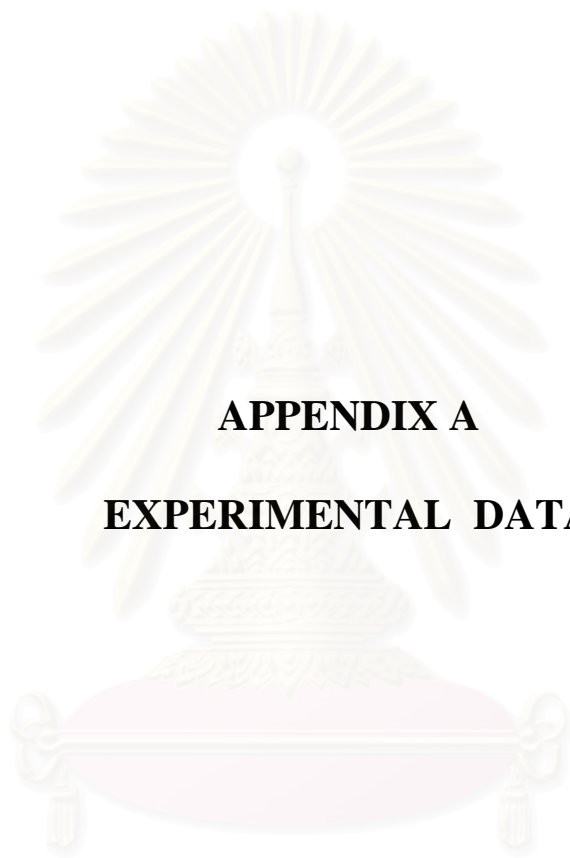


สถาบันวิทยบริการ  
จุฬาลงกรณ์มหาวิทยาลัย



**APPENDICES**

สถาบันวิทยบริการ  
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**APPENDIX A**  
**EXPERIMENTAL DATA**

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**Table A-1** Data of raw water from the observed shallow wells

Sample Dates	The observerd	pH	Temp.	Turbidity	Alkalinity	TOC	DOC	UV-254	SUVA	Chloride	Chlorine	THM <sub>0</sub>	THMFP
			°C	NTU	mg/L as CaCO <sub>3</sub>	mg/L	mg/L	cm <sup>-1</sup>	L/mg-m	mg/L	Demand mg/L	µg/L	(THM <sub>7</sub> ) µg/L
23-Sep-03	1	6.64	26.0	5.76	210	5.386	3.469	0.283	8.164	-	34.60	0	187.813
	2	-	-	-	-	-	-	-	-	-	-	-	-
	3	6.44	26.5	2.06	260	5.793	4.126	0.418	10.133	-	33.05	0	262.613
8-Oct-03	1	6.40	26.0	2.50	120	1.140	0.791	0.202	25.537	-	14.18	0	108.901
	2	7.89	26.0	4.10	1400	8.176	5.520	14.97	271.196	-	67.36	0	201.996
	3	6.67	26.5	2.20	188	1.281	0.774	0.271	35.026	-	21.27	0	172.061
22-Oct-03	1	6.16	25.0	2.75	136	1.778	1.765	0.213	12.068	-	21.27	0	118.322
	2	7.57	25.0	3.38	1310	5.9	2.807	15.344	546.633	-	63.69	0	170.511
	3	6.19	25.5	1.03	160	1.624	1.566	0.276	17.625	-	18.60	0	149.372
5-Nov-03	1	6.21	26.0	2.86	140	1.614	1.401	0.275	19.629	58.63	23.46	0	120.237
	2	7.71	25.5	4.76	1450	11.862	6.528	15.838	242.616	570.49	69.12	0	217.560
	3	6.92	26.5	1.2	205	1.783	1.774	0.302	17.001	210.43	27.48	0	179.959
26-Dec-03	1	6.82	21.0	4.58	208	2.585	1.602	0.279	17.406	64.9798	28.86	0	172.478
	2	7.81	19.5	10.3	1700	18.470	16.83	16.236	96.471	579.82	74.445	0	241.938
	3	6.72	21.0	3.72	232	4.514	4.071	0.356	8.745	254.92	31.55	0	201.454
30-Jan-04	1	6.79	22.0	3.4	180	2.967	1.657	0.273	16.476	49.98	24.44	0	126.724
	2	7.92	21.5	5.5	1500	16.672	14.533	15.843	109.014	561.49	68.70	0	217.56
	3	6.91	22.5	0.87	232	3.189	3.103	0.276	8.885	204.93	30.45	0	180.632
Range	1	6.16 - 6.82	21.0 - 26.0	2.50 - 5.76	120 - 210	1.14 - 5.386	0.791 - 3.469	0.202 - 0.283	8.16 - 25.54	58.63-64.97	14.18 - 34.60	0	108.9-187.8
	2	7.57 - 7.92	19.5 - 26.0	3.38 -10.3	1310 - 1700	5.90 - 18.470	2.807 - 16.830	14.97 - 16.236	96.47-546.33	561.49-579.82	63.69 - 74.45	0	170.5-241.9
	3	6.19 - 6.92	21.0 - 26.5	0.87 - 3.72	160 - 260	1.281 - 5.793	0.774 - 4.126	0.271 - 0.418	8.882 - 35.03	204.93-254.92	18.60 - 33.05	0	149.4-262.6
Average	1	6.50	24.33	3.64	165.67	2.58	1.78	0.25	16.55	57.86	24.47	0.0	139.08
	2	7.78	23.50	5.61	1472.00	12.22	9.24	15.65	253.19	570.60	68.66	0.0	209.91
	3	6.64	24.75	1.85	212.83	3.03	2.57	0.32	16.24	223.43	27.07	0.0	191.02
SD	1	0.2884	2.2509	1.2756	38.9547	1.5280	0.8968	0.0365	6.0234	7.5292	6.9151	0.0	32.6793
	2	0.1428	2.8504	2.7379	145.4991	5.3691	6.0869	0.4929	181.5852	9.1655	3.8757	0.0	26.2572
	3	0.2832	2.4031	1.0695	35.8576	1.8140	1.4018	0.0591	10.0297	27.4123	5.8788	0.0	38.8810

