



CHAPTER IV

FRACTIONATION AND HALOACETIC ACIDS FORMATION POTENTIAL

4.1 Theoretical backgrounds

4.1.1 Fractionation

DOC is typically used as a parameter to measure organic content in water. It remains a priority for water treatment because DOC holds the key to understanding, predicting, and controlling DOC reactivities under water treatment conditions. Nonetheless, DOC does not indicate the character of the organic matter in water. It includes literally thousands of organics in different chemical forms, hence, the evaluation of the organic properties based on a comprehensive compilation of an individual compound is not realistic. Many researchers, therefore, have attempted to categorize DOC into several groups of compounds with similar physical/chemical properties (. One common technique for this categorization is fractionation technique.

Fractionation into more homogeneous components has been the most common approach to facilitate the interpretation of results from DOC characterization and reactivity studies. A complete fractionation of DOC in the water sample is an admirable, but usually unattainable goal. Both positive and negative errors are common, for example, some molecules might be collected that do not fall in the target fraction, and some that should fall into the target group but are not detected. In addition, some losses of DOC often occur during the fractionation process. This is perhaps due to the following reasons: (i) the interference of salt on the resin adsorption capacity, (ii) inadvertent errors from the fractionation procedure, e.g. sticking to the walls of freeze-drying vessels, volatilization during vacuum evaporation steps, some form precipitates in the concentration procedures (Croue *et al.*, 2000)

Even if many analytical techniques have been applied to fractionate DOC samples, no technique currently available is capable of efficiently isolating low molecular weight and low aromaticity organic compounds (Croue *et al.*, 2000). In fact, no universal fractionation procedure exists for all applications, most have to be modified to suit the variety of research objectives and sample matrices (Aiken and Leenheer, 1993, and Leenheer *et al.*, 2000). A number of isolation techniques were currently available, including evaporation, reverse osmosis (RO) and nanofiltration (NF), iron-oxide-coated sand (IOCS), and resin adsorption. Each technique has both advantages and disadvantages as summarized in Table 4-1.

Among the various methods, resin adsorption was reported as the most effective in separating organic from inorganic matters. Basically, there was no limitation on the separation capacity, as this depended on the quantity of adsorption resins. However, high capacity separation could require a considerably long separation time. Also the quantity of the product water was quite close to the original quantity which suggested a minimal loss during the fractionation (Croue *et al.*, 2000). Therefore only the resin adsorption technique is discussed from this point onwards.

4.1.2 Type of adsorption resins

Resin adsorption employs various synthetic resins in fractionating DOC based on the chemical properties of the organic fractions. Adsorption procedures have been proposed for the fractionation of DOC involving the use of a number of adsorbents, for instance,

1. DAX-type resin (SUPELCO)

DAX is a non-ionic resin with a relatively high adsorption affinities for DOC with high elution efficiencies and very low affinities for inorganic salts. The resin adsorbs DOC through a combination of non-polar and polar interactions. There are several types of DAX resins, i.e. DAX-2, DAX-4, DAX-7, and DAX-8. In recent years, two types of DAX resin, i.e. DAX-4 and DAX-8, have been widely adopted. Both are styrene-divinylbenzene copolymers which are non-polar and generally in the

form of white beads (Daignault *et al.*, 1988). The properties of these two DAX resins are given below.

- DAX-8 resin:
 - Adsorb all hydrophobic organic fraction at acidic condition
 - Adsorb only hydrophobic neutral organic fraction at neutral pH condition.
 - Adsorb hydrophobic base (and possibly neutral) organic fraction at high pH.
- DAX-4 resin:
 - Adsorb organic fraction that could not be classified as either hydrophobic or hydrophilic (often referred to as transphilic organic fraction) at acidic condition.

2. AG-MP-50 (BIO-RAD)

AG-MP-50 is a strong acid cationic exchange resin commonly used in concentrating cationic solutes and for analytical determinations of various mixed cationic solutions (BIO-RAD). The cationic exchange resin is thermally stable and resistant to solvents, reducing agents, and oxidizing agents. AG-MP-50 resin does not interact with neutral and acid molecules and, hence, only base characteristic organic fractions are adsorbed onto the resin. Usually the resin is pretreated with strong acid to induce the selectivity property for the base organic fraction.

