

## CHAPTER IV

### DOM FRACTIONS AND THEIR THMFP IN INDUSTRIAL ESTATE WASTEWATER TREATED BY STABILIZATION PONDS

#### 4.1 Introduction and Literature Reviews

Dissolved organic matter (DOM) in water sources is of particular concern because DOM can react with chlorine used in the disinfection process to form potentially carcinogenic disinfection by-products (DBPs) such as haloacetic acids (HAAs) and trihalomethanes (THMs). Resin fractionation has been employed by many researchers to fractionate DOM in groundwater (Swietlik *et al.* 2004), reservoir water (Imai *et al.* 2001 and 2002, Goslan *et al.* 2004; and Janhom 2004) and river water (Marhaba and Van 1999, Imai *et al.* 2001; and Kimura *et al.* 2004) in order to provide a better understanding of the characteristics of the DOM in the water. For instance, resin fractionation can separate the DOM into specific organic groups based on their physical and chemical properties. DOM in water samples can be fractionated into two categories using DAX-8 resins: the hydrophobic organic (HPO) fraction and hydrophilic organic (HPI) fraction. By using a series of DAX-8, AG-MP-50, and Duolite A-7, WA-10 or AG-MP-1, the DOM in water can be fractionated into six fractions: hydrophobic neutral (HPON), hydrophobic base (HPOB), hydrophobic acid (HPOA), hydrophilic base (HPIB), hydrophilic acid (HPIA) and hydrophilic neutral (HPIN). By conducting THMFP tests on the DOM fractions, the ability of each DOM fraction's capacity to react with chlorine and form potentially carcinogenic substances such as THMs and HAAs is identified.

Musikavong *et al.* (2005) reported that the levels of DOM surrogate parameters such as dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UV-254) and trihalomethane formation potential (THMFP) in a treated wastewater of the selected industrial estate were moderately high when compared with other surface waters in Thailand (Wattanachira *et al.* 2004, Homklin 2004, Janhom 2004, Panyapinyopol *et al.* 2005; and Phumpaisanchai 2005). As stated previously, treated wastewater will be used as raw water for the water supply plant and chlorine is used daily in the water treatment process for chlorination. Hence, the characteristics of DOM in the treated wastewater and the DOM's ability to react with chlorine to form THMs should be seriously taken into

consideration, as DOM in treated wastewater has a high potential to form potentially carcinogenic substances. In addition, the nature of DOM in treated wastewater also depends upon the characteristics of the influent wastewater and the performance capability of the central wastewater treatment plant for reducing DOM. Therefore, it is also necessary to determine the characteristics of the DOM in the influent wastewater and its treated wastewater after each process of the stabilization pond system. These new pieces of information could be used to facilitate the control and removal of DOM and DBPs. The performance capability of the central wastewater treatment plant for reducing DOM will be presented in Chapter 7.

#### **4.2 Objectives of This Chapter**

The main objectives of this chapter were to investigate the mass distribution of DOM fractions in influent wastewater and effluent water from the aeration, facultative, oxidation, and detention ponds of the central wastewater treatment plant of the Northern-Region Industrial Estate using the resin fractionation technique developed by Leenheer (1981) and Marhaba *et al.* (2003). The THMFP and specific THMFP values of each individual DOM fraction of each water sample were determined. The DOM fractions, THMFP and specific THMFP results could be used to facilitate the control and removal of DOM and DBPs.

#### **4.3 Material and Methods**

Effluent water from the detention pond collected on June 24, 2004 was filtered through a well-washed cellulose acetate membrane (0.45  $\mu\text{m}$  pore size) and measured for DOC, UV-254, SUVA and THMFP. Influent wastewater and effluent water from the aeration, facultative, oxidation, and detention ponds collected on February 18, 2005 were filtered through a pre-combusted (550  $^{\circ}\text{C}$  for 2 h) Whatman GF/F filter (nominal pore size 0.7  $\mu\text{m}$ ) and measured for the mentioned parameters. The resin adsorption procedure (Leenheer, 1981 and Marhaba *et al.*, 2003) was used to fractionate five liters of the filtered effluent water from the detention pond collected on June 24, 2004 and fifteen liters of filtered water from all samples collected on February 18, 2005 into the following six DOM fractions: HPON, HPOB, HPOA, HPIB, HPIA and HPIN. The six DOM fractions of all water samples were then analyzed for their UV-254, SUVA, DOC and

THMFP values. Details of the resin fractionation procedure and analytical methods for analyzing UV-254, DOC and THMFP are presented in Chapter 3.

#### 4.4 Results and Discussion

##### 4.4.1 Characterization of DOM Fractions by Resin Fractionation

In general, the resin fractionation method has only been applied to certain types of water for drinking water supply facilities. In this study, resin fractionation was utilized to fractionate wastewater prior to and after treatment that contained moderately high values of DOM surrogate parameters when compared with water normally used by drinking water supply facilities. Therefore, the effectiveness of the resin fractionation method for characterizing DOM in wastewater and its treated wastewater should be confirmed. The percent differences between the summations of the DOC content of the six DOM fractions and the DOC content of unfractionated water samples (percent differences of DOC) and between the summation of the THMFP of the six DOM fractions and the THMFP of unfractionated water samples (percent differences of THMFP) were determined in order to confirm the effectiveness of the resin fractionation method and are presented in Table 4.1.

Percent differences between the summations of the DOC of the six DOM fractions and DOC of the unfractionated influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds collected in February 2005 were -3.9, +8.8, +7.7, +7.9 and +6.2%, respectively, while that of the effluent water from the detention pond collected in June 2004 was +4.2%. The weight surplus may have come from resin bleeding during the elution process (Leenheer, 1981). Day *et al.* (1991) and Marhaba and Pipada (2000) reported tolerance of percent differences of DOC from the resin fractionation process as much as 10-15 %. Croue *et al.* (1993) also reported a variation of 8-12 % of percent differences of DOC. The loss of weight after the resin fractionation process may be due to the effectiveness of the elution process since some DOM is still absorbed in the resins. In accordance with the low level of percent differences of DOC obtained in this study, it can be deduced that the resin fractionation method could be successfully utilized to fractionate DOM in influent wastewater and its treated wastewater in terms of DOC.

**Table 4.1:** Percent difference of DOC and THMFP in influent wastewater and effluent water from aeration, facultative, oxidation and detention ponds collected in June 2004 and February 2005

Water samples	DOC(mg/L)		% Difference <sup>1</sup>	THMFP (µg/L)		% Difference <sup>1</sup>
	Unfractionated water	Summation of the six DOM fractions <sup>2</sup>		Unfractionated water	Summation of the six DOM fractions <sup>3</sup>	
Influent wastewater <sup>4</sup>	10.3±0.2	9.9	-3.9	1214±3	889	-36.6
Effluent water from aeration ponds <sup>4</sup>	5.6±0.02	6.1	+8.8	530±16	536	+1.1
Effluent water from facultative ponds <sup>4</sup>	6.0±0.5	6.5	+7.7	564±11	582	+3.1
Effluent water from oxidation ponds <sup>4</sup>	5.6±0.1	6.0	+7.9	572±7	592	+3.4
Effluent water from detention ponds <sup>4</sup>	6.1±0.3	6.5	+6.2	588±5	623	+5.6
Effluent water from detention ponds <sup>5</sup>	6.8±0.2	7.1	+4.2	625±4	944	+33.8

Remarks: <sup>1</sup> % different was equal to ((Sum. of six fractions)-Unfractionated water)/(Sum. of six fractions)\*100.

<sup>2</sup>Summation of the DOC of the six DOM fractions was calculated from the summation of the DOC of HPON, HPOB, HPOA, HPIB, HPIA and HPIN.

<sup>3</sup>Summation of THMFP of the six DOM fractions was calculated from the summation of the THMFP of HPON, HPOB, HPOA, HPIB, HPIA and HPIN.

<sup>4</sup>Water samples were collected on February 18, 2005.

<sup>5</sup>Water sample was collected on June 24, 2004.

In addition, the summation of the DOC content of the six DOM fractions could be used to represent the level of DOC of the unfractionated treated wastewater.

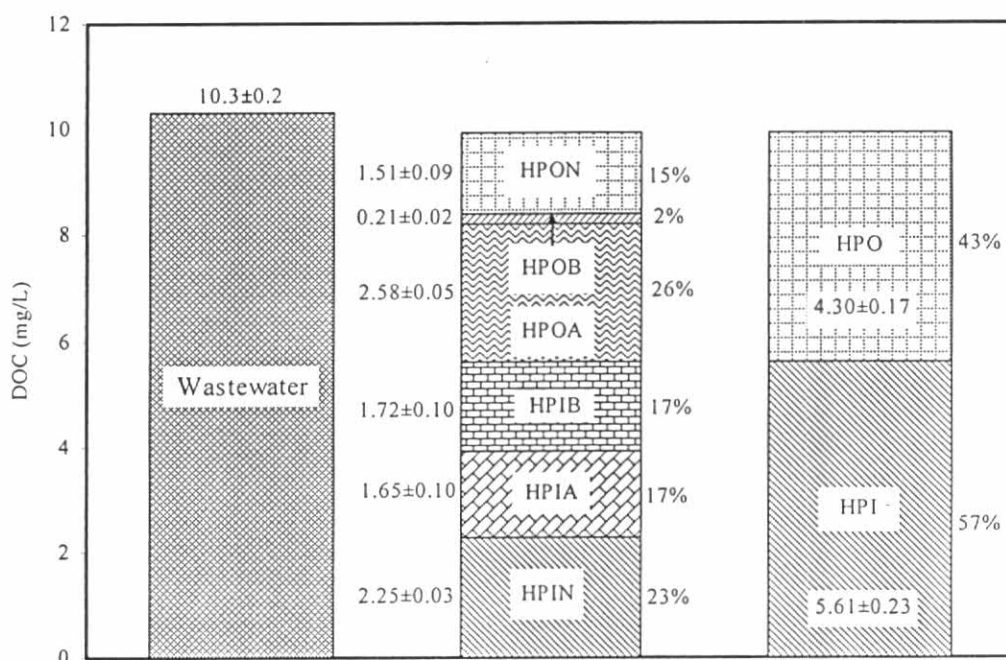
Percent differences between the summations of the THMFP of the six DOM fractions and THMFP of unfractionated influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds collected in February 2005 were -36.6, +1.1, +3.1, +3.4 and +5.6%, respectively, while that of the effluent water from the detention pond collected in June 2004 was +33.8%. In the case of a surplus of THMFP, it is suspected that organic substances sometimes did not completely react with chlorine to form THMs when the six DOM fractions came together in the unfractionated treated wastewater. In comparison, when the six DOM fractions were separated into individual DOM fractions, each DOM fraction was capable of reacting completely with chlorine to form THMs. Another possibility would be a change in the complex compositions of DOM due to the pH adjustment in the resin fractionation method. The pH adjustment process may have created electron-rich sites in organic structures that have a tendency to react with chlorine species, i.e. electrophiles (Rook, 1977; Scully *et al.* 1988 and Harrington *et al.*1996). With regard to the THMFP of the six DOM fractions in the influent wastewater and unfractionated influent wastewater, the summation of the THMFP of the six DOM fractions was very low when compared with the THMFP of unfractionated water. This may have been due to the small loss of DOC during the resin fractionation process that resulted from the ineffectiveness of the elution process. Since some DOM still absorbed in the resins. Moreover, the DOM fractions of influent wastewater may have contained organic compounds that were inactive with chlorine and therefore failed to form THMs. The ability of each DOM fraction to react with chlorine to form THMs will be discussed further in the specific THMFP section.