**Table A-2** The coagulation experimental results of the shallow well water from the observed well no. 1**pH5**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	6.82	0	110.00	0.279	0.00
10	5.76	15.5	22.5	0.224	19.71
20	5.48	19.6	18.5	0.218	21.86
30	5.23	23.3	11	0.215	22.94
40	5.35	21.6	12.5	0.203	27.24
50	5.45	20.1	18	0.208	25.45
60	6.02	11.7	24	0.215	22.94

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	2.585	0.00	1.602	0.000	17.42	0.00
10	2.011	22.21	1.558	2.747	14.38	17.45
20	1.858	28.12	1.532	4.370	14.23	18.29
30	1.672	35.32	1.524	4.869	14.11	19.00
40	1.734	32.92	1.508	5.868	13.46	22.70
50	1.784	30.99	1.541	3.808	13.79	20.80
60	1.805	30.17	1.574	3.808	13.95	19.89

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	28.86	172.487	0
10	20.56	132.56	23.15
20	19.43	130.42	24.39
30	18.72	128.73	25.37
40	18.93	131.69	23.65
50	19.64	135.98	21.17
60	20.04	140.16	18.74

**pH6**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	6.82	0	110.00	0.279	0.00
10	5.93	13.0	22	0.236	15.41
20	5.54	18.8	19.5	0.225	19.35
30	5.37	21.3	13.5	0.219	21.51
40	5.43	20.4	18	0.221	20.79
50	5.52	19.1	19	0.223	20.07
60	6.11	10.4	22	0.224	19.71

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	2.585	0.00	1.602	0.000	17.42	0.00
10	2.183	15.55	1.598	0.250	14.77	15.20
20	1.955	24.37	1.586	0.999	14.19	18.54
30	1.721	33.42	1.572	1.873	13.93	20.01
40	1.789	30.79	1.586	0.999	13.93	19.99
50	1.893	26.77	1.563	0.999	14.06	19.27
60	1.942	24.87	1.578	2.434	14.33	17.71

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	28.86	172.487	0
10	20.49	131.97	23.49
20	19.68	131.56	23.73
30	19.03	129.46	24.95
40	19.15	132.59	23.13
50	20.11	136.78	20.70
60	20.1	140.03	18.82

**Table A-2** The coagulation experimental results of the shallow well water from the observed well no. 1 (cont.)**pH 7**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as CaCO <sub>3</sub> )	UV-254 cm-1	UV-254 %Reduction
0	6.82	0	110.00	0.279	0.00
10	6.03	11.6	25	0.254	8.96
20	5.76	15.5	23.5	0.243	12.90
30	5.54	18.8	16.5	0.235	15.77
40	5.67	16.9	20	0.237	15.05
50	5.71	16.3	21.5	0.239	14.34
60	6.25	8.4	25.5	0.241	13.62

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	2.585	0.00	1.602	0.000	17.42	0.00
10	2.216	14.27	1.598	0.250	15.89	8.73
20	2.068	20.00	1.596	0.375	15.23	12.58
30	1.965	23.98	1.579	1.436	14.88	14.54
40	1.976	23.56	1.596	0.375	14.85	14.73
50	1.989	23.06	1.574	0.375	14.97	14.01
60	2.135	17.41	1.58	1.748	15.31	12.08

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	28.86	172.487	0
10	22.43	139.56	19.09
20	21.32	133.89	22.38
30	20.97	132.96	22.92
40	20.89	134.42	22.07
50	21.56	139.89	18.90
60	22.13	145.63	15.57

**pH 8**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as CaCO <sub>3</sub> )	UV-254 cm-1	UV-254 %Reduction
0	6.82	0	110.00	0.279	0.00
10	6.12	10.3	25.5	0.263	5.73
20	5.91	13.3	25	0.254	8.96
30	5.63	17.4	17	0.247	11.47
40	5.74	15.8	20.5	0.246	11.83
50	5.86	14.1	22	0.249	10.75
60	6.27	8.1	25.5	0.251	10.04

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	2.585	0.00	1.602	0.000	17.42	0.00
10	2.301	10.99	1.6	0.125	16.44	5.62
20	2.158	16.52	1.597	0.312	15.90	8.68
30	2.056	20.46	1.562	2.497	15.81	9.20
40	2.154	16.67	1.598	0.250	15.39	11.61
50	2.203	14.78	1.583	0.250	15.58	10.53
60	2.278	11.88	1.587	1.186	15.86	8.96

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	28.86	172.487	0
10	25.1	143.56	16.77
20	23.56	136.97	20.59
30	22.89	139.52	19.11
40	23.16	140.75	18.40
50	23.59	143.33	16.90
60	24.23	149.65	13.24