3. WA-10 (SUPLECO)

WA-10 is a weak anion exchange resin, macroporous, phenol-formaldehyde condensation product (SUPLECO). It was proposed by Marhaba *et al.* (2003) to replace Duolite-7 as this resin could reduce the organic bleeding during the elution.

4.1.3 Literature review

Several criteria have been used to categorize dissolved organic matters, e.g. water soluble property, molecular weight, pH. Each categorization method often encountered problems in separating the different organic species. For instance, the

separation of humic from non-humic fractions could not be achieved with great accuracy as molecules from the two groups could form complexes or otherwise associated with one another in the solution (Lytle and Perdue, 1981 and Leenheer, 1989). Nonetheless, there are conventional operational approaches which have been commonly applied and these are detailed below.

In 1979, Leenheer and Huffman proposed the use of DAX and other resins in a fractionation procedure to characterize DOC based on its hydrophobic-hydrophilic and acid-base properties. Each fraction was often further fractionated into acidic, basic, and neutral fractions by selective elution and subsequent sorption and elution procedures. This approach was subsequently expanded and developed further by many researchers. The modified approaches by Leenheer (1981) and Thurman and Malcolm (1981) were thus far among the most widely adopted fractionation method for DOC. This procedure was lately modified by Marhaba and Pu (2000) and Marhaba *et al.* (2003) to minimize the organic loss during the extraction by changing the type of resin. Principally, the resin fractionation method was capable of separating the dissolved organic carbon into six fractions (Leenheer and Huffman, 1979, Leenheer, 1981, Burner *et al.*, 1987, Marhaba and Pipada, 2000, Croue *et al.*, 2000, Howe *et al.*, 2002, Butterfield *et al.*, 2002, and Marhaba *et al.*, 2002) i.e.

1. Hydrophobic acids (HPOA) – aliphatic carboxylic acids of five to nine carbons, one and two-ring aromatic carboxylic acids, aromatic acids, one and two-ring phenols, and tannins.

2. Hydrophobic bases (HPOB) – proteins, one and two-ring aromatic amines except pyridine, and high molecular weight alkyl.

3. Hydrophobic neutrals (HPON) – hydrocarbon; aliphatic alcohols, alkyl alcohols, ethers, ketones, and aldehydes, more than five carbons; aliphatic carboxylic acids and aliphatic amines, more than nine carbons; aromatic carboxylic acids and aromatic amines of three rings and greater.

4. Hydrophilic acids (HPIA) – aliphatic acids of less than five carbons, hydroxyl acids, sugars, low molecular weight alkyl monocarboxylic and dicarboxylic acids.

5. Hydrophilic bases (HPIB) – aliphatic amines less than nine carbons, amino acids, pyridines, purines, pyrimidines, low molecular weight alkyl amines.

6. Hydrophilic neutrals (HPIN) – aliphatic amides, alcohols, aldehydes, esters, and ketones less than five carbons, polysaccharides.

The application of this fractionation method was subject to several interferences, i.e. (i) specific conductance in water sample not exceeding 2,000 $\mu\text{mhos/cm}$ as above this level, the concentration of inorganic ionic salts would exceed the capacity of ion exchange resins, (ii) the precipitation from organic which could have taken place at pH 2 in the fractionation procedure, and (iii) colloid clay that could foul the resin adsorbents.

Note that the definitions of the DOC fractions are based on an operational definition of the physical/chemical isolation procedure. In addition, although the sample fractionation provided the opportunities to study the mechanism by which DOC interacted with chlorine, it is important to note that the collective behavior of the individual fractions may not be the same as the behavior of the intact water sample in an actual water treatment plant.

4.2 Objectives of this chapter

The objectives of this chapter were:

1. To determine organic matter concentrations and the contents of such organic compounds in the source water
2. To determine HAAs formation potentials (HAAFP) of the source water and of each organic fraction in the source water

4.3 Experimental procedure

Water samples used in this study were collected from the common intake of Bangkhen water treatment plant (Bangkhen WTP). Water quality characteristics of the raw water were measured. Six liters of each sample were then

fractionated to observe the variation of organic matters. The formation potential of HAAs was then determined for each organic fraction. The details of water sampling, fractionation procedure, and the formation of HAAs were performed in chapter 3 (see Sections 3.2 – 3.7).