In addition, the THMFP of the summation of the six DOM fractions collected in June 2004 was clearly higher than of the THMFP summation from the February 2005 sampling. However, the THMFP values of the unfractionated treated wastewater collected in June 2004 and February 2005 were only slightly different (the DOC values of the respective waters were also slightly different). From this difference, it can be stated that the ability of each DOM fraction in the treated wastewater to react with chlorine to

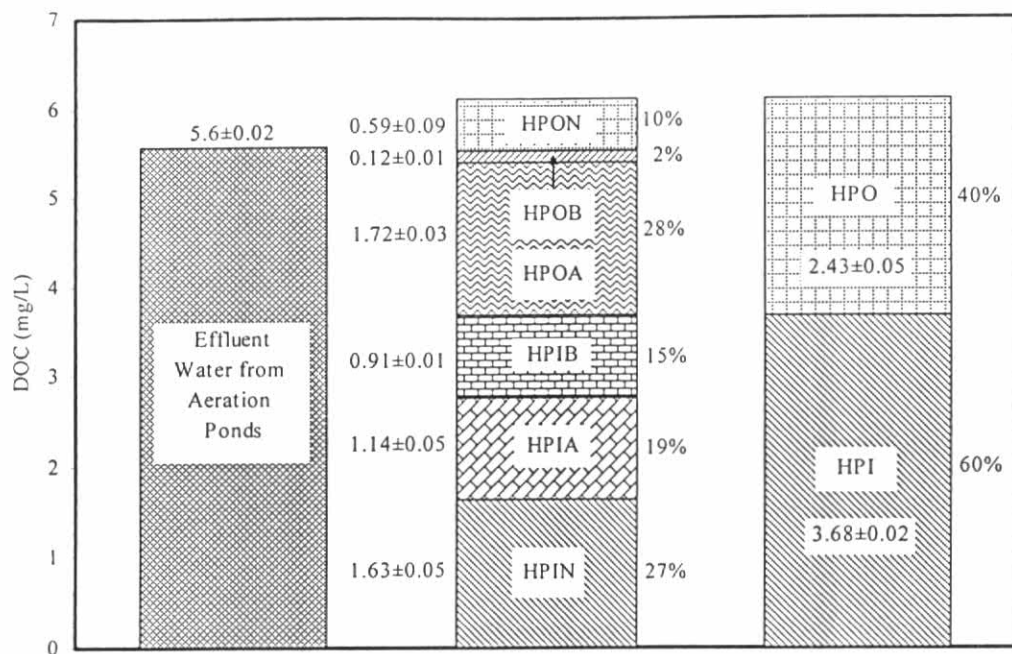
form THMs may differ. This will also be discussed further in the specific THMFP section.

#### 4.4.2 Distribution of DOM Fractions in Terms of DOC

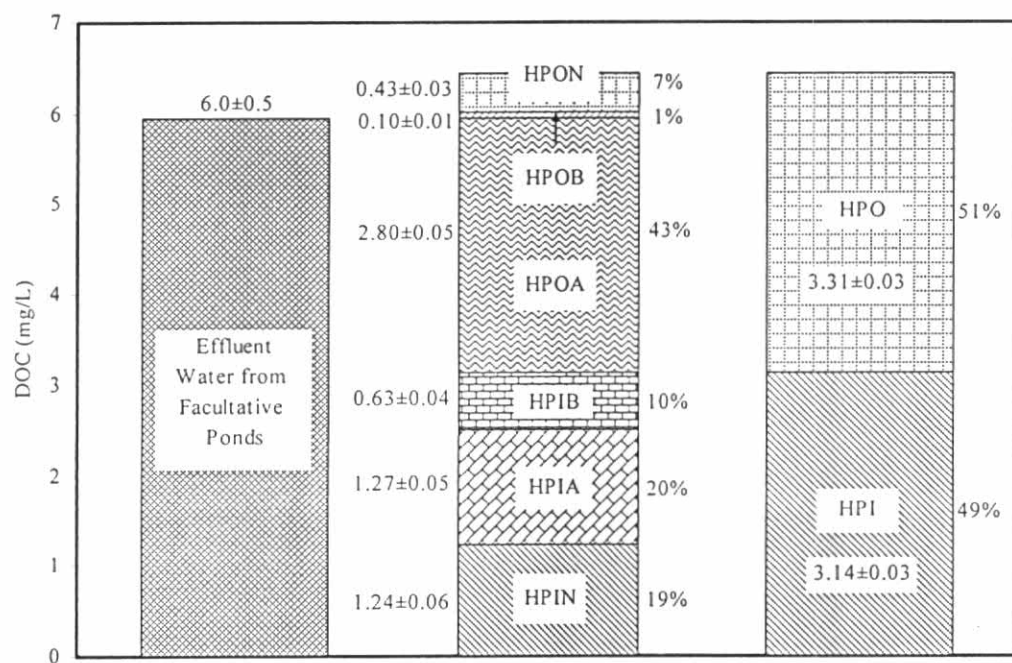
The DOC mass distribution of influent wastewater and effluent water from the aeration, facultative, oxidation ponds collected in February 2005 are depicted in Figures 4.1, 4.2, 4.3 and 4.4, respectively; whereas the DOC mass distribution of the effluent water from the detention pond collected in June 2004 and February 2005 is presented in Figure 4.5. The mass distribution sequences and percent mass distribution of six DOM fractions and of the hydrophobic and hydrophilic DOM fractions of all water samples are tabulated in Table 4.2.



**Figure 4.1:** DOC of influent wastewater, DOC of six organic fractions (with standard deviation ranges) and of HPO and HPI with their percent distribution sampling taken in February 2005



**Figure 4.2:** DOC of effluent water from aeration ponds, DOC of six organic fractions (with standard deviation ranges) and of HPO and HPI with their percent distribution taken in February 2005



**Figure 4.3:** DOC of effluent water from facultative ponds, DOC of six organic fractions (with standard deviation ranges) and of HPO and HPI with their percent distribution taken in February 2005

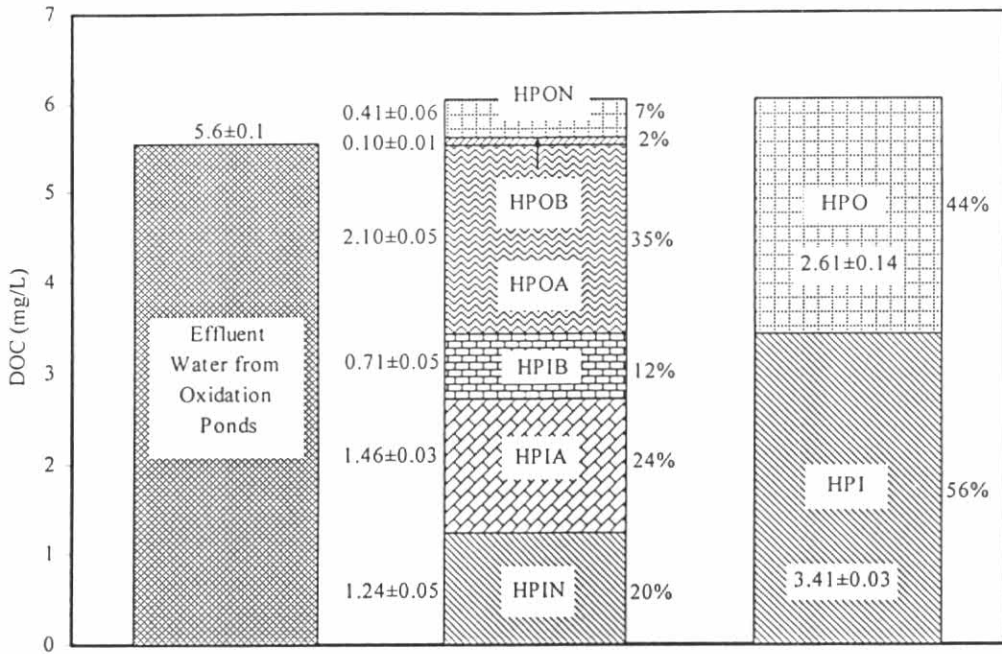


Figure 4.4: DOC of effluent water from oxidation ponds, DOC of six organic fractions (with standard deviation ranges) and of HPO and HPI with their percent distribution taken in February 2005

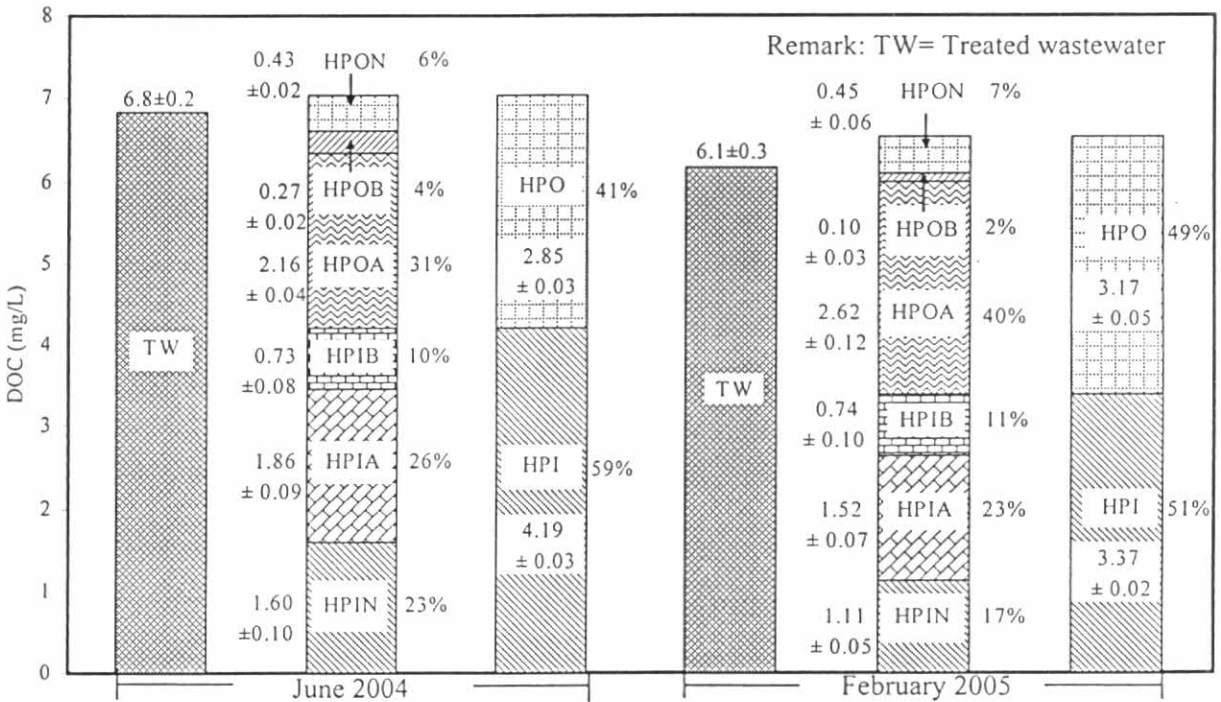


Figure 4.5: DOC of treated wastewater, DOC of six organic fractions (with standard deviation ranges) and of HPO and HPI with their percent distribution taken in June 2004 and February 2005



**Table 4.2:** The mass distribution sequences and percent mass distribution of the six DOM fractions and of the hydrophobic and hydrophilic DOM fractions of influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds

Water samples	Mass distribution sequence from high to low (percent distribution by weight)	
	Six DOM fractions	Hydrophobic (HPO) <sup>3</sup> and hydrophilic (HPI) <sup>4</sup> fractions
Influent wastewater <sup>1</sup>	HPOA (26%) > HPIN (23%) > HPIB (17.3%) > HPIA (16.7%) > HPON (15%) > HPOB (2%)	HPI (57%) > HPO (43%)
Effluent water from aeration ponds <sup>1</sup>	HPOA (28%) > HPIN (27%) > HPIA (19%) > HPIB (15%) > HPON (10%) > HPOB (2%)	HPI (60%) > HPO (40%)
Effluent water from facultative ponds <sup>1</sup>	HPOA (43%) > HPIA (20%) > HPIN (19%) > HPIB (10%) > HPON (7%) > HPOB (1%)	HPO (51%) > HPI (49%)
Effluent water from oxidation ponds <sup>1</sup>	HPOA (35%) > HPIA (24%) > HPIN (20%) > HPIB (12%) > HPON (7%) > HPOB (2%)	HPI (56%) > HPO (44%)
Effluent water from detention pond <sup>1</sup>	HPOA (40%) > HPIA (23%) > HPIN (17%) > HPIB (11%) > HPON (7%) > HPOB (2%)	HPI (51%) > HPO (49%)
Effluent water from detention pond <sup>2</sup>	HPOA (31%) > HPIA (26%) > HPIN (23%) > HPIB (10%) > HPON (6%) > HPOB (4%)	HPI (59%) > HPO (41%)

Remark: <sup>1</sup>Water samples were collected on February 18, 2005.