**Table A-3** The coagulation experimental results of the shallow well water from the observed well no. 2**pH5**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	7.43	0	1700.00	16.236	0
10	3.24	56.4	580	8.656	46.69
20	2.25	69.7	580	7.555	53.47
30	2.3	69.0	580	6.865	57.72
40	2.33	68.6	590	7.381	54.54
50	2.74	63.1	590	8.392	48.31
60	3.15	57.6	600	8.985	44.66

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	18.47	0.00	16.83	0.000	96.47	0.00
10	13.727	25.68	10.966	34.843	78.93	18.18
20	9.655	47.73	8.504	49.471	88.84	7.91
30	8.948	51.55	8.238	51.052	83.33	13.62
40	9.49	48.62	8.521	49.370	86.62	10.21
50	9.746	47.23	8.918	47.011	94.10	2.46
60	10.158	45.00	9.316	44.646	96.45	0.02

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	74.445	236.21565	0.000
10	51.33	158.482	32.908
20	48.72	151.35	35.927
30	47.21	148.956	36.941
40	50.09	154.62	34.543
50	54.68	158.37	32.955
60	58.74	162.48	31.215

**pH6**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	7.43	0	1700.00	16.236	0
10	3.3	55.6	585	7.896	51.37
20	2.5	66.4	583	7.645	52.91
30	2.34	68.5	583	6.954	57.17
40	2.45	67.0	585	7.542	53.55
50	2.8	62.3	590	8.458	47.91
60	3.24	56.4	590	9.345	42.44

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	18.47	0.00	16.83	0.000	96.47	0.00
10	14.021	24.09	10.156	39.655	77.75	19.41
20	10.213	44.70	9.473	43.714	80.70	16.34
30	9.645	47.78	8.365	50.297	83.13	13.83
40	9.542	48.34	8.746	48.033	86.23	10.61
50	9.871	46.56	9.158	45.585	92.36	4.26
60	10.246	44.53	9.697	42.383	96.37	0.10

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	74.445	236.21565	0.000
10	53.96	165.43	29.967
20	50.12	159.99	32.270
30	49.56	152.31	35.521
40	55.87	159.63	32.422
50	59.81	160.94	31.867
60	60.35	166.26	29.615

**Table A-3** The coagulation experimental results of the shallow well water from the observed well no. 2 (cont.)**pH 7**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	7.43	0	1700.00	16.236	0
10	3.42	54.0	590	7.978	50.86
20	2.76	62.9	585	7.752	52.25
30	2.48	66.6	585	7.054	56.55
40	2.53	65.9	590	8.295	48.91
50	2.84	61.8	595	8.568	47.23
60	3.39	54.4	595	9.472	41.66

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	18.47	0.00	16.83	0.000	96.47	0.00
10	14.321	22.46	11.289	32.923	70.67	26.74
20	10.546	42.90	10.008	40.535	77.46	19.71
30	9.782	47.04	8.594	48.936	82.08	14.92
40	9.623	47.90	9.176	45.478	90.40	6.29
50	9.954	46.11	9.295	44.771	92.18	4.45
60	10.328	44.08	9.946	40.903	95.23	1.28

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	74.445	236.21565	0.000
10	59.29	178.46	24.450
20	58.56	162.923	31.028
30	57.92	146.39	38.027
40	59.63	149.26	36.812
50	60.096	156.89	33.582
60	62.35	164.52	30.352

**pH 8**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	7.43	0	1700.00	16.236	0
10	3.52	52.6	595	8.186	49.58
20	2.84	61.8	590	7.903	51.32
30	2.67	64.1	590	7.254	55.32
40	2.62	64.7	595	7.768	52.16
50	2.91	60.8	600	8.629	46.85
60	3.45	53.6	605	8.752	46.10

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	18.47	0.00	16.83	0.000	96.47	0.00
10	14.562	21.16	11.465	31.878	71.40	25.99
20	11.896	35.59	11.213	33.375	70.48	26.94
30	9.945	46.16	8.872	47.285	81.76	15.25
40	9.734	47.30	8.976	46.667	86.54	10.29
50	10.215	44.69	9.358	44.397	92.21	4.42
60	10.406	43.66	9.472	43.720	92.40	4.22

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	74.445	236.21565	0.000
10	60.96	185.69	21.390
20	59.23	173.32	26.626
30	58.46	153.84	34.873
40	60.79	165.121	30.097
50	62.98	169.51	28.239
60	62.89	170.76	27.710

**Table A-4** The coagulation experimental results of the shallow well water from the observed well no. 3**pH5**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	6.72	0	232.00	0.356	0.00
10	2.59	61.5	35	0.284	20.22
20	2.01	70.1	35	0.278	21.91
30	1.84	72.6	30	0.273	23.31
40	1.78	73.5	30	0.251	29.49
50	2.13	68.3	30	0.259	27.25
60	2.35	65.0	33	0.279	21.63

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	4.514	0.00	4.071	0.000	8.74	0.00
10	3.575	20.80	3.346	17.809	8.49	2.94
20	3.598	20.29	3.325	18.325	8.36	4.39
30	3.492	22.64	3.298	18.988	8.28	5.34
40	3.443	23.73	3.14	22.869	7.99	8.59
50	3.976	11.92	3.256	20.020	7.95	9.04
60	4.217	6.58	3.34	17.956	8.35	4.48