4.4 Results and discussion

The results from the investigation were obtained from six rounds of sampling. The first round was performed in early summer session (Mar 23, 2003), the second and third rounds were during late summer (May 13 and 30, same year), while the last three rounds were during the middle of rainy season (Jun, 15 and 27, and Aug 5, 2003).

4.4.1 Characterization of DOCs in water source

DOC was used as an indicator for the organic content in the water samples. Table 4-2 illustrates that the DOC for all the samples were in the range between 2.78 to 4.73 mg/L. This level of DOC was similar to those reported for many other water treatment facilities around the world. For instance, DOC concentration at Canal Road WTP, Raritan-Millstone WTP, New Jersey was found to be around 4 mg/L, 4.69 mg/L in Seine River, France, and also approximately the same level for Suwannee River, Georgia and Passaic Valley WTP. Certain places might exhibit high level of DOC such as 7.5 mg/L in South Platte River, Colorado, and the evidence suggested that it is more likely to see a lower DOC level in rivers, e.g. 2.55 mg/L in Colorado River, 2.52 mg/L in Colorado Sacramento Delta, California, 2.60 mg/L in South Platte River, and 2.81 mg/L in Colorado, Lake Bret, France. Table 4-3 summarizes DOC reported in various water sources.

4.4.2 Characterization of isolated fractions

Table 4-4 summarizes the analytical fractionation results based on DOC tests. It is generally accepted that loss or transformation of certain organics during the purification is unavoidable. However, the result as summarized in Table 4-4 indicates a percent surplus which means that the quantity of the six fractions exceeded

the total amount of initial DOC. This is most likely due to the organics released from the resin during the elution. Our preliminary results demonstrated that organic bleeds in acid and base eluants of the clean resin columns could be as high as 0.3 mg/L and this resulted in a weight surplus in the resulting organic fractions.

According to the data summarized in Table 4-4, the average distribution proportions in rainy season (during June and August) of the hydrophobic and hydrophilic organics were 42 and 58%, respectively. This finding was different from the general knowledge which stated that hydrophobic substance would constitute a larger fraction than the hydrophilic in natural water. It is worth mentioned that the hydrophilic substances were reported to indicate a contamination of the water source. Bangkhen WTP is located downstream of Chao Phraya river and, hence, the water taken from the river would, unsurprisingly, be contaminated by various types of pollutants generated both by residential and industrial activities upstream. This potentially led to the accumulation of the hydrophilic substances as detected from the fractionation procedure employed in this work. Due to some inadvertently experimental technique, our initial results were not complete and the hydrophobic neutral organic fraction could not be separated. Hence, the distributive proportions of organic substances in summer (during March and May) could not be concluded.

It was important to observe that the percent DOC fraction distribution for each sample did not appear to be dramatically different from each other. The sequence of six fractions could be summarized in order from large to small as: hydrophilic neutral > hydrophobic acid > hydrophilic acid > hydrophobic neutral > hydrophilic base, hydrophobic base. This is illustrated in Figure 4-1.

Hydrophobic acid and hydrophilic neutral were the two most abundant fractions based on organic carbon content. The extent of each fraction in the water source was often found to be different from place to place. For instance, at Passaic Valley WTP, Canal Road WTP, and Raritan-Millstone WTP in New Jersey, the hydrophilic acid fraction appeared to be a dominated fraction with 53, 46, and 42 percent mass fraction in each water source, respectively, whereas hydrophobic and

hydrophilic bases were found to be the smallest. This trend was similar to those found in Seine River, France and Sacramento Delta, California (only about 1.7 and 1.0% of hydrophilic base, respectively). The hydrophobic neutral fraction accounted for 5% of DOC in Grenet river, France and this was in a similar level with that in Bangkok WTP found in this work.

4.4.3 Characterization of UV and SUVA in water source

UV spectroscopy can be used on unaltered samples and therefore require much less time and effort per analysis than other techniques. Only carbon compounds in aromatic structure have been shown to unambiguously exhibit UV absorbance spectrum and this might facilitate in indicating the level of many aromatic species, e.g. humic acids, in water sources. The ratio of UV to DOC, referred to as specific ultraviolet absorbance or SUVA, is calculated as the absorbance per meter at 254 nm per mg organic carbon per liter (L/mg-m). Normally, SUVA of less than 3 L/mg-m represents a large amount of nonhumic substances, whereas SUVA in the range of 4-5 L/mg-m represents mainly humic substances (USEPA, 1994). SUVA has also been reported to suggest the possibility of DOCs to form hazardous disinfection by-products. In addition, as the humic matter can be easily coagulated and high SUVA (or high humic fraction) indicates that large fraction of organics could be easily coagulated. The USEPA, in Disinfectant and Disinfection Byproduct (D/DBP) Rule, included a SUVA of 2 L/mg-m as a criterion for the requirement of enhanced coagulation (USEPA, 1994).