<sup>2</sup>Water sample was collected on June 24, 2004.

<sup>3</sup>HPO = HPON + HPOB + HPOA

<sup>4</sup>HPI = HPIA + HPIB + HPIN

Based on the obtained results in Figures 4.1, 4.2, 4.3, 4.4, 4.5 and Table 4.2, it was found that HPOA and HPIN were the major DOM fractions in the influent wastewater (the summation of the DOC of HPOA and HPIN was approximately more than 45% by weight of the total DOC). After the influent wastewater was treated by the aeration ponds, HPOA and HPIN were also obtained as the major DOM fractions. The summation of the DOC of HPOA and HPIN was approximately more than 50% by weight of total DOC. Interestingly, after effluent water from the aeration ponds was treated by the facultative ponds, the major DOM fractions became organic acids, HPOA and HPIA (the summation of the DOC of HPOA and HPIA was approximately more than 60% by weight of total DOC). In addition, HPOA and HPIA were also found to be the major DOM fractions in the effluent water from both the oxidation ponds and the detention pond. Summations of the DOC of HPOA and HPIA of the effluent water from both the oxidation ponds and the detention pond were approximately more than 55% by weight of the total DOC concentration. These obtained results demonstrate that the distribution sequence of the six DOM fractions changed after the facultative ponds. This may have been due to the fact that each pond process may easily remove HPIN and have difficulty in removing

HPOA and HPIA. In addition, the biological treatment process may transform HPIN, HPIB, HPON, and HPOB into HPOA and HPIA. The reduction of the six DOM fractions using the stabilization pond processes, therefore, will be discussed in more detail in Chapter 7.

When the DOC mass distribution of the detention pond effluent collected in June 2004 was compared with that of February 2005, it was found that the order of the DOC distribution of the treated wastewater collected in June 2004 and February 2005 were significantly similar and could be express as follows: HPOA > HPIA > HPIN > HPIB > HPON > HPOB. It can be stated that the nature of the DOM fractions in the detention pond effluent (treated wastewater) was considerably stable.

In addition, it must be advantageous to compare the characteristics of the treated wastewater obtained in this study with those of other studies. The DOC, UV-254, SUVA and percent distribution of the DOC values of the treated wastewater obtained in this study and in literature data are presented in Table 4.3. Imai *et al.* (2001, 2002) reported that HPIA and HPOA were the major DOM fractions in the effluent water from activated sludge wastewater treatment plants in Japan. Barber *et al.* (2001) reported that HPOA and HPIA were found to be the dominant DOM fractions in effluent water from an activated sludge wastewater treatment plant to wetlands in the USA. Hence, it can be proposed that organic acids, HPOA and HPIA, are probably the major DOM fractions in biologically treated wastewater. The totals of the DOC concentrations of HPON, HPOB and HPOA could be utilized to represent the DOC of the HPO fraction. The summation of the DOC contents of HPIB, HPIA and HPIN was considerably similar to the DOC of the HPI fraction. As can be seen from Figures 4.1, 4.2, 4.3, 4.4, and 4.5 and Table 4.2, the percentages of HPO and HPI to the total DOC concentration in the influent wastewater and effluent water from the aeration, facultative and oxidation ponds were 43 and 57%, 40 and 61%, 51 and 49%, and 44 and 56%, respectively. In addition, the percentages of HPO and HPI to the total DOC content in the effluent water from the detention pond collected in June 2004 were 41 and 59 %, respectively; where as 49 and 51 % were the percentages observed for the sample collected in February 2005. It could be summarized that there is a possibility that influent wastewater and its treated wastewater contains more HPI than HPO.

**Table 4.3:** DOC, UV-254, SUVA and percent distribution of DOC obtained in treated wastewater in this study and from literature data.

No.	Water Sources	DOC mg/L	UV-254 cm <sup>-1</sup>	SUVA L mg <sup>-1</sup> m <sup>-1</sup>	Percent distribution of DOC							
					Percent		Percent					
					HPO	HPI	HPON	HPOB	HPOA	HPIB	HPIA	HPIN
1	Effluent from a small WWTP, Japan (Imai <i>et al.</i> 2002)	3.5	0.042	1.2	25	75	5	2	18	9	53	13
2	Effluent from a large WWTP, Japan (Imai <i>et al.</i> 2002)	3.7	0.071	1.9	40	60	8	4	28	14	40	6
3	Effluent from a medium-sized WWTP, Japan (Imai <i>et al.</i> 2002)	4.3	0.069	1.6	34	66	9	1	24	12	47	7
4	Effluent from WWTP, Japan (Imai <i>et al.</i> 2001)*	4.9	0.084	1.7	31	69	4	NA	27	14	45	10
5	Treated industrial estate wastewater, Thailand (This study, February 2004)	6.1	0.112	1.8	49	51	7	2	40	11	23	17
6	Treated industrial estate wastewater, Thailand (This study June 2004)	6.8	0.208	3.1	41	59	6	4	31	10	26	23
7	Effluent from WWTP to wetland (P-3), San Jacinto, CA, USA (Barber <i>et al.</i> 2001)**	8.5	0.134	1.6	49	52	12	1	36	17	30	5
8	Effluent from WWTP to wetland (P-1), San Jacinto, CA, USA (Barber <i>et al.</i> 2001)***	8.9	0.129	1.4	54	47	20	1	33	18	27	2
9	Effluent from WWTP to wetland, San Jacinto, CA, USA (Barber <i>et al.</i> 2001)****	8.9	0.140	1.6	50	49	8	1	41	12	36	1
10	Treated secondary effluent, Sigapore (Hu <i>et al.</i> 2003)	9.5	0.170	1.8	60	40	9	6	45	5	2	33
11	Treated secondary effluent, Sigapore (Hu <i>et al.</i> 2003)	11.9	0.180	1.5	48	52	9	4	35	2	9	42
12	Effluent from wetland, Arcata, CA, USA (Barber <i>et al.</i> 2001)	12.4	0.251	2.0	50	50	5	2	43	21	10	20
13	Effluent from Wetland (P-1), San Jacinto, CA, USA (Barber <i>et al.</i> 2001)**	15.5	0.365	2.4	64	35	18	less	46	15	13	7
14	Effluent from Wetland (P-3), San Jacinto, CA, USA (Barber <i>et al.</i> 2001)***	17.0	0.236	1.4	45	55	5	1	39	16	37	2
15	Effluent from WWTP to wetland, Arcata, CA, USA (Barber <i>et al.</i> 2001)****	27.4	0.316	1.2	62	39	17	2	43	10	15	14
16	Effluent from wetland, San Jacinto, CA, USA (Barber <i>et al.</i> 2001)	29.0	0.251	0.9	37	64	1	1	35	19	44	1

Remark; In case of the water sample was fractionated into six fractions, HPO= HPON+HPOB+HPOA and HPI = HPIB+HPIA+HPIN

NA= Not available, WWTP = Wastewater treatment plant

\*HPOB was negligible

\*\*P-1 = 1-phase cells (uniform emergent bulrush marsh) of multipurpose wetlands at Hemet/San Jacinto Reginal Wastewater Reclamation Facility

\*\*\* P-3 = 3-phase cells (marsh-pond-marsh) of multipurpose wetlands at Hemet/San Jacinto Reginal Wastewater Reclamation Facility

\*\*\*\*wetland = demonstration wetland

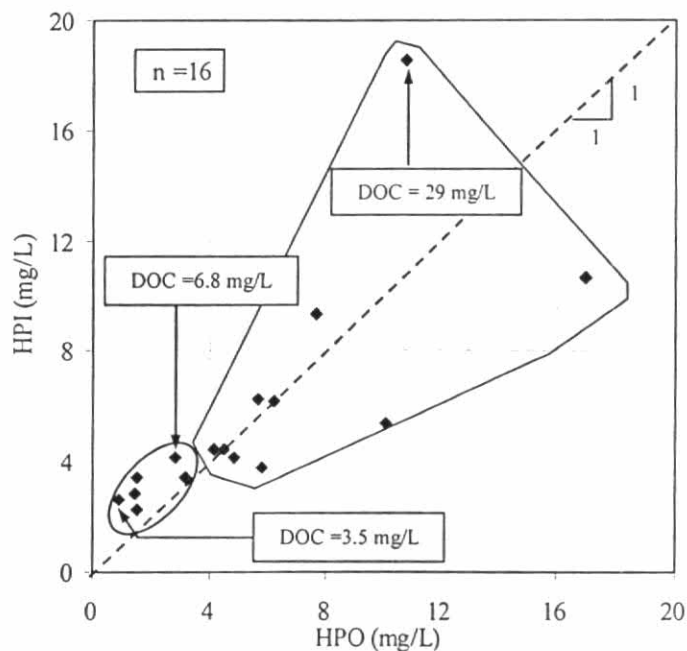
#### 4.4.3 Distribution of DOM Fractions in Treated Wastewater from this study and from literature data and in Groundwater and Reservoir, Lake, and River water from literature data

It is advantageous and meaningful to summarize the available data on the distribution of DOM fractions in groundwater and reservoir, lake, and river water and compare them with the distribution of DOM fractions in treated wastewater from this study and literature data because treated wastewater is one of the major sources of DOM that is discharged to natural waters.

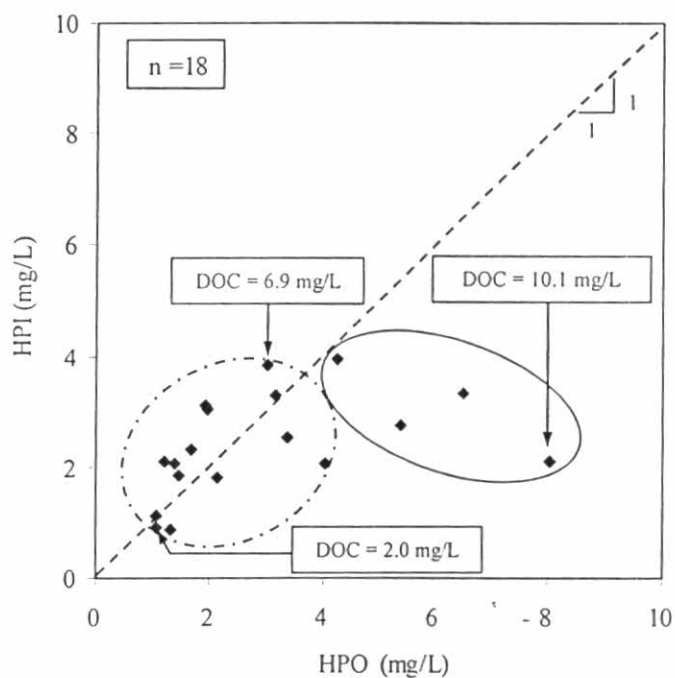
As can be seen from Table 4.3, DOC levels of the treated wastewater ranged from low to high; the lowest DOC reading, about 3.5 mg/L, was found in effluent water from a small wastewater treatment plant in Japan (Imai *et al.* 2002); and a DOC value of 29.0 mg/L, from effluent from wetlands in San Jacinto, CA, USA, was found to be the highest (Barber *et al.* 2001). The UV-254 and SUVA values in treated wastewater ranged from 0.042 to 0.365  $\text{cm}^{-1}$  and from 0.9 to 3.1 L/mg-m, respectively. In addition, the relationship between HPI and HPO in treated wastewater is presented in Figure 4.6. The DOC of unfractionated water ranged from 3.5 to 6.8 mg/L, HPI was the dominant DOM fraction in treated wastewater; its concentration accounted for more than 50 % by weight of the total DOC. There was no significant tendency for HPO and HPI when the DOC concentration increased to 29 mg/L. This variation on HPO and HPI may have been due to the different characteristics of wastewater and performance capability of the wastewater treatment process for removing DOM from the wastewater. These results suggested that in treated wastewater with low DOC concentrations, the HPI fraction was found to be dominant.