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	31.55	201.454	0.000
10	26.97	190.69	5.343
20	26.02	180.22	10.540
30	25.16	170.26	15.484
40	24.31	162.95	19.113
50	25.94	162.76	19.207
60	27.56	165.42	17.887

**pH6**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as Caco3)	UV-254 cm-1	UV-254 %Reduction
0	6.72	0	232.00	0.356	0.00
10	2.53	62.4	30	0.274	23.03
20	1.94	71.1	30	0.271	23.88
30	1.73	74.3	25	0.268	24.72
40	1.72	74.4	25	0.265	25.56
50	1.93	71.3	25	0.269	24.44
60	2.22	67.0	30	0.274	23.03

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	4.514	0.00	4.071	0.000	8.74	0.00
10	3.526	21.89	3.152	22.574	8.69	0.59
20	3.494	22.60	3.134	23.016	8.65	1.12
30	3.467	23.19	3.105	23.729	8.63	1.30
40	3.4	24.68	3.052	25.031	8.68	0.71
50	3.849	14.73	3.12	23.360	8.62	1.41
60	4.213	6.67	3.286	19.283	8.34	4.65

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	31.55	201.454	0.000
10	26.25	186.23	7.557
20	25.34	172.469	14.388
30	24.82	165.36	17.917
40	23.96	159.98	20.587
50	27.43	160.65	20.255
60	28.86	167.34	16.934

**Table A-4** The coagulation experimental results of the shallow well water from the observed well no. 3 (cont.)**pH 7**

Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as CaCO <sub>3</sub> )	UV-254 cm-1	UV-254 %Reduction
0	6.72	0.0	232.00	0.356	0.00
10	2.78	58.6	35	0.284	20.22
20	2.13	68.3	33	0.279	21.63
30	1.96	70.8	28	0.271	23.88
40	1.82	72.9	28	0.268	24.72
50	2.03	69.8	30	0.273	23.31
60	2.29	65.9	35	0.275	22.75

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	4.514	0.00	4.071	0.000	8.74	0.00
10	3.645	19.25	3.259	19.946	8.71	0.35
20	3.589	20.49	3.256	20.020	8.57	2.01
30	3.491	22.66	3.201	21.371	8.47	3.19
40	3.462	23.31	3.183	21.813	8.42	3.72
50	3.897	13.67	3.198	21.444	8.54	2.38
60	4.351	3.61	3.339	17.981	8.24	5.82

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	31.55	201.454	0.000
10	27.43	192.1	4.643
20	26.89	184.83	8.252
30	26.21	172.51	14.368
40	25.63	165.28	17.956
50	25.82	165.04	18.076
60	26.94	165.22	17.986

**pH 8**

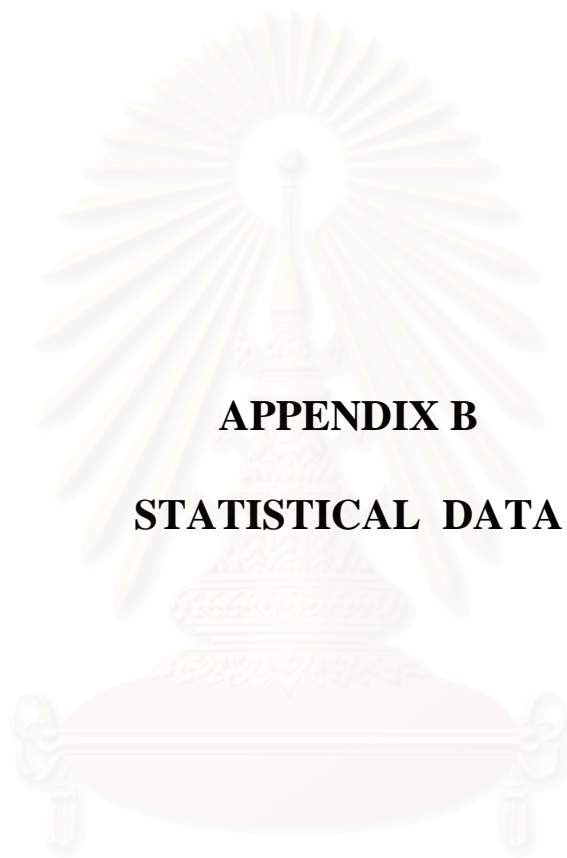
Alum (mg/L)	Turbidity (NTU)	Turbidity %Removal	Alkalinity (mg/L as CaCO <sub>3</sub> )	UV-254 cm-1	UV-254 %Reduction
0	6.72	0	232.00	0.356	0.00
10	2.86	57.4	35	0.298	16.29
20	2.49	62.9	35	0.287	19.38
30	2.1	68.8	30	0.274	23.03
40	1.96	70.8	30	0.253	28.93
50	2.24	66.7	33	0.269	24.44
60	2.51	62.6	37	0.281	21.07

Alum (mg/L)	TOC mg/L	TOC Removal %Removal	DOC mg/L	DOC %Removal	SUVA L/mg-m	SUVA %Reduction
0	4.514	0.00	4.071	0.000	8.74	0.00
10	3.876	14.13	3.451	15.230	8.64	1.25
20	3.752	16.88	3.328	18.251	8.62	1.38
30	3.546	21.44	3.297	19.013	8.31	4.97
40	3.496	22.55	3.213	21.076	7.87	9.95
50	3.953	12.43	3.254	21.076	8.37	4.26
60	4.415	2.19	3.598	20.069	8.64	1.25