SUVA for each fraction of the water samples in this work is summarized in Table 4-5. In this study, SUVA values generally varied from 1.502 to 2.774 L/mg-m and these levels were relatively low in comparison with other studies. For example, Table 4-6 shows that the SUVA in San Joaquin River, Twitchell Is. Drainage, Middle River, and Old river, were found to be 3.20, 4.91, 2.82, and 4.25 L/mg-m, respectively (Vrijenhoek *et al.*, 2000). This means that the water from Bangkok WTP might not be coagulated as easily as other water sources. It is difficult to conclude here, however, that the chances of the formation of disinfection by-

products from this water source is low as there might exist other organic fractions that were not detected by SUVA.

4.4.4 HAA formation potential (HAAFP)

As demonstrate in Table 4-7, the HAAFP in the raw water was found to be approx. 290 µg/L. This was in the same range as the summation of HAAFP from the individual six fractions (at approx. 300 µg/L). In this section, HAAFP for each of the six fractions would be evaluated to determine the most reactive organic fraction to the formation of HAAs. In addition, five specific species of HAAs, i.e. mono-, di-, trichloroacetic acids, mono-, and dibromoacetic acids, would be identified as discussed below.

Two definitions of HAAFP will be introduced and used in the evaluation hereafter. These are (i) total HAAFP and (ii) specific HAAFP. The total HAAFP is defined as the HAAFP per unit mass of all organic matters in the water sample (DOC) whereas the specific HAAFP is the HAAFP per unit mass of each organic fraction. The objective of defining the specific HAAFP was to facilitate the evaluation of the potential of each organic fraction in the formation of HAAs.

Figure 4-2 illustrates that the hydrophobic and hydrophilic base fractions contributed only slightly to the formation of HAAs and the total HAAFP for these two fractions were small compared with those of acid and neutral fractions. As the hydrophobic base and hydrophilic base fractions only accounted for no more than 10% of the total DOC of the water source, the quantity of HAAs derived from these two species was rather small. Most HAAs were then converted from the reaction between the more abundant species such as acid and neutral organic fractions. However, the results in Figure 4-2 also revealed that specific HAAFPs for these two base fractions were quite high. This indicated that these base fractions were the two most reactive precursors for the formation of HAAs. Results in Figure 4-2 suggested that HAAs precursors could be ordered from the most active to the least as: hydrophobic base > hydrophilic base > hydrophilic neutral > hydrophobic neutral > hydrophobic acid > hydrophilic acid.

It should be reminded that the distribution of each organic fraction in the various watercourses may vary significantly depending upon the parent organic materials and the biogeochemical processes involved in the carbon cycle within the specific watershed. Hence, the mechanism that generates HAAs in the various watercourses might be location specific and should be investigated in a case by case basis. The following investigation focused on the capability of each organic fraction in the formation of HAAs for the water samples from Bangkok WTP.

4.4.4.1 HAAFP of hydrophobic neutral fraction (HPON)

The fact that HPON was the least reactive is curious in view of the fact that it was the most aromatic of the isolates and aromatic structures are putative precursors for HAAs compound. The reason behind this was reported by Krasner and Amy (1995) that HPON contained considerable quantity of ash with small carbon content. This characteristic resulted in a low total HAAFP as obvious from the results for both total and specific HAAFP (3.52 $\mu\text{g/L}$ DOC and 61.48 $\mu\text{g/L}$ HPON, respectively). Moreover, Marhaba and Van (1999) stated that HPON fraction was effectively reduced through the water treatment process when compared with other hydrophobic fractions. Therefore the formation of DBP due to this organic fraction might not be as significant as the extent delivered by other organic fractions.