The relationship between HPI and HPO in reservoir water is depicted in Figure 4.7 (using the data from Table 2.1). The extremely high concentration data of the Inkpot Lake, Victoria, Australia (Day *et al.* 1991) was not included in this figure. The plots of HPI and HPO scattered along the line with the slope of unity when the DOC of unfractionated water ranged from 2.0 to 6.9 mg/L. In this range, the DOC concentrations of HPO and HPI were more or less 50 % by weight of the total DOC. In spite of that, HPO considerably increased along with the DOC concentrations up until about 10.1

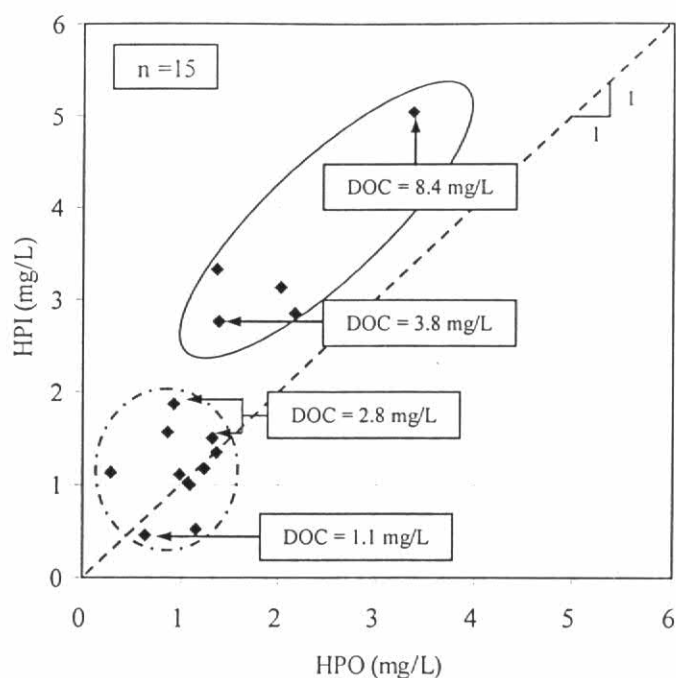
mg/L. It can be proposed that HPO is generally found as the major DOM fraction in reservoir and lake water that contains high concentrations of DOCs.



**Figure 4.6:** Relationship between HPI and HPO in treated wastewater (Remark; DOC was equal to DOC of unfractionated water)



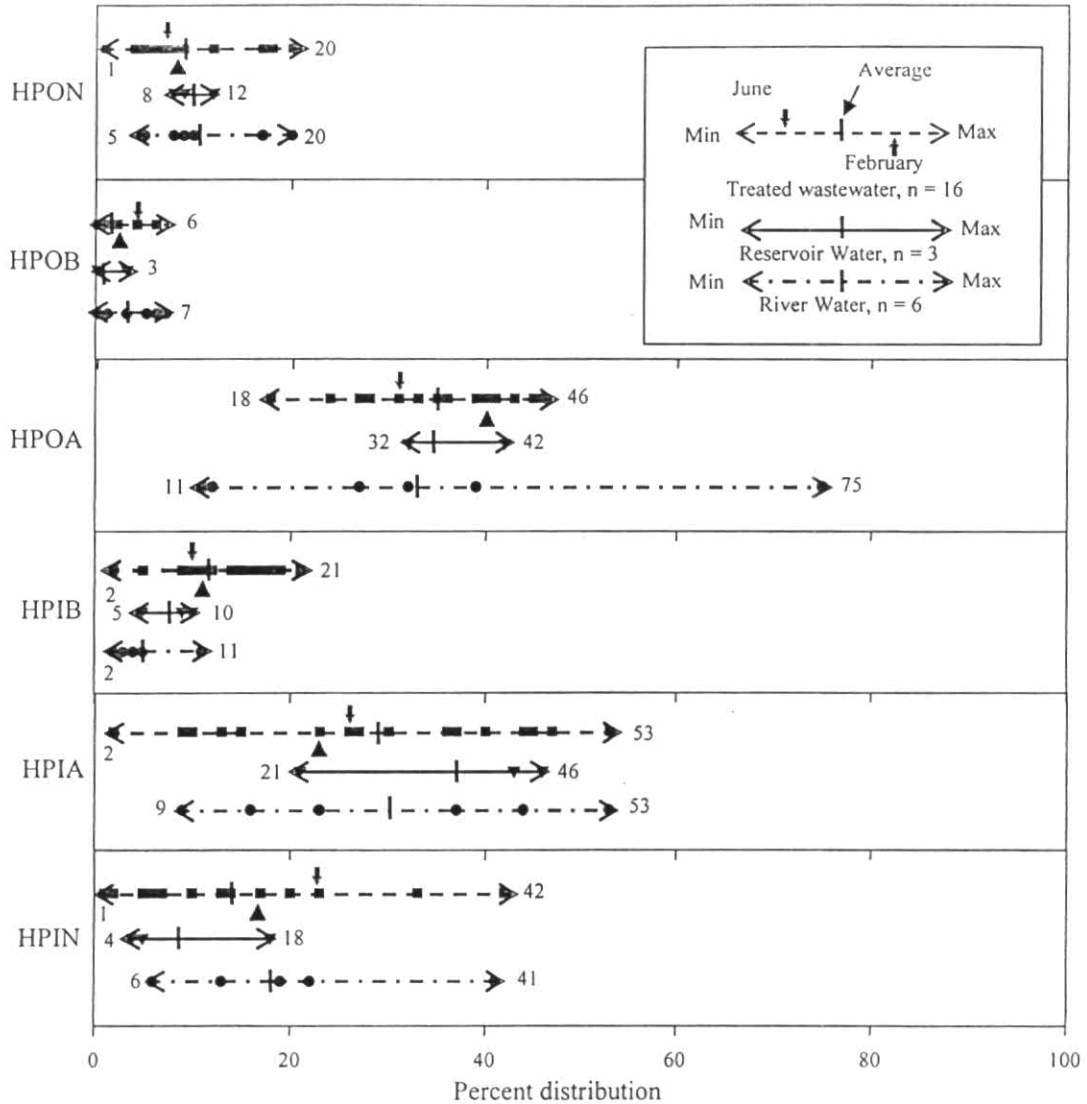
**Figure 4.7:** Relationship between HPI and HPO in reservoir water (Remark; DOC was equal to DOC of unfractionated water)



**Figure 4.8:** Relationship between HPI and HPO in river water (Remark; DOC was equal to DOC of unfractionated water)

The relationship between HPI and HPO in river water is demonstrated in Figure 4.8 (using the data from Table 2.2). The data from Red Water Creek, Victoria, Australia (Day *et al.* 1991) was not included in this figure. When considering the DOC range of 1.1 to 2.8 mg/L, in nearly all cases, the plot of HPI versus HPO scattered on both sides of the line with the slope of unity. Nevertheless, when the DOC concentration increased from 3.8 to 8.4 mg/L, the DOC concentration of HPI accounted for more than 50 % by weight of the total DOC. It must be implied that in the case of low DOC concentrations, either HPO or HPI could be the dominant DOM fraction. Whilst, in the case of high DOC concentrations, river water might be contaminated with treated wastewater in which HPI could be the dominant DOM fraction. Therefore, HPI becomes frequently the dominant DOM fraction in river water that has high DOC concentrations.

The range and average values of percent mass distribution of the six DOM fractions in treated wastewater, reservoir water and river water are depicted in Figure 4.9. It must be noted that resin fractionation has been applied to characterize DOM in many specific water sources; however, sometimes the literature data did not demonstrate the type of water source. Therefore, some results of the percent mass distribution of the six DOM fractions were not available for comparison in this study.



**Figure 4.9:** Range of percent distribution of six organic fractions in treated wastewater, river water and reservoir water

When considering treated wastewater, it can be stated that very broad ranges of percent mass distribution of HPOA, HPIA and HPIN were observed, yet slightly narrow ranges of percent mass distribution of HPON and HPIB were obtained, and HPOB was found in a very narrow range. The average values of percent mass distribution of the six DOM fractions were as follows: HPON (9%), HPOB (2%), HPOA (35%), HPIB (13%), HPIA (29%) and HPIN (13%). On this basis, it can be proposed that HPOA and HPIA were found to be the dominant DOM fractions. Slightly low HPIN, HPIB and HPON concentrations were determined and the lowest mass distribution of the DOM fractions was HPOB.

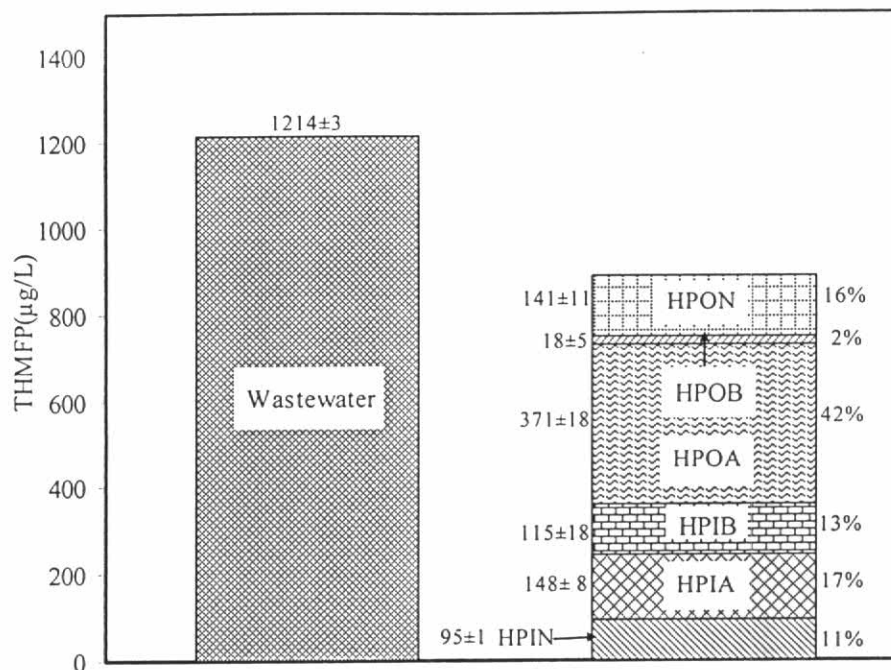
In the case of groundwater, only one report of percent mass distribution was found (Table 2.1), it came from the study of Swietlik *et al.* (2004). For reservoir water, only three sets of data on the six DOM fractions were found (Imai *et al.* 2001, 2003 and Janhom *et al.* 2005). According to this limited amount of data, the range and average values of percent mass distribution of the six DOM fractions in groundwater and reservoir water could not be summarized.

With regard to the ranges of the percent mass distribution of the six DOM fractions in river water, it appears that HPOA, HPIA and HPIN were observed in very broad ranges of percent mass distribution. This may be attributed to the fact that river water could be contaminated by treated wastewater and wastewater. The very board range of percent mass distributions of organic fractions in river water therefore could be introduced from discharge of contaminated sources. The percent mass distribution of HPON was obtained in slightly narrow ranges, while that of HPOB and HPIB were found in very narrow ranges. The average values of percent mass distribution of the six DOM fractions were as follows: HPON (11%), HPOB (4%), HPOA (33%), HPIB (5 percent %), HPIA (30%) and HPIN (18%). HPOA and HPIA were the dominant DOM fractions in river water. The slightly low percent mass distributions of HPIN and HPON were determined, while the percent mass distributions of HPOB and HPIB were found at very low levels.