Alum (mg/L)	Chlorine mg/L	THMFP mg/L	THMFP %Reduction
0	31.55	201.454	0.000
10	28.016	193.21	4.092
20	27.22	186.46	7.443
30	26.956	175.49	12.888
40	25.64	168.6	16.308
50	25.73	168.71	16.254
60	26.29	169.64	15.792



**APPENDIX B**

**STATISTICAL DATA**

สถาบันวิทยบริการ  
จุฬาลงกรณ์มหาวิทยาลัย

**Table B-1** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the raw water from the observed well no. 1

### Correlations

		THMFP	UV_254
THMFP	Pearson Correlation	1.000	.678
	Sig. (2-tailed)	.	.139
	N	6	6
UV_254	Pearson Correlation	.678	1.000
	Sig. (2-tailed)	.139	.
	N	6	6

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV_254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.678 <sup>a</sup>	.459	.324	26.8732

a. Predictors: (Constant), UV\_254

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2451.056	1	2451.056	3.394	.139 <sup>a</sup>
	Residual	2888.671	4	722.168		
	Total	5339.728	5			

a. Predictors: (Constant), UV\_254

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-15.195	84.456		-.180	.866
	UV_254	606.979	329.470	.678	1.842	.139

a. Dependent Variable: THMFP

**Table B-2** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the raw water from the observed well no. 1

#### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.843*
	Sig. (2-tailed)	.	.035
	N	6	6
TOC	Pearson Correlation	.843*	1.000
	Sig. (2-tailed)	.035	.
	N	6	6

\*. Correlation is significant at the 0.05 level (2-tailed).

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.843 <sup>a</sup>	.711	.639	19.6294

a. Predictors: (Constant), TOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3798.481	1	3798.481	9.858	.035 <sup>a</sup>
	Residual	1541.247	4	385.312		
	Total	5339.728	5			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	92.580	16.839		5.498	.005
	TOC	18.043	5.747	.843	3.140	.035

a. Dependent Variable: THMFP

**Table B-3** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the raw water from the observed well no. 1

#### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.656
	Sig. (2-tailed)	.	.157
	N	6	6
DOC	Pearson Correlation	.656	1.000
	Sig. (2-tailed)	.157	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.656 <sup>a</sup>	.430	.287	27.5891

a. Predictors: (Constant), DOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2295.101	1	2295.101	3.015	.157 <sup>a</sup>
	Residual	3044.627	4	761.157		
	Total	5339.728	5			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	95.612	27.449		3.483	.025
	DOC	22.319	12.853	.656	1.736	.157

a. Dependent Variable: THMFP



**Table B-4** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the raw water from the observed well no. 1

#### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	-.504
	Sig. (2-tailed)	.	.308
	N	6	6
SUVA	Pearson Correlation	-.504	1.000
	Sig. (2-tailed)	.308	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.504 <sup>a</sup>	.254	.067	31.5650

a. Predictors: (Constant), SUVA

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1354.336	1	1354.336	1.359	.308 <sup>a</sup>
	Residual	3985.392	4	996.348		
	Total	5339.728	5			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	178.076	35.845		4.968	.008
	SUVA	-2.514	2.156	-.504	-1.166	.308

a. Dependent Variable: THMFP

**Table B-5** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the raw water from the observed well no. 1

#### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.918**
	Sig. (2-tailed)	.	.010
	N	6	6
D_CL	Pearson Correlation	.918**	1.000
	Sig. (2-tailed)	.010	.
	N	6	6

\*\* . Correlation is significant at the 0.01 level

#### Regression

##### Variables Entered/Removed<sup>d</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.918 <sup>a</sup>	.842	.802	14.5253

a. Predictors: (Constant), D\_CL

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4495.792	1	4495.792	21.309	.010 <sup>a</sup>
	Residual	843.935	4	210.984		
	Total	5339.728	5			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	32.964	23.740		1.389	.237
	D_CL	4.337	.939	.918	4.616	.010

a. Dependent Variable: THMFP

**Table B-6** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the raw water from the observed well no. 2

#### Correlations

		THMFP	UV_254
THMFP	Pearson Correlation	1.000	.797
	Sig. (2-tailed)	.	.057
	N	6	6
UV_254	Pearson Correlation	.797	1.000
	Sig. (2-tailed)	.057	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV_254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.797 <sup>a</sup>	.636	.545	17.4312

a. Predictors: (Constant), UV\_254

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2121.067	1	2121.067	6.981	.057 <sup>a</sup>
	Residual	1215.391	4	303.848		
	Total	3336.458	5			

a. Predictors: (Constant), UV\_254

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-458.406	254.710		-1.800	.146
	UV_254	42.779	16.191	.797	2.642	.057

a. Dependent Variable: THMFP

**Table B-7** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the raw water from the observed well no. 2

#### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.922*
	Sig. (2-tailed)	.	.009
	N	6	6
TOC	Pearson Correlation	.922*	1.000
	Sig. (2-tailed)	.009	.
	N	6	6

\*\* . Correlation is significant at the 0.01 level

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.922 <sup>a</sup>	.851	.814	11.1501

a. Predictors: (Constant), TOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2839.162	1	2839.162	22.837	.009 <sup>a</sup>
	Residual	497.296	4	124.324		
	Total	3336.458	5			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	154.365	13.343		11.569	.000
	TOC	4.613	.965	.922	4.779	.009

a. Dependent Variable: THMFP

**Table B-8** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the raw water from the observed well no. 2

#### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.865*
	Sig. (2-tailed)	.	.026
	N	6	6
DOC	Pearson Correlation	.865*	1.000
	Sig. (2-tailed)	.026	.
	N	6	6

\*. Correlation is significant at the 0.05 level (2-tailed).