4.4.4.2 HAAFP of hydrophobic base fraction (HPOB)

HPOB, widely referred to in the literature as humic substances, was present in the smallest quantity (in terms of DOC) among all of the hydrophobic fractions. This resulted in a low total HAA FP (at 5.72 $\mu\text{g/L}$ DOC). HPOB consisted of one and two-ring aromatic amines, amino acids, proteic materials, sugar, and polysaccharides, all of which, except for polysaccharides, were prone to react with chlorine to produce HAAs. This could be the reason for its high specific HAAFP (208 $\mu\text{g/L}$ HPOB). This was in good agreement with the finding of Liang and Singer (2003) who reported that hydrophobic carbon rich in aromatic content and conjugated double bonds was the major HAA precursor in natural waters.

4.4.4.3 HAAFP of hydrophobic acid fraction (HPOA)

HPOA was found to be the second most abundant fraction in this source water. The distinctive yellow-brown color of HPOA fraction was clearly visible. This fraction was also the second most important species responsible for the formation of HAAs (15.21 $\mu\text{g/L}$ DOC). This was largely due to the abundance of HPOA fraction mass in the original sample. Fortunately, this fraction was reported to be the most easily removed among the six fractions by alum coagulation (Croue *et al.*, 2000). The specific HAAFP for this fraction was found to be relatively low (44.31 $\mu\text{g/L}$ HPOA). This indicated that the ability of this fraction in forming HAAs was the lowest among the hydrophobic organic fractions.

4.4.4.4 HAAFP of hydrophilic base fraction (HPIB)

HPIB had similar characteristics as the HPOB in the formation of HAAs. Specifically, HPIB was the lowest hydrophilic constituent in terms of DOC which led to its low total HAAFP of 4.72 $\mu\text{g/L}$ DOC. However, the specific HAAFP of HPIB was extraordinary high, and with its HAAFP of 139.31 $\mu\text{g/L}$ HPIB, it was the most active hydrophilic species in the chlorination reaction.

4.4.4.5 HAAFP of hydrophilic acid fraction (HPIA)

HPIA exhibited comparatively low total and specific HAAFP at 6.78 $\mu\text{g/L}$ DOC and 38.11 $\mu\text{g/L}$ HPIA, respectively. This meant that HPIA was not an active precursor for HAAs. This finding was in contrast with that of Marhaba and Van (1999) who revealed that HPIA was not only the most reactivity fraction when exposed to chlorine, but also the most problematic precursor in the formation of HAAs. This was perhaps due to the different in the nature of the organic fraction in different water sources.

4.4.4.6 HAAFP of hydrophilic neutral fraction (HPIN)

HPIN was found to be the most dominant fraction in this source water (about 40-50% by weight). Correspondingly, this fraction was found to be the main precursor for HAAs as indicated by its high total HAAFP of 28.50 $\mu\text{g/L}$ DOC.

However, this fraction was by far not the most active in the formation of HAAs. With the specific HAAFP of 63.45 $\mu\text{g/L}$ HPIN, this fraction was only the third active species. It was reported that this fraction might have contained a large amount of polysaccharides which were not reactive with chlorine, and this might be the reason for the low specified reactivity (Bruchet *et al.*, 1987).

Although HPIN was not the most active species in the formation of HAAs, it accounted for as much as 45% of all HAAFP formed in this water sample. This fraction alone should therefore be given special attention in the treatment strategy to ensure that an effective control and removal technique for such constituent be developed.

4.5 Concluding remarks

This work also revealed that there was a possibility of the existence of carcinogenic substances, HAAs, in the potable water. The mechanism of the formation of HAAs was investigated and it was shown that the most reactive organic components for the formation of HAAs were the base fractions. For the sample collected at the time of this work, however, these fractions were only presented in small quantity and contributed only slightly to the quantity of HAAs formed in the sample. The most problematic component was the hydrophilic neutral fraction which was presented in large amount. Despite its relatively inactive nature, a large quantity of HAAs was formed from this fraction due to the abundance of such organic fraction. The results from this work will be beneficial for the future management of the water treatment facility as the design of the treatment method should be focused on the removal of the active precursor to the formation of HAAs.

Table 4-1 Advantages and disadvantages of isolation techniques

Isolation method	Advantages	Disadvantages
Evaporation	Very efficient for concentrating non-volatile DOC.	Time consuming and not isolate the DOC from inorganic matrix.
RO and NF	Convenient ways to concentrate DOC from large volumes of water.	Expensive and high inorganic salts concentration occurred in high inorganic content source water.
IOCS	No need for sample preparation.	Low capacity.
Resin adsorption	Certain fraction of DOC, high purity of DOC concentration (ash <5%), solve desalting problem, and the operations imitate natural water sample condition.	Time consuming and need extensive preparation of media.