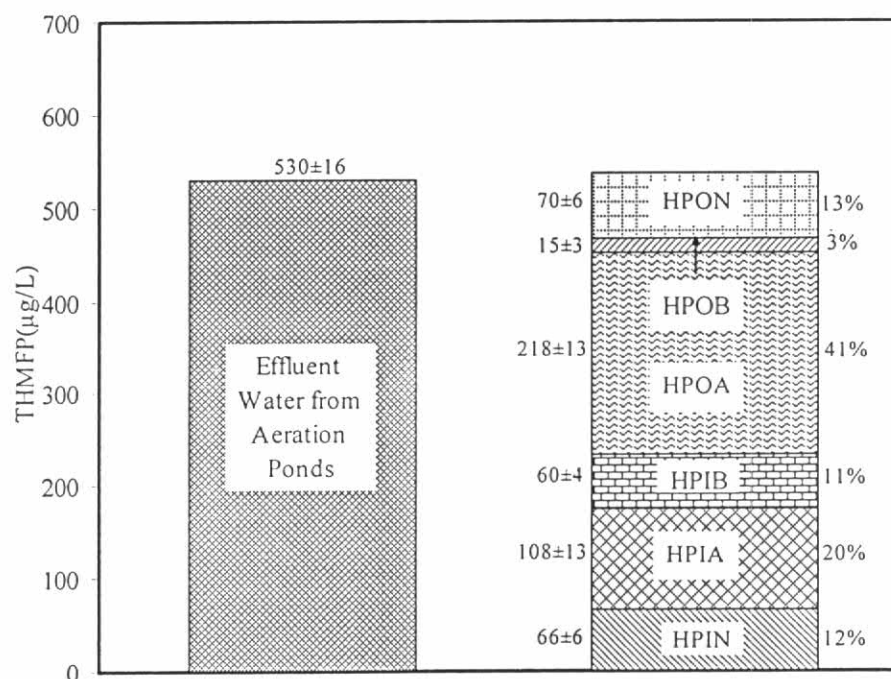
#### 4.4.4 THMFP of DOM Fractions

The THMFP distribution of influent wastewater and effluent water from the aeration, facultative, oxidation collected in February 2005 are shown in Figures 4.10, 4.11, 4.12 and 4.13, respectively, and that of the effluent water from the detention pond collected in June 2004 and February 2005 is presented in Figure 4.14. The THMFP distribution sequences and percent THMFP distribution of the six DOM fractions of all water samples were tabulated and are presented in Table 4.4.

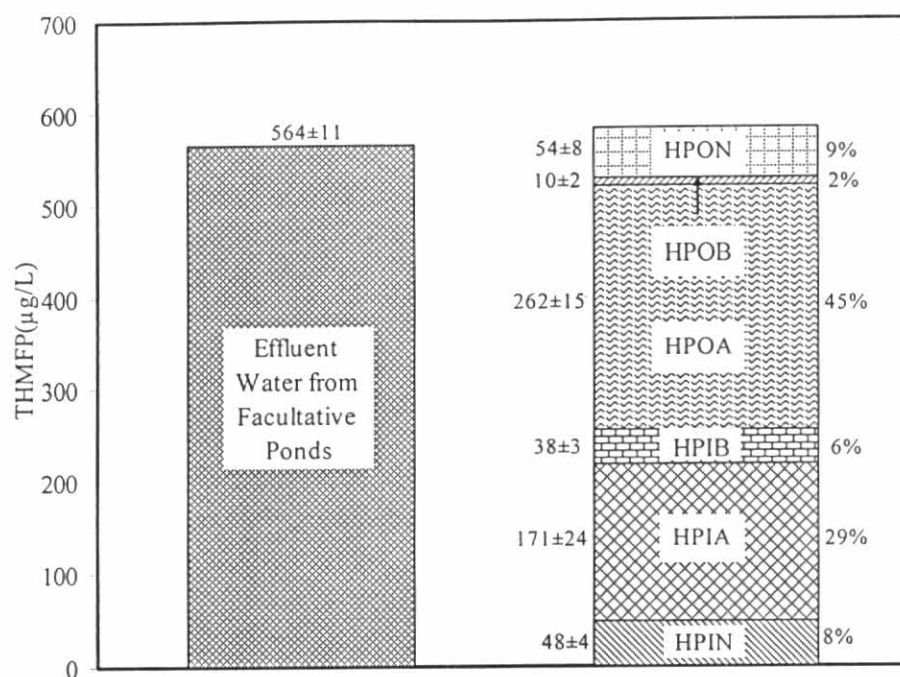




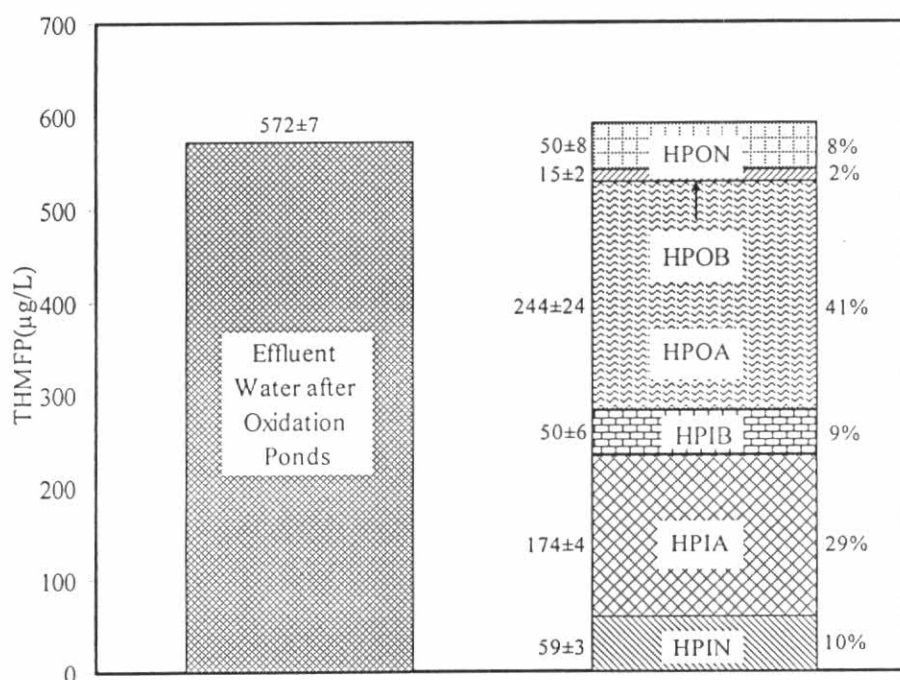
**Figure 4.10:** THMFP of influent wastewater and THMFP of the six organic fractions (with standard deviation ranges) with their percent distribution sampling from February 2005



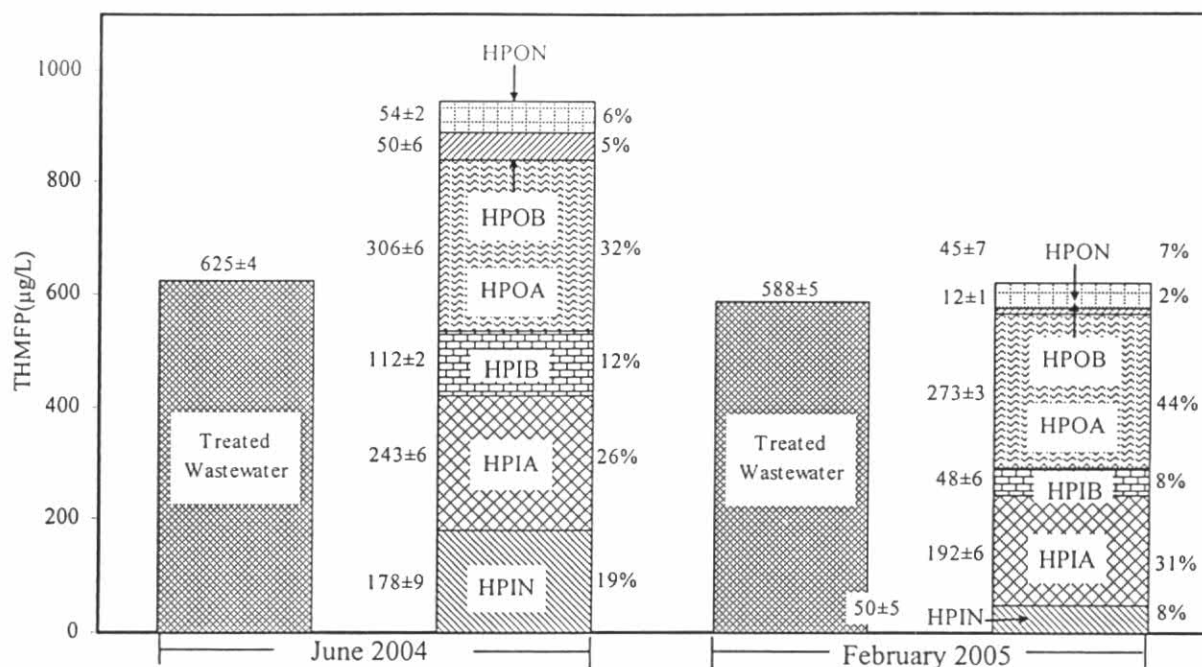
**Figure 4.11:** THMFP of effluent water from the aeration ponds and THMFP of the six organic fractions (with standard deviation ranges) with their percent distribution sampling from February 2005



**Figure 4.12:** THMFP of effluent water from the facultative ponds and THMFP of the six organic fractions (with standard deviation ranges) with their percent distribution sampling from February 2005



**Figure 4.13:** THMFP of effluent water from the oxidation ponds and THMFP of the six organic fractions (with standard deviation ranges) with their percent distribution sampling from February 2005



**Figure 4.14:** THMFP of treated wastewater and THMFP of the six organic fractions (with standard deviation ranges) with their percent distribution sampling from June 2004 and February 2005

**Table 4.4:** The THMFP distribution sequences and percent THMFP distribution of the six DOM fractions of influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds

Water samples	THMFP distribution sequence from high to low of six DOM fractions (percent distribution by weight)
Influent wastewater <sup>1</sup>	HPOA (42%) > HPIA (17%) > HPON (16%) > HPIB (13%) > HPIN (11%) > HPOB (2%)
Effluent water from aeration ponds <sup>1</sup>	HPOA (41%) > HPIA (20%) > HPON (13%) > HPIN (12%) > HPIB (11%) > HPOB (3%)
Effluent water from facultative ponds <sup>1</sup>	HPOA (45%) > HPIA (29%) > HPON (9%) > HPIN (8%) > HPIB (6%) > HPOB (2%)
Effluent water from oxidation ponds <sup>1</sup>	HPOA (41%) > HPIA (29%) > HPIN (10%) > HPIB (9%) > HPON (8%) > HPOB (2%)
Effluent water from detention pond <sup>1</sup>	HPOA (44%) > HPIA (31%) > HPIN (8%) > HPIB (8%) > HPON (7%) > HPOB (2%)
Effluent water from detention pond <sup>2</sup>	HPOA (32%) > HPIA (26%) > HPIN (19%) > HPIB (12%) > HPON (6%) > HPOB (5%)

Remark: <sup>1</sup>Water samples were collected on February 18, 2005.

<sup>2</sup>Water sample was collected on June 24, 2004.

According to results from Figures 4.10, 4.11, 4.12, 4.13, and 4.14 and Table 4.4, it was very clearly found that organic acids, HPOA and HPIA were the main THMs precursors in all water samples. The summations of  $\text{THMFP}_{\text{HPOA}}$  and  $\text{THMFP}_{\text{HPIA}}$  obtained in the influent wastewater and effluent water from the aeration, facultative and oxidation ponds were approximately more than 55, 60, 70 and 65% of the total THMFP, respectively. In addition, the summations of  $\text{THMFP}_{\text{HPOA}}$  and  $\text{THMFP}_{\text{HPIA}}$  of approximately more than 55% of total THMFP were obtained in effluent water from the detention pond collected in February 2005 and June 2004. As stated previously, HPOA and HPIN were the major DOM fractions in the influent wastewater and effluent water from the aeration ponds; however, only HPOA was a major THM precursor. Organic compounds in HPIN may have been inactive with chlorine and therefore failed to form THMs. When comparing the THMFP distributions of the detention pond effluent samples collected in February 2005 and June 2004, it was found that the order of their THMFP distribution sequences were significantly similar and could be expressed as follows:  $\text{THMFP}_{\text{HPOA}} > \text{THMFP}_{\text{HPIA}} > \text{THMFP}_{\text{HPIN}} > \text{THMFP}_{\text{HPIB}} > \text{THMFP}_{\text{HPON}} > \text{THMFP}_{\text{HPOB}}$ .