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.865 <sup>a</sup>	.748	.685	14.4922

a. Predictors: (Constant), DOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2496.367	1	2496.367	11.886	.026 <sup>a</sup>
	Residual	840.092	4	210.023		
	Total	3336.458	5			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	176.754	12.394		14.261	.000
	DOC	3.550	1.030	.865	3.448	.026

a. Dependent Variable: THMFP

**Table B-9** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the raw water from the observed well no. 2

#### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	-.943*
	Sig. (2-tailed)	.	.005
	N	6	6
SUVA	Pearson Correlation	-.943*	1.000
	Sig. (2-tailed)	.005	.
	N	6	6

\*\* . Correlation is significant at the 0.01 level

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.943 <sup>a</sup>	.889	.861	9.6363

a. Predictors: (Constant), SUVA

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2965.028	1	2965.028	31.931	.005 <sup>a</sup>
	Residual	371.431	4	92.858		
	Total	3336.458	5			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	245.779	6.820		36.040	.000
	SUVA	-.139	.025	-.943	-5.651	.005

a. Dependent Variable: THMFP

**Table B-10** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the raw water from the observed well no. 2

#### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.904*
	Sig. (2-tailed)	.	.013
	N	6	6
D_CL	Pearson Correlation	.904*	1.000
	Sig. (2-tailed)	.013	.
	N	6	6

\*. Correlation is significant at the 0.05 level (2-tailed).

#### Regression

##### Variables Entered/Removed<sup>d</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.904 <sup>a</sup>	.817	.771	12.3598

a. Predictors: (Constant), D\_CL

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2725.404	1	2725.404	17.841	.013 <sup>a</sup>
	Residual	611.054	4	152.763		
	Total	3336.458	5			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-248.039	109.576		-2.264	.086
	D_CL	6.726	1.592	.904	4.224	.013

a. Dependent Variable: THMFP

**Table B-11** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the raw water from the observed well no. 3

### Correlations

		THMFP	UV_254
THMFP	Pearson Correlation	1.000	.942**
	Sig. (2-tailed)	.	.005
	N	6	6
UV_254	Pearson Correlation	.942**	1.000
	Sig. (2-tailed)	.005	.
	N	6	6

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV_254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.942 <sup>a</sup>	.887	.859	14.5820

a. Predictors: (Constant), UV\_254

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6707.268	1	6707.268	31.544	.005 <sup>a</sup>
	Residual	850.541	4	212.635		
	Total	7557.810	5			

a. Predictors: (Constant), UV\_254

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.353	35.467		-.151	.887
	UV_254	620.448	110.471	.942	5.616	.005

a. Dependent Variable: THMFP



**Table B-12** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the raw water from the observed well no. 3

#### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.899*
	Sig. (2-tailed)	.	.015
	N	6	6
TOC	Pearson Correlation	.899*	1.000
	Sig. (2-tailed)	.015	.
	N	6	6

\*. Correlation is significant at the 0.05 level (2-tailed).

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.899 <sup>a</sup>	.809	.761	18.9932

a. Predictors: (Constant), TOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6114.840	1	6114.840	16.951	.015 <sup>a</sup>
	Residual	1442.970	4	360.742		
	Total	7557.810	5			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	132.592	16.171		8.199	.001
	TOC	19.279	4.683	.899	4.117	.015

a. Dependent Variable: THMFP

**Table B-13** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the raw water from the observed well no. 3

#### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.757
	Sig. (2-tailed)	.	.082
	N	6	6
DOC	Pearson Correlation	.757	1.000
	Sig. (2-tailed)	.082	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.757 <sup>a</sup>	.573	.466	28.4197

a. Predictors: (Constant), DOC

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4327.104	1	4327.104	5.357	.082 <sup>a</sup>
	Residual	3230.706	4	807.677		
	Total	7557.810	5			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	137.107	26.022		5.269	.006
	DOC	20.986	9.067	.757	2.315	.082

a. Dependent Variable: THMFP

**Table B-14** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the raw water from the observed well no. 3

#### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	-.441
	Sig. (2-tailed)	.	.381
	N	6	6
SUVA	Pearson Correlation	-.441	1.000
	Sig. (2-tailed)	.381	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.441 <sup>a</sup>	.195	-.006	39.0035

a. Predictors: (Constant), SUVA

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1472.715	1	1472.715	.968	.381 <sup>a</sup>
	Residual	6085.094	4	1521.274		
	Total	7557.810	5			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	218.801	32.416		6.750	.003
	SUVA	-1.711	1.739	-.441	-.984	.381

a. Dependent Variable: THMFP

**Table B-15** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the raw water from the observed well no. 3

#### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.785
	Sig. (2-tailed)	.	.064
	N	6	6
D_CL	Pearson Correlation	.785	1.000
	Sig. (2-tailed)	.064	.
	N	6	6