Table 4-2 Raw water characteristics

Sampling	DOC (mg/L)	pH	Alkalinity (mg/L-CaCO ₃)	Turbidity (NTU)	DO (mg/L)	UV (cm ⁻¹)
Mar 23, 03	3.67	7.69	90	98.9	4.28	0.065
May 13, 03	3.52	8.21	89	95.7	4.20	0.077
May 30, 03	2.78	8.05	92	92.0	4.16	0.052
Jun 15, 03	4.00	8.00	83	76.7	5.00	0.061
Jun 27, 03	4.73	7.62	88	103.0	5.31	0.071
Aug 5, 03	4.72	8.12	96	105.2	4.62	0.131

Table 4-3 DOC in several water sources

Water source	DOC (mg/l)	Reference
Colorado River, California	2.55	Leenheer <i>et al.</i> , 2001
Colorado Sacramento Delta, California	2.52	Leenheer <i>et al.</i> , 2001
South Platte River, France	2.60	Croue <i>et al.</i> , 2000
Lake Austin, Austin	2.70	Symons <i>et al.</i> , 1994
Colorado, France	2.81	Krasner <i>et al.</i> , 1996
Canal Road WTP, NJ	4.00	Marhaba <i>et al.</i> , 2000
Bangkhen WTP, Thailand	4.00	This work
Suwannee River, Georgia	4.60	Croue <i>et al.</i> , 2000
Passaic Valley WTP, Colorado	4.60	Marhaba <i>et al.</i> , 2000
Seine River, France	4.69	Leenheer <i>et al.</i> , 2001
South Platte River, Colorado	7.50	Marhaba <i>et al.</i> , 2000

Table 4-4 Fractionation results based on DOC (mg/L) in water source

Sampling Date	Raw water	HPON	HPOB	HPOA	HPIB	HPIA	HPIN	Percent surplus
Mar 23, 03	3.67	n.d.	0.11	1.20	0.08	0.42	1.24	n.d.
May 13, 03	3.52	n.d.	0.24	1.32	0.05	0.21	1.16	n.d.
May 30, 03	2.78	n.d.	0.10	0.52	0.12	0.21	1.56	n.d.
Jun 15, 03	4.00	0.48	0.23	1.24	0.22	0.32	1.70	+ 4.9
Jun 27, 03	4.73	0.52	0.04	1.50	0.20	0.84	1.41	+ 0.1
Aug 5, 03	4.72	0.27	0.13	1.62	0.16	0.84	2.12	+ 9.0

n.d. = non-detectable

Table 4-5 UV and SUVA of organic fractions in water sample from Bangkhen WTP

Sampling Date	Raw water		HPON	HPOB	HPOA	HPIB	HPIA	HPIN
	UV (cm^{-1})	SUVA (L/mg-m)	(cm^{-1})	(cm^{-1})	(cm^{-1})	(cm^{-1})	(cm^{-1})	(cm^{-1})
Mar 23, 03	0.065	1.770	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
May 13, 03	0.077	2.185	n.d.	0.003	0.024	0.002	0.008	0.026
May 30, 03	0.052	1.868	n.d.	0.001	0.038	0.001	0.004	0.021
Jun 15, 03	0.061	1.525	0.013	0.003	0.036	0.006	0.010	0.024
Jun 27, 03	0.071	1.502	0.024	0.001	0.048	0.003	0.013	0.022
Aug 5, 03	0.131	2.774	0.026	0.008	0.054	0.009	0.015	0.022

n.d. = non-detectable

Table 4-6 SUVA in various water sources

Water source	SUVA (L/mg-m)	Reference
Middle River	2.82	Vrijenhoek <i>et al.</i> , 1998
Peloponnese River, Greece	2.40-4.20	Kampioti and Stephanou, 2002
State Project River, California	3.00	Krasner <i>et al.</i> , 1996
San Joaquin River, California	3.20	Vrijenhoek <i>et al.</i> , 2000
Colorado River, California	3.00-3.60	Krasner and Amy, 1995
Old river	4.25	Vrijenhoek <i>et al.</i> , 2000
Twitchell Is. Drainage	4.91	Vrijenhoek <i>et al.</i> , 2000