There have been some studies that have determined the THMFP of the six DOM fractions. Marhaba and Van (2000) reported on the THMFP of the six organic fractions in water from the Passaic River, New Jersey, USA. Their result showed that the THMFP distribution from high to low was  $\text{THMFP}_{\text{HPIA}}$  (69% of total THMFP),  $\text{THMFP}_{\text{HPON}}$  (18%),  $\text{THMFP}_{\text{HPOA}}$  (6%),  $\text{THMFP}_{\text{HPOB}}$  (4%),  $\text{THMFP}_{\text{HPIB}}$  (2%), and  $\text{THMFP}_{\text{HPIN}}$  (1%). HPIA and HPON were the first and second major THMs precursors. Panyapinyophol *et al.* (2005) presented that the THMFP distribution sequence of the six organic fractions in water from the Chao Phraya River, Bangkok, Thailand from high to low was  $\text{THMFP}_{\text{HPIN}}$  (32 percent of total THMFP),  $\text{THMFP}_{\text{HPOA}}$  (21%),  $\text{THMFP}_{\text{HPIB}}$  (15%),  $\text{THMFP}_{\text{HPOB}}$  (13%),  $\text{THMFP}_{\text{HPIA}}$  (13%), and  $\text{THMFP}_{\text{HPON}}$  (6%). In this water source, HPIN was the major THM precursor followed by HPOA. Janhom *et al.* (2005) demonstrated that the THMFP distribution sequence of the six organic fractions in water from a raw water supply reservoir in Lamphun, Thailand, from high to low was  $\text{THMFP}_{\text{HPOA}}$  (41% of total THMFP),  $\text{THMFP}_{\text{HPIA}}$  (19%),  $\text{THMFP}_{\text{HPIB}}$  (11%),  $\text{THMFP}_{\text{HPIN}}$  (11%),  $\text{THMFP}_{\text{HPON}}$  (11%) and  $\text{THMFP}_{\text{HPOB}}$  (7%). HPOA was the major THM precursor followed by HPIA in this water source. These results suggested that different water sources may contain

different organic constituents, and have different capabilities of reacting with chlorine to form THMs.

#### 4.4.5 Specific THMFP

The specific THMFP values of the unfractionated waters and of each DOM fraction are defined as follows:

$$\text{Specific THMFP}_x (\mu\text{g THMFP}/\text{mg DOC}) = \frac{\text{THMFP}_x (\mu\text{g THMFP}/\text{L})}{\text{DOC}_x (\text{mg DOC}/\text{L})}$$

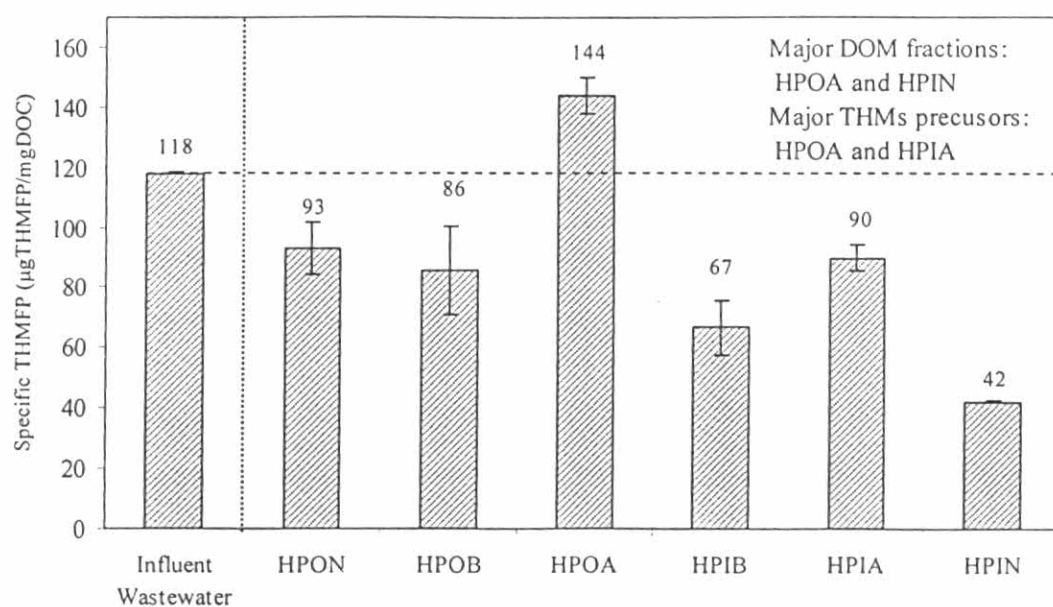
Where,  $x$  = unfractionated water or each DOM fractions

THMFP = THMs created from unfractionated wastewaters or THMs created from each DOM fractions

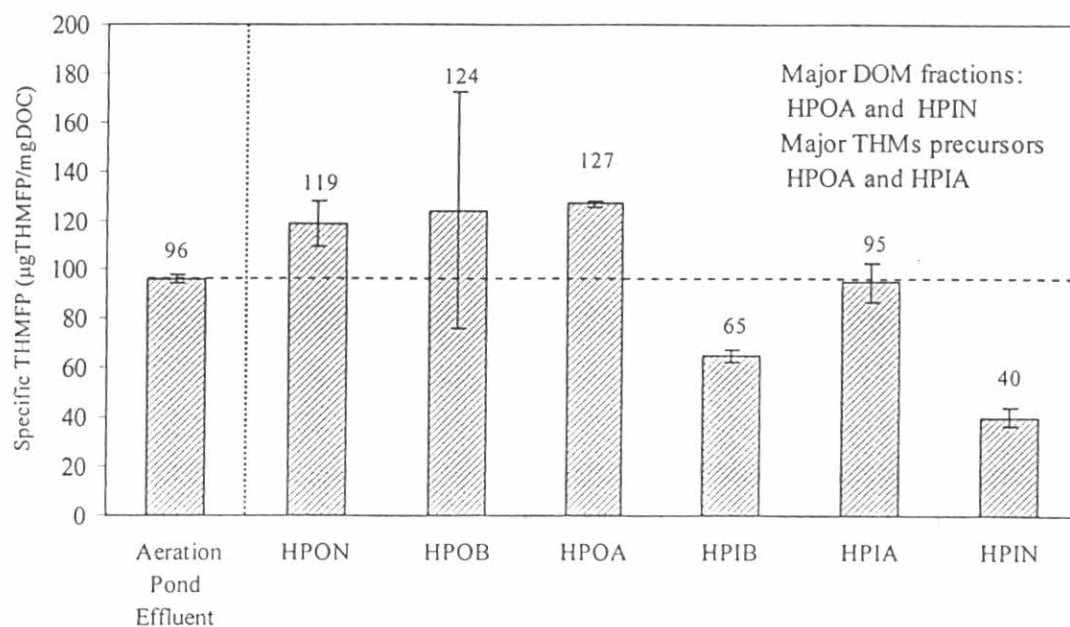
DOC = DOC of unfractionated water or DOC of each DOM fractions

Specific THMFP represents the ability of the DOM in water to react with chlorine to form THMs. Figures 4.15, 4.16, 4.17 and 4.18 present the specific THMFP values of the influent wastewater and effluent water samples from the aeration, facultative, and oxidation ponds collected in February 2005; whereas Figure 4.19 illustrates the specific THMFP of the effluent water sample from the detention ponds collected in June 2004 and February 2005. The specific THMFP sequences and specific THMFP values of the unfractionated water samples and of their six DOM fractions are tabulated in Table 4.5.

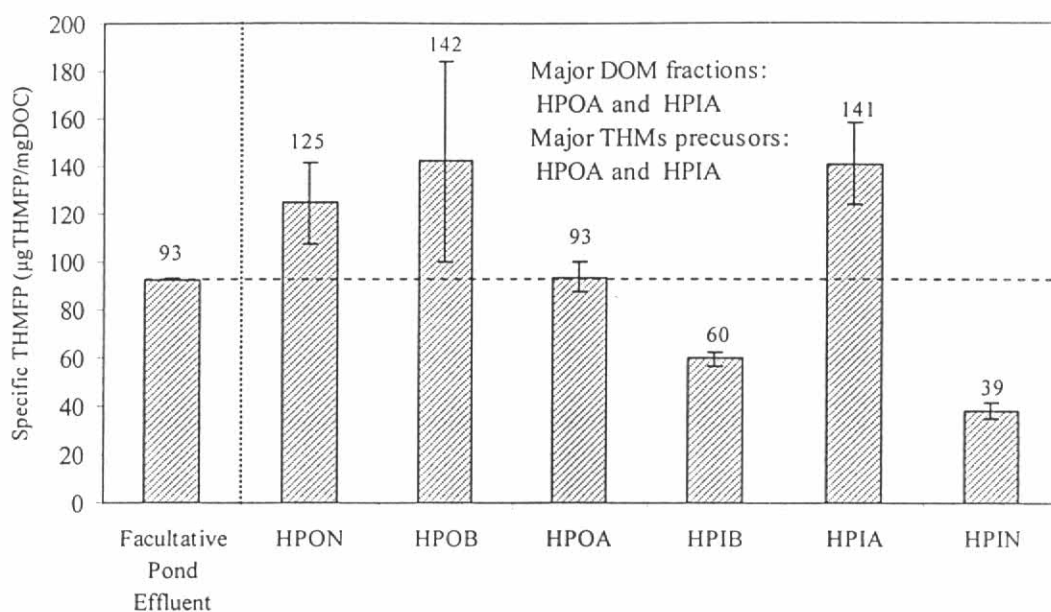
As can be seen from Figure 4.15 and Table 4.5, when comparing the specific THMFP of each DOM fraction of the influent wastewater, HPOA (major DOM fraction) demonstrated itself as the highest active source for the formation of THMs followed by HPON, while HPIN (major DOM fraction) and HPIB were found as the first and the second most inactive sources, respectively. In addition, when comparing the specific THMFP of each DOM fraction with that of the unfractionated influent wastewater, the specific THMFP values of HPON, HPOB, HPIB, HPIA and HPIN were moderately lower than those of the unfractionated influent wastewater, while the specific THMFP of HPOA was moderately higher than that of the unfractionated influent wastewater. This could be used to support the observation that the summation of the THMFP of the six DOM fractions was much lower than the THMFP of the unfractionated influent wastewater.