#### Regression

##### Variables Entered/Removed<sup>d</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785 <sup>a</sup>	.617	.521	26.9066

a. Predictors: (Constant), D\_CL

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4661.956	1	4661.956	6.439	.064 <sup>a</sup>
	Residual	2895.854	4	723.964		
	Total	7557.810	5			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	50.433	56.479		.893	.422
	D_CL	5.194	2.047	.785	2.538	.064

a. Dependent Variable: THMFP

**Table B-16** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the coagulated water from the observed well no. 1

### Correlations

		THMFP	UV254
THMFP	Pearson Correlation	1.000	.726**
	Sig. (2-tailed)	.	.000
	N	25	25
UV254	Pearson Correlation	.726**	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.726 <sup>a</sup>	.527	.507	6.2824

a. Predictors: (Constant), UV254

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1013.246	1	1013.246	25.672	.000 <sup>a</sup>
	Residual	907.780	23	39.469		
	Total	1921.026	24			

a. Predictors: (Constant), UV254

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	54.938	16.477		3.334	.003
	UV254	354.592	69.984	.726	5.067	.000

a. Dependent Variable: THMFP

**Table B-17** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the coagulated water from the observed well no. 1

### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.780*
	Sig. (2-tailed)	.	.000
	N	25	25
TOC	Pearson Correlation	.780*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.780 <sup>a</sup>	.609	.592	5.7168

a. Predictors: (Constant), TOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1169.335	1	1169.335	35.779	.000 <sup>a</sup>
	Residual	751.691	23	32.682		
	Total	1921.026	24			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	73.092	10.942		6.680	.000
	TOC	32.267	5.394	.780	5.982	.000

a. Dependent Variable: THMFP

**Table B-18** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the coagulated water from the observed well no. 1

### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.425*
	Sig. (2-tailed)	.	.034
	N	25	25
DOC	Pearson Correlation	.425*	1.000
	Sig. (2-tailed)	.034	.
	N	25	25

\*. Correlation is significant at the 0.05 level (2-tailed).

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.425 <sup>a</sup>	.181	.145	8.2710

a. Predictors: (Constant), DOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	347.596	1	347.596	5.081	.034 <sup>a</sup>
	Residual	1573.431	23	68.410		
	Total	1921.026	24			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-97.548	104.590		-.933	.361
	DOC	149.681	66.403	.425		

a. Dependent Variable: THMFP

**Table B-19** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the coagulated water from the observed well no. 1

### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	.742*
	Sig. (2-tailed)	.	.000
	N	25	25
SUVA	Pearson Correlation	.742*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.742 <sup>a</sup>	.550	.531	6.1285

a. Predictors: (Constant), SUVA

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1057.183	1	1057.183	28.148	.000 <sup>a</sup>
	Residual	863.843	23	37.558		
	Total	1921.026	24			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	38.944	18.745		2.078	.049
	SUVA	6.662	1.256	.742	5.305	.000

a. Dependent Variable: THMFP



**Table B-20** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the coagulated water from the observed well no. 1

### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.879*
	Sig. (2-tailed)	.	.000
	N	25	25
D_CL	Pearson Correlation	.879*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.879 <sup>a</sup>	.773	.763	4.3530

a. Predictors: (Constant), D\_CL

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1485.208	1	1485.208	78.381	.000 <sup>a</sup>
	Residual	435.818	23	18.949		
	Total	1921.026	24			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	66.924	8.096		8.267	.000
	D_CL	3.320	.375	.879	8.853	.000

a. Dependent Variable: THMFP

**Table B-21** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the coagulated water from the observed well no. 2

### Correlations

		THMFP	UV254
THMFP	Pearson Correlation	1.000	.957*
	Sig. (2-tailed)	.	.000
	N	25	25
UV254	Pearson Correlation	.957*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.957 <sup>a</sup>	.917	.913	8.7591

a. Predictors: (Constant), UV254

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19423.37	1	19423.366	253.164	.000 <sup>a</sup>
	Residual	1764.620	23	76.723		
	Total	21187.99	24			

a. Predictors: (Constant), UV254

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	88.475	5.570		15.885	.000
	UV254	9.023	.567	.957	15.911	.000

a. Dependent Variable: THMFP

**Table B-22** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the coagulated water from the observed well no. 2

### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.943*
	Sig. (2-tailed)	.	.000
	N	25	25
TOC	Pearson Correlation	.943*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.943 <sup>a</sup>	.889	.884	10.1304

a. Predictors: (Constant), TOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18827.62	1	18827.615	183.461	.000 <sup>a</sup>
	Residual	2360.371	23	102.625		
	Total	21187.99	24			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	70.906	7.777		9.118	.000
	TOC	8.472	.625	.943	13.545	.000

a. Dependent Variable: THMFP

**Table B-23** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the coagulated water from the observed well no. 2

### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.986**
	Sig. (2-tailed)	.	.000
	N	25	25
DOC	Pearson Correlation	.986**	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.986 <sup>a</sup>	.973	.972	5.0044

a. Predictors: (Constant), DOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20611.98	1	20611.976	823.033	.000 <sup>a</sup>
	Residual	576.010	23	25.044		
	Total	21187.99	24			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	64.046	3.914		16.363	.000
	DOC	10.155	.354	.986	28.689	.000

a. Dependent Variable: THMFP

**Table B-24** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the coagulated water from the observed well no. 2

#### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	.362
	Sig. (2-tailed)	.	.075
	N	25	25
SUVA	Pearson Correlation	.362	1.000
	Sig. (2-tailed)	.075	.
	N	25	25

#### Regression

##### Variables Entered/Removed<sup>d</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

##### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.362 <sup>a</sup>	.131	.093	28.2932

a. Predictors: (Constant), SUVA

##### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2776.375	1	2776.375	3.468	.075 <sup>a</sup>
	Residual	18411.61	23	800.505		
	Total	21187.99	24			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

##### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	67.017	56.975		1.176	.252
	SUVA	1.221	.655	.362	1.862	.075

a. Dependent Variable: THMFP

**Table B-25** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the coagulated water from the observed well no. 2

### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.887*
	Sig. (2-tailed)	.	.000
	N	25	25
D_CL	Pearson Correlation	.887*	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.887 <sup>a</sup>	.787	.778	14.0006

a. Predictors: (Constant), D\_CL

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16679.57	1	16679.574	85.092	.000 <sup>a</sup>
	Residual	4508.412	23	196.018		
	Total	21187.99	24			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-19.067	20.966		-.909	.373
	D_CL	3.249	.352	.887	9.225	.000

a. Dependent Variable: THMFP

**Table B-26** Correlation and regression between THMFP (dependent variable) and UV-254 (independent variable) of the coagulated water from the observed well no. 3

### Correlations

		THMFP	UV254
THMFP	Pearson Correlation	1.000	.842*
	Sig. (2-tailed)	.	.000
	N	28	28
UV254	Pearson Correlation	.842*	1.000
	Sig. (2-tailed)	.000	.
	N	28	28

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	UV254 <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.842 <sup>a</sup>	.709	.698	7.7276

a. Predictors: (Constant), UV254

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3784.993	1	3784.993	63.384	.000 <sup>a</sup>
	Residual	1552.602	26	59.715		
	Total	5337.594	27			

a. Predictors: (Constant), UV254

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	68.217	13.747		4.962	.000
	UV254	381.802	47.957	.842	7.961	.000

a. Dependent Variable: THMFP

**Table B-27** Correlation and regression between THMFP (dependent variable) and TOC (independent variable) of the coagulated water from the observed well no. 3

### Correlations

		THMFP	TOC
THMFP	Pearson Correlation	1.000	.412*
	Sig. (2-tailed)	.	.029
	N	28	28
TOC	Pearson Correlation	.412*	1.000
	Sig. (2-tailed)	.029	.
	N	28	28

\*. Correlation is significant at the 0.05 level (2-tailed).

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	TOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.412 <sup>a</sup>	.170	.138	13.0532

a. Predictors: (Constant), TOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	907.577	1	907.577	5.327	.029 <sup>a</sup>
	Residual	4430.017	26	170.385		
	Total	5337.594	27			

a. Predictors: (Constant), TOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	120.863	24.467		4.940	.000
	TOC	14.595	6.324	.412	2.308	.029

a. Dependent Variable: THMFP



**Table B-28** Correlation and regression between THMFP (dependent variable) and DOC (independent variable) of the coagulated water from the observed well no. 3

### Correlations

		THMFP	DOC
THMFP	Pearson Correlation	1.000	.769*
	Sig. (2-tailed)	.	.000
	N	28	28
DOC	Pearson Correlation	.769*	1.000
	Sig. (2-tailed)	.000	.
	N	28	28

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	DOC <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.769 <sup>a</sup>	.591	.575	9.1669

a. Predictors: (Constant), DOC

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3152.770	1	3152.770	37.519	.000 <sup>a</sup>
	Residual	2184.824	26	84.032		
	Total	5337.594	27			

a. Predictors: (Constant), DOC

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	59.789	19.221		3.111	.004
	DOC	34.773	5.677	.769	6.125	.000

a. Dependent Variable: THMFP

**Table B-29** Correlation and regression between THMFP (dependent variable) and SUVA (independent variable) of the coagulated water from the observed well no. 3

### Correlations

		THMFP	SUVA
THMFP	Pearson Correlation	1.000	.577*
	Sig. (2-tailed)	.	.001
	N	28	28
SUVA	Pearson Correlation	.577*	1.000
	Sig. (2-tailed)	.001	.
	N	28	28

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	SUVA <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.577 <sup>a</sup>	.333	.307	11.7049

a. Predictors: (Constant), SUVA

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1775.464	1	1775.464	12.959	.001 <sup>a</sup>
	Residual	3562.130	26	137.005		
	Total	5337.594	27			

a. Predictors: (Constant), SUVA

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-70.384	68.768		-1.023	.316
	SUVA	29.299	8.139	.577	3.600	.001

a. Dependent Variable: THMFP

**Table B-30** Correlation and regression between THMFP (dependent variable) and chlorine demand (independent variable) of the coagulated water from the observed well no. 3

### Correlations

		THMFP	D_CL
THMFP	Pearson Correlation	1.000	.779*
	Sig. (2-tailed)	.	.000
	N	28	28
D_CL	Pearson Correlation	.779*	1.000
	Sig. (2-tailed)	.000	.
	N	28	28

\*\* . Correlation is significant at the 0.01 level

### Regression

#### Variables Entered/Removed<sup>b</sup>

Model	Variables Entered	Variables Removed	Method
1	D_CL <sup>a</sup>	.	Enter

a. All requested variables entered.

b. Dependent Variable: THMFP

#### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.779 <sup>a</sup>	.608	.592	8.9762

a. Predictors: (Constant), D\_CL

#### ANOVA<sup>b</sup>

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3242.731	1	3242.731	40.247	.000 <sup>a</sup>
	Residual	2094.863	26	80.572		
	Total	5337.594	27			

a. Predictors: (Constant), D\_CL

b. Dependent Variable: THMFP

#### Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	39.695	21.716		1.828	.079
	D_CL	5.076	.800	.779	6.344	.000

a. Dependent Variable: THMFP

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