Table 4-7 Haloacetic acids formation potential and chlorine demand of each organic fraction

Organic matter	Chlorine demand (mg/L)	Residual chlorine (mg/L)	HAAFP ($\mu\text{g/L}$)
HPON	0.61	4.39	16.6
HPOB	0.22	4.78	27.0
HPOA	1.33	4.67	71.8
HPIB	1.33	4.67	22.3
HPIA	0.40	4.60	32.0
HPIN	3.47	4.53	134.5
Raw water	8.80	4.20	279.5

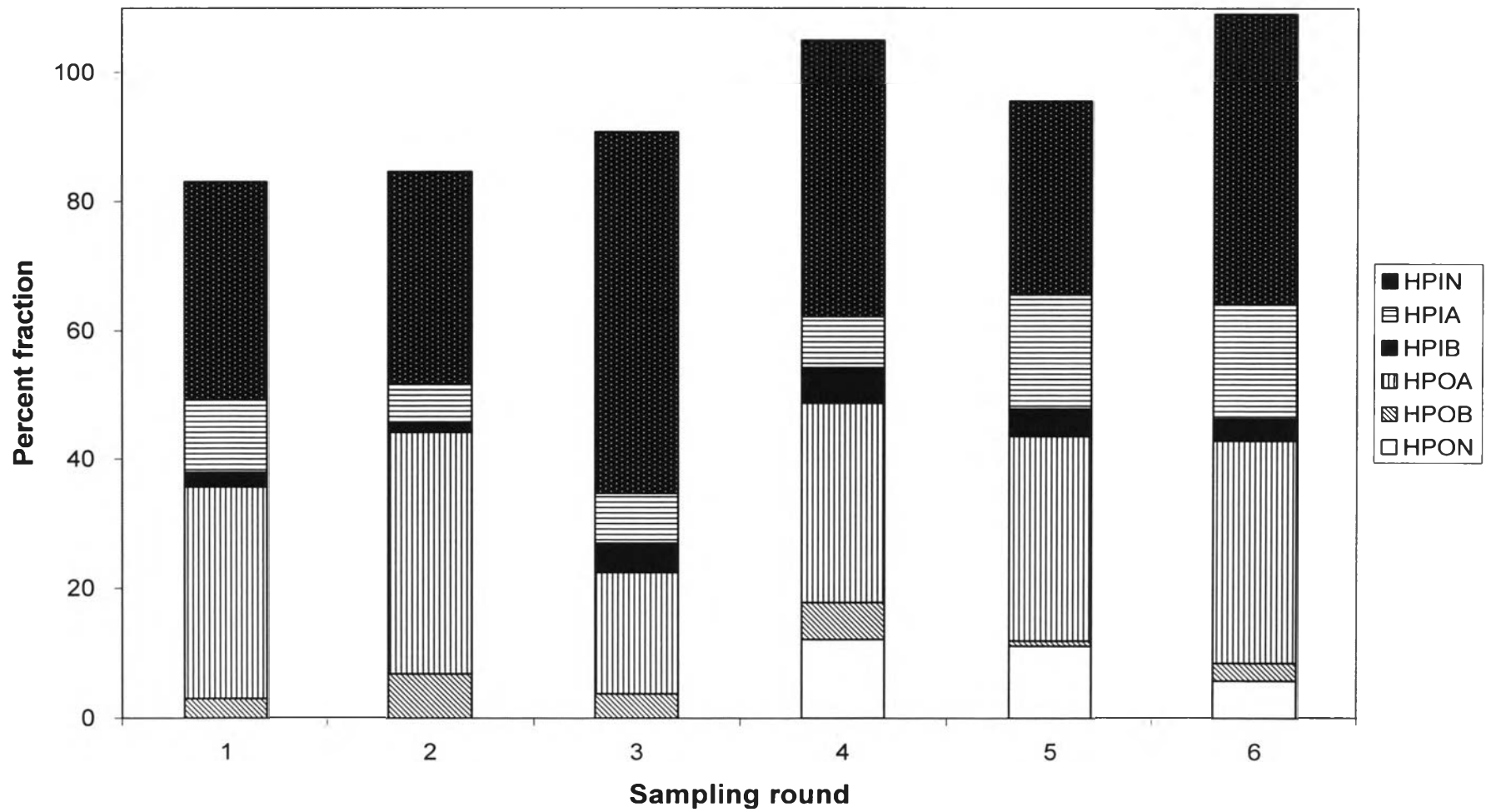


Figure 4-1 Distribution of the six organic fractions in Bangkhen WTP

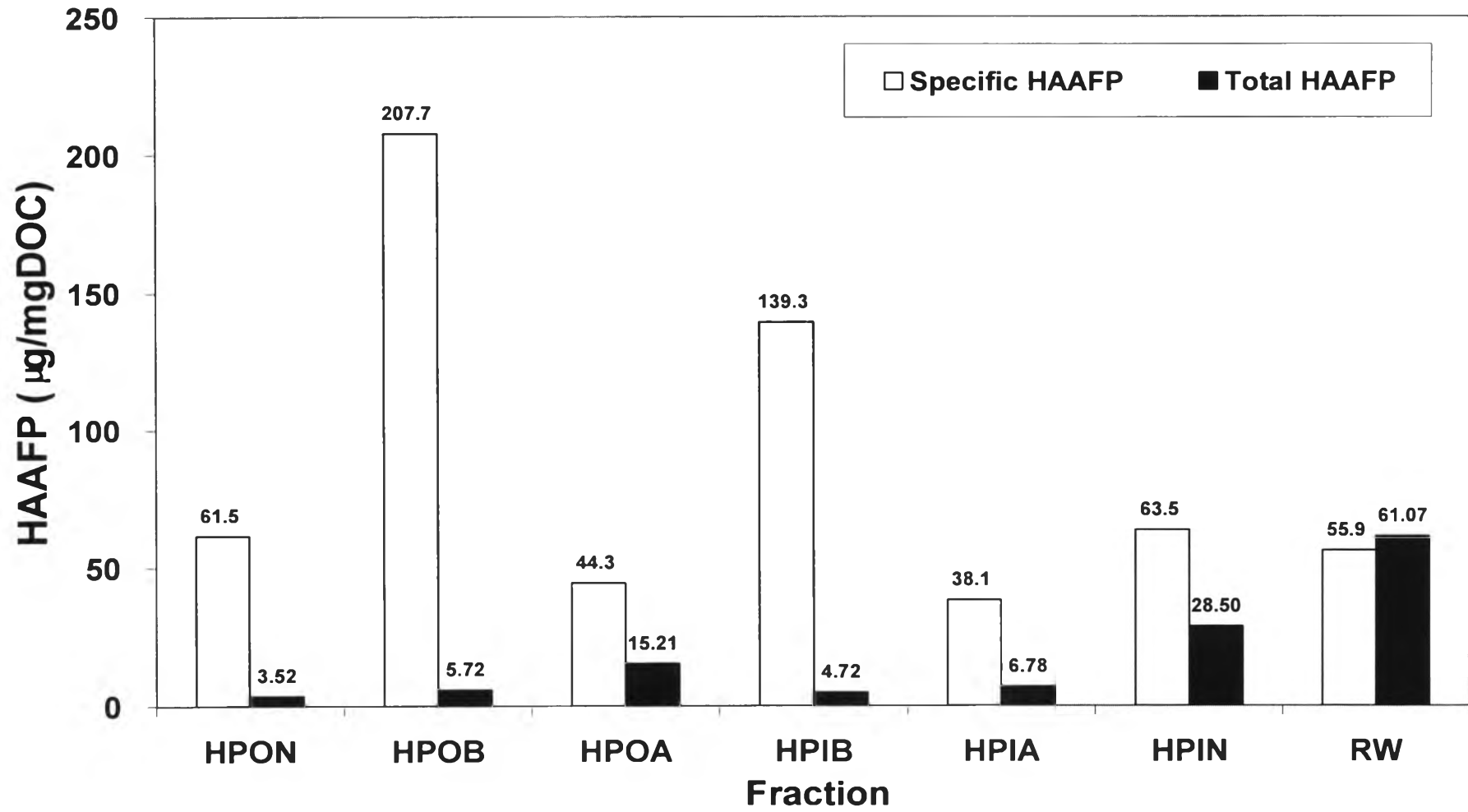


Figure 4-2 HAAFP of single fraction in water source