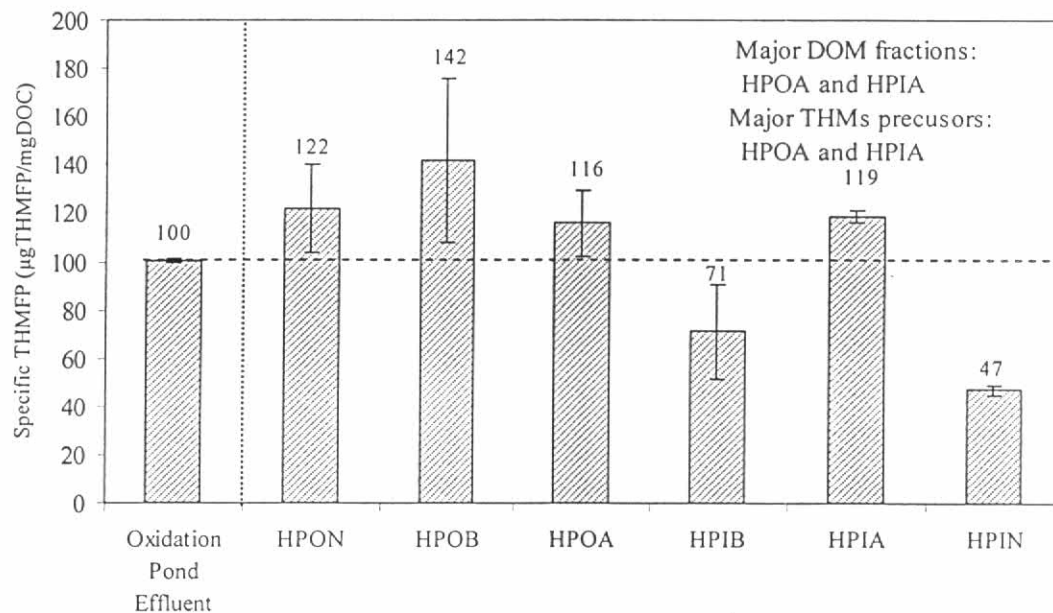
**Figure 4.15:** Specific THMFP of influent wastewater collected in February 2005 and specific THMFP of the six fractions in the influent wastewater (with standard deviation ranges)



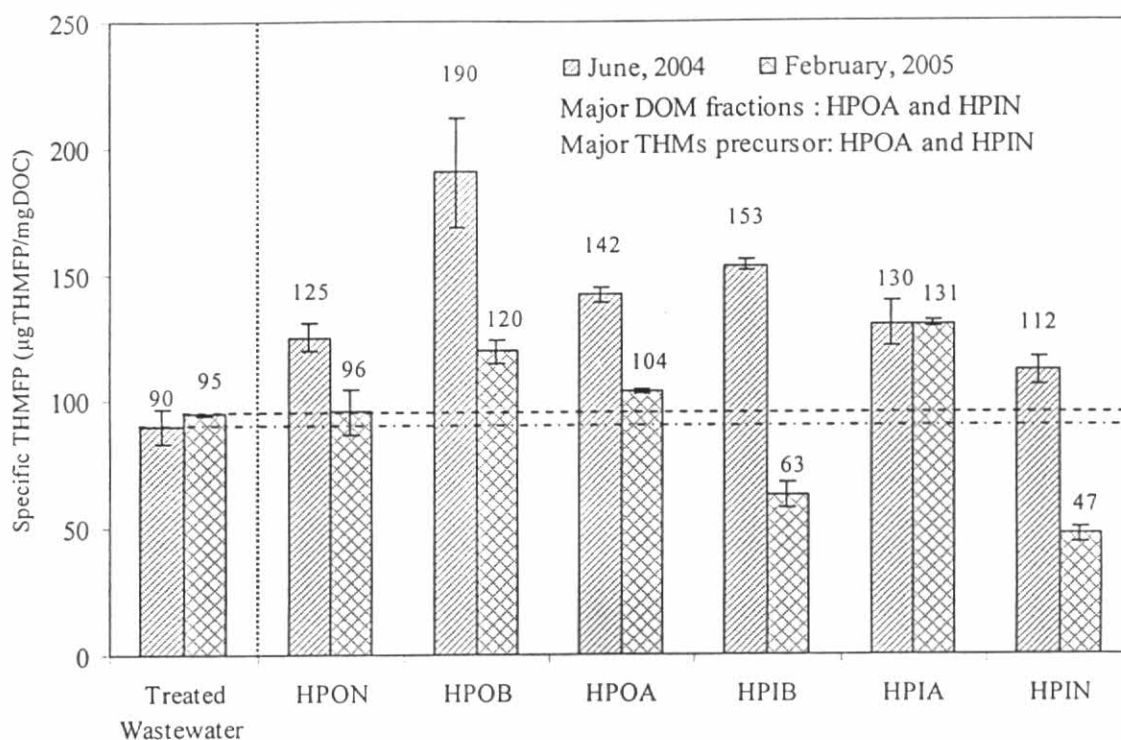
**Figure 4.16:** Specific THMFP of effluent water from the aeration ponds collected in February 2005 and specific THMFP of the six fractions in effluent water from the aeration ponds (with standard deviation ranges)



**Figure 4.17:** Specific THMFP of effluent water from the facultative ponds collected in February 2005 and specific THMFP of the six fractions in effluent water from the facultative ponds (with standard deviation ranges)



**Figure 4.18:** Specific THMFP of effluent water from the oxidation ponds collected in February 2005 and specific THMFP of the six fractions of effluent water from the oxidation ponds (with standard deviation ranges)



**Figure 4.19:** Specific THMFP of treated wastewater collected in June 2004 and February 2005 and specific THMFP of the six fractions in the respective water samples (with standard deviation ranges)

According to the obtained results from Figure 4.16 and Table 4.7, HPOA (major DOM fraction) and HPOB were the first and second most active sources in the formation of THMs, while HPIN (major DOM fraction) was the most inactive source in the formation of THMs, followed by HPIB in the aeration pond effluent. From Figure 4.17 and Table 4.7, HPOB demonstrated itself as the highest active source in the formation of THMs followed by HPIA (major DOM fractions), while HPIN and HPIB were found to be the first and the second most inactive sources in the formation of THMs in the facultative pond effluent, respectively. Based on results in Figure 4.18 and Table 4.7, HPOB and HPON were the first and second most active sources in the formation of THMs, while HPIN was the most inactive source in the formation of THMs followed by HPIB in the oxidation pond effluent.



**Table 4.5:** The specific THMFP sequences and specific THMFP values of the unfractionated water samples and six DOM fractions in influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds

Water samples	Specific THMFP sequence from high to low of unfractionated water samples and six DOM fractions (specific THMFP value, $\mu\text{g THMFP}/\text{mg DOC}$ )
Influent wastewater (Inf. WW) <sup>1</sup>	HPOA (144) > Inf. WW (118) > HPON (93) > HPIA (90) > HPOB (86) > HPIB (67) > HPIN (42)
Effluent water from aeration ponds (Eff. AP) <sup>1</sup>	HPOA (127) > HPOB (124) > HPON (119) > Eff. AP (96) > HPIA(95) > HPIB (65) > HPIN (40)
Effluent water from facultative ponds (Eff. FP) <sup>1</sup>	HPOB (142) > HPIA (141) > HPON (125) > Eff. FP (93) = HPOA(93) > HPIB (60) > HPIN (39)
Effluent water from oxidation ponds (Eff. OP) <sup>1</sup>	HPOB (142) > HPON (125) > HPIA (119) > HPOA(116) > Eff. OP (100) > HPIB (71) > HPIN (47)
Effluent water from detention pond (Eff. DP) <sup>1</sup>	HPIA (131) > HPOB (120) > HPOA (104) > HPON(96) > Eff. DP (95) > HPIB (63) > HPIN (47)
Effluent water from detention pond (Eff. DP) <sup>2</sup>	HPOB (190) > HPIB (153) > HPOA (142) > HPIA(130) > HPON (125) > HPIN (112) > Eff. DP (90)

Remark: <sup>1</sup>Water samples were collected on February 18, 2005.

<sup>2</sup>Water sample was collected on June 24, 2004.

Based on the results shown in Figure 4.19 and Table 4.5 the specific THMFPs of HPON, HPOB, HPOA, HPIB, HPIA and HPIN in the treated wastewater collected in June 2004 were higher than those of the unfractionated treated wastewater. It is evident that the individual DOM fraction has a great ability to react completely with chlorine to form THMs. The cause of the extremely high summation value of the THMFP of the six DOM fractions may be due to the great ability of DOM fractions to form THMs. In the case of the treated wastewater collected in February 2005, the specific THMFPs of HPOB, HPOA and HPIA were higher than those of the unfractionated treated wastewater, while the specific THMFPs of HPIB and HPIN were lower than those of the unfractionated treated wastewater. The specific THMFP of HPON was considerably similar to that of the unfractionated water. Since the ability for reacting with chlorine of HPOA and HPIA (major DOM fractions) were moderately higher than that of the unfractionated treated wastewater, the summation of the THMFPs of the six organic

fractions, therefore, was slightly higher than THMFP of the unfractionated treated wastewater.

In addition, there were differences in the specific THMFP values of the six DOM fractions of the treated wastewater collected in June 2004 and February 2005. The sampling times in June 2004 and February 2005 could be considered the end of the dry season and the beginning of the dry season, respectively. According to the rainfall data, the dry weather day before the sampling time in June 2004 was 1 day and the 7-day accumulative rainfall before the sampling time was 5.7 mm. This rainwater in the watershed area of the industrial estate of approximately 286 hectares was discharged to the detention pond. In the case of the sampling time in February 2005, the most recent dry weather day prior to the sampling was 52 days. Therefore, in the case of the treated wastewater collected in February 2005, there was no effect from the rainwater on the characteristics of the treated wastewater in the detention pond due to the very long period of dry weather days. However, in the case of the treated wastewater collected on June 2004, the discharge of rainwater into the detention pond may have had an effect on the nature of the treated wastewater in this pond. Therefore, differences in the specific THMFPs of the six DOM fractions in the treated wastewater collected in June 2004 and February 2005 were obtained.

After considering the specific THMFP values of the DOM fractions from all the water samples, it can be stated that the first and second active sources for forming THMs in the influent wastewater and effluent water from aeration, facultative, oxidation and detention ponds were considerably different. A conclusion on the active sources for the formation of THMs, therefore, could not be drawn. When the specific THMFPs of HPIN and HPIB were determined, low values were obtained in all the water samples. This may have been due to the fact that the DOM in HPIB and HPIN were characteristically prone to react with chlorine to form THMs. For instance, it has been reported that  $< C_5$  aliphatic amide, alcohols, aldehydes, esters and ketones, polyfunctional alcohol, carbohydrates, cyclic amides (Barber *et al.* 2001), oligosaccharides, polysaccharides (Imai *et al.* 2001) and sugar (Leenheer and Croue, 2003) were organic matter characterized as HPIN. In addition, polysaccharide is prone to react with chlorine to form THMs (Bruchet *et al.* 1987). When, polysaccharide is the dominant organic substance in HPIN then the

ability of HPIN to react with chlorine to form THMs must decrease. The details of the organic compounds/chemical classes contained in the influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds will be presented in Chapter 5.

From the specific THMFP results of the treated wastewater, it is quite certain that the specific THMFPs of HPOA and HPIA of the treated wastewater collected in June 2004 and February 2005 were considerably higher than those of the treated wastewater. Since HPOA and HPIA were the major DOM fractions and THMFP precursors, these two fractions should be removed from the treated wastewater before chlorination. Therefore, it must be advantageous and useful to summarize the available data on the DOM fraction removal.

Musikavong *et al.* (2005) used jar-test coagulation experiments with variations of separate alum and ferric chloride dosages from 10 to 80 mg/L at pH conditions ranging from 5 to 6.5 to reduce DOC and THMFP in treated wastewater of a studied industrial estate. It was found that DOC were reduced from an average value of 5.1 mg/L to a level of about 4.0 mg/L by alum and ferric chloride dosages of approximately 40 mg/L. Maximum percentage removal of THMFP of 25 and 28% by using alum and ferric chloride dosages of about 80 mg/L at pH 5.5 and 5 were obtained, respectively, at the examined conditions. On this basis, it can be stated that alum and ferric chlorine alone could not effectively reduce DOC and THMFP to the acceptable level, a further study, therefore, was recommended to focus on developing a removal technique to reduce the DOM in the treated wastewater.

Marhaba and Pipada (2000) used alum coagulation to investigate its effectiveness in removing DOM fractions. Water samples were collected from the intake of the Raritan/Millstone (R/M) and Canal Road (CR) surface water treatment plants of Elizabethtown Water Company (Westfield, NJ). The sources of water for both plants are the Raritan and Millstone Rivers, augmented by the Spruce Run and Round Valley Reservoirs, and the Delaware and Raritan Canal. Coagulation was carried out at controlled pH values of 6 ( $\pm 0.1$ ) and 8 ( $\pm 0.1$ ) (using NaOH and H<sub>2</sub>SO<sub>4</sub>) over a range of alum dosages (up to 60 mg/L). It was found that the reductions of TOC, UVA and SUVA

of all six fractions at a pH of about 6 were greater than those that occurred at pH 8. With the exception of HPOB and HPOA, their reductions still increased with further additions of alum. The maximum removal of HPOA and HPOB occurred at pH 6 and an alum dosage of 40 mg/L, in which 70% TOC, 84% UV-254, and 45% SUVA removals were obtained. In the case of HPIA and HPON, an alum dosage of 60 mg/L at pH 6 could reduce the TOC of HPIA and HPON by more than 50%. In addition, HPIB and HPIN had a perceptible TOC removal of about 45% at the same maximum conditions.

Marhabar and Van (2000) determined the variation of mass and DBP formation potential of DOM fractions along the Passaic Valley surface water treatment plant (WTP) of Passaic Valley Water Commission PV, Little Falls, New Jersey, USA. The WTP draws from the Passaic River located in northern New Jersey. The WTP utilizes pre-chlorination, coagulation, sedimentation, post-chlorination, and anthracite over-sand filtration. Alum dosages between 20 and 70 mg/L were used in the treatment processes. HPIN, HPIA, and HPOA had the highest removals through the WTP of 67%, 65% and 64%, respectively, followed by HPOB, HPON, and HPIB (34%, 27% and 5%, respectively). In terms of THMFP removal, the WTP could reduce HPIA, HPOA, HPOB, HPON and HPIB by 30%, 30%, 55%, 47% and 15%, respectively. It can be noticed that although the DOC of the DOM fractions could be reduced as much as 60% by the WTP, only a 30 percent reduction of the THMFP was achieved.

Kim and Yu (2005) determined the reduction of natural organic matter in conventional water treatment processes in order to select the suitable treatment processes for removing DBPs precursors. Pre-chlorination, coagulation-flocculation, sedimentation, and sand filtrations removed the hydrophobic fraction more than the hydrophilic fractions.

Sharp *et al.* (2006) studied impact of fractional character on the coagulation of NOM. Water samples were collected from the Albert Water Treatment Works (WTW), a moorland waterworks in the north of England, situated in Halifax. Water samples were taken during a 36-month period from April 2002 until October 2004, with the water source typically characterized as a low turbidity (3.7-7.0 NTU), low alkalinity (20 mg/L CaCO<sub>3</sub>), high colour (44-160 Hazens) and high DOC (6.6-13.3 mg/L) source. The water

samples were fractionated into HPOA and HPIA by using XAD resin. HPOA was then further separated by reducing the pH to 1 and precipitating the humic acid fraction (HAF), with the fulvic acid fraction (FAF) remaining in the supernatant. The non-adsorbed fraction was defined as hydrophilic non acid (HPINA). The results show that in the case of the coagulation of raw water, a removal of 70% of the HAF fraction was possible at a zeta potential of 12.5mV, whereas, only 35% was possible for the FAF fraction. This corresponded well with the work of Zouboulis *et al.* (2003), who also were able to achieve a significant humic acid removal of 92% at a zeta value of 12.6mV. In the case of NOM fractions, removal data for the individual NOM fractions confirmed the efficacy of conventional coagulation for the hydrophobic fractions, with 84 and 64% removal for HAF and FAF, respectively. The maximum achievable removals for the hydrophilic fractions were 14 and 17%, for the HPIA and HPINA fractions, respectively. It can be stated that the concentration and character of the FAF fraction is probably able to control the coagulation conditions and the operational zeta potential envelope, whereas the hydrophilic fractions are likely to influence the achievable residual following treatment.

There are other processes that are able to remove DOM from water sources, such as adsorption, ion exchange, membrane filtration, and advanced oxidation processes. The AWWA (1998) examined the capability of granular activated carbon (GAC) to adsorb DBPs precursors from several source waters. Water samples were collected from six utilities including the Cincinnati Waterworks (source water: Ohio River, ORW), South Central Connecticut Regional Water Authority (Lake Gaillard, LGW), Jefferson Parish Water Department (Mississippi River, MRW), Passaic Valley Water Commission (Passaic River, PRW), City of Phoenix (Salt River Project, SRPW), and Florida Cities Water Company (groundwater, FGW). It was found that the early GAC effluent samples were composed of nonadsorbable NOM, which were found to be almost entire nonhumic and aliphatic and composed of small molecular size fractions. Samples later in the breakthrough curve gradually demonstrated the appearance of humic and aromatic fractions and larger molecular size fractions. Pretreatment with coagulation almost equally had an effect on the humic and nonhumic fractions. Larger and humic material was preferentially removed by ozonation and biofiltration over smaller and nonhumic material. Optimizing coagulation pretreatment could result in longer GAC life.

Korshin *et al.* (1997) studied the adsorption of NOM on hydrous iron oxide. The water sources were the influents to the water treatment plants in Everett, WA and Mt Veron, WA. It was found that the surface of iron oxide considerably interacted with HPON, HPOB, HPOA, HPIB, and HPIA in the influent, and not HPIN. HPIA and HPOA interact most strongly with the iron oxide surface. Bolto *et al.* (2002) studied the removal of natural organic matter by ion exchange. Four fractions of water samples were fractionated into very hydrophobic acids (VHS), slightly hydrophobic acids (SHA), charged hydrophilic compounds and neutral hydrophilic compound. The resins tested were received from Rohm and Hass, Bayer, ResinTech and Purolite. Anion exchangers of open structure and high water content were observed as the best resin type for the very efficient removal of hydrophobic and hydrophilic organic matter.

Membrane filtration has been used to remove DOM. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) membranes have been utilized to remove DOM from water. Many studies focused on the fouling of the UF, NF and RO by DOM, because it could provide a basis for the appropriate selection and operation of membrane technology for drinking water treatment. Fan *et al.* (2001) ordered potential foulants: hydrophilic neutrals > hydrophobic acids > transphilic acids. Lee *et al.* (2004) evaluated fouling in low-pressure membrane (MF/UF) filtration by NOM. Two MF and UF membranes possessing hydrophilic and hydrophobic properties were used. Four French surface waters, Marne River, Cazau Lake, La Bultiere Reservoir and Yffiniac River, were selected as the water samples and fractionated into hydrophobic, transphilic and hydrophilic fractions. Source water that contained a high HPI fraction content of NOM resulted in a significant flux decline. A difference in the flux decline between hydrophobic and hydrophilic membranes was not founded. The shape and size of molecules and roughness of membrane were found to be important influential factors that affected flux decline. Membrane fouling mechanisms were not only a function of membrane type but also depended upon feed water characteristics. Kennedy *et al.* (2005) evaluated the NOM fouling of ultrafiltration membranes. Water samples were collected from Ijssel Lake (Andijk, North Holland) and fractionated into three NOM fractions: hydrophobic, hydrophilic and transphilic. Hollow fiber UFC M5 membranes from X-Flow were used for the UF made of a hydrophilic PES/PVP blend (MWCO 150-200

KDa). The filtration of three NOM fractions suggested that the fouling potential ordered from high to low was as follows: hydrophilic > hydrophobic > transphilic.

Hu *et al.* (2003) studied the treatability of organic fractions derived from secondary effluent by reverse osmosis (RO) membrane. The water sample was treated secondary effluent from a local water reclamation plant. The experimental procedure was conducted in three phases. In the first phase, the secondary effluent was filtered through microfiltration and fractionated using resin fractionation into seven fractions including HPON, HPOB, humic acid (HA), fulvic acid (FA) (HA + FA = HPOA), HPIB, HPIA and HPIN. In the second phase, each fraction was subjected to treatment by the RO process to study the treatability of organic fractions using the RO system. In the third phase, the same batch of secondary treated effluent was filtered through microfiltration prior to being feed into the RO process. The RO feed, RO concentrate and RO permeate were subsequently fractionated into six fractions. The RO system was obtained from Nimbus<sup>TM</sup> (NIMBUS<sup>TM</sup> H-400) using a thin film polyamide membrane. In the case of the treatability of organic fractions by the RO process (first and second phases), it was found that the RO treatment had a better performance in removing hydrophobic fractions than hydrophilic fractions (except for the based fractions). The highest DOC removal was obtained from HPOA, whereas in the case of HPIA, it was not readily rejected and tended to permeate through the membrane. When compared among the hydrophobic fractions or hydrophilic fractions, the removal efficiencies from high to low were ordered as follows: Acid > Neutral > Base (except for HPIN). For the treatment efficiency of the RO process with respect to each DOM fraction (third phase), the percentage composition of the hydrophobic fractions in the permeate decreased, while the percentage composition of the hydrophilic fractions increased. The RO process could effectively reduce HPOA.

The advanced oxidation processes (AOP) has been reported to have the potential to remove NOM from water sources. Parsons and Murray (2004) utilized Fenton's reagent, photo-Fenton's reagent and titanium dioxide photocatalysis to remove NOM from water from the inlet to the Albert Water Treatment Works, England. In comparison to conventional coagulation/flocculation processes, these three processes had higher removal efficiencies in terms of both DOC and UV-254 absorbance. Under the optimum conditions all three processes could remove DOC and UV-254 over 80% and 90%

respectively. Goslan *et al.* (2006) investigated reservoir NOM reduction by UV photolysis and AOP. They utilized four treatment technologies, including UV-C photolysis, UV/H<sub>2</sub>O<sub>2</sub>, Fenton's reagent (FR) and photo-Fenton's reagent (PFR), to remove NOM in moorland reservoir water from the Gorple (lower) Reservoir, one of the sources for the Albert WTW, England. It was found that the reduction of UV-254 required very high UV-C doses, in which UV-C irradiation did not result in DOC removal at doses up to 1100 J cm<sup>-2</sup>. H<sub>2</sub>O<sub>2</sub> treatment combined with UV-C light could increase the reduction of UV-254 compared with UV-light alone. In terms of UV-254 reduction, PFR did not show remarkably good treatment efficiency at the optimum condition compared with FR, however, in terms of DOC removal, PFR was the most efficient process.

From literature data on the removal of DOM fractions, it can be seen that hydrophobic organic fractions, especially HPOA, could be successfully removed using coagulation/flocculation, GAC and membrane processes, whereas these processes were considerably unsuccessful to remove hydrophilic fractions. However, different water sources may lead to different water characteristics, therefore, the performance capabilities of treatment processes to remove DOM could be different. A recommendation for the removal of HPOA and HPIA from treated wastewater could be drawn: enhanced coagulation practices may be an appropriate technique for removing HPOA from the treated wastewater. The GAC and membrane filtration processes could be used after coagulation to enhance the reduction of HPIA, however, the effects of the membrane properties such as roughness, hydrophobicity and hydrophilicity, and surface charge on removing HPIA should be investigated in order to provide an appropriate selection and operation of membrane technology for reclamation plants.

#### 4.5 Concluding Remarks

This work was aimed at characterizing the organic contaminants in influent wastewater and effluent water from the aeration, facultative, oxidation and detention ponds of an industrial estate in northern Thailand's Lamphun province. HPOA and HPIN were the major DOM fractions in the influent wastewater and effluent water from the aeration ponds, whereas HPOA and HPIA were found to be the dominant organic fractions in the effluent water from the facultative, oxidation and detention ponds. With regard to the obtained results in this study and those of others, the hydrophilic organic fraction (HPI)



was the dominant DOM fraction in the treated wastewater when the DOC ranged from 3.5 to 6.8 mg/L. When considering the DOC mass distribution of the six organic fractions in the treated wastewater, very broad ranges of percent mass distribution of HPOA, HPIA and HPIN were observed; yet slightly narrow ranges of percent mass distribution for HPON and HPIB were obtained, and HPOB was found in a very narrow range in the treated wastewater. With regard to the formation of carcinogenic substances, in all water samples, the THMFP values obtained from HPOA and HPIA were found to be in the largest quantities when compared to others species. In addition, the specific THMFPs of HPOA and HPIA were considerably high. These two fractions, therefore, should be removed from the treated wastewater prior to it being disinfected with chlorine in the water supply plant. Since the ability of DOM fractions to react with chlorine to form THMs mainly depends upon the complex composition of the DOM in water such as chemical classes and functional groups, a resin fractionation technique could not provide this information. In the next chapter, the distribution of chemical classes contained in the influent and effluent of the studied ponds and in their six DOM fractions will be described further based on the results of an application of a pyrolysis gas chromatography mass spectrometer (GC/MS).