

# CHAPTER IV

## RESULTS AND DISCUSSIONS



### 4.1 Characteristics of raw waters from Aung-Keaw Reservoir, Mae-Kuang Reservoir and Mae-Sa River.

The characteristics of reservoir and river water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River are summarized in Table 4.1.

**Table 4.1:** Characteristics of raw waters from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River.

Parameter	Source of Raw waters		
	Aung-Keaw Reservoir	Mae-Kuang Reservoir	Mae-Sa River
pH	7.23	7.30	8.52
Temperature (°C)	24.0	21.5	19.0
Alkalinity (mg/L as CaCO <sub>3</sub> )	28.9	38.8	177.2
Turbidity (NTU)	5.57	3.50	2.73
UV-254 (1/cm)	0.1085	0.0496	0.0244
TOC (mg/L)	2.43	2.11	1.81
DOC (mg/L)	2.35	2.02	1.76
DOC/TOC	0.97	0.96	0.97
SUVA (L/mg-m)	4.61	2.45	1.39
THMs (µg/L)	ND.*	ND.*	ND.*

\* ND.= not detectable

As can be seen in Table 4.1, the average pH values of raw water in Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River were 7.23, 7.30, and 8.52, respectively. It can be stated that pH of reservoir water was close to neutral whereas

the pH of river water was slightly higher. Therefore the acid solution should be added to adjust pH in this water prior to coagulation. Alkalinity of about 28.9, 38.8, and 177.2 mg/L as CaCO<sub>3</sub> in raw water from Aung-Keaw, and Mae-Kuang Reservoir, and Mae-Sa River was observed, respectively. Due to the slightly low alkalinity, additional alkalinity must be added to the raw water from the Aung-Keaw and Mae-Kuang Reservoirs during coagulation since alkalinity must be neutralized in the reaction with a coagulant to produce floc.

The average values of turbidity in raw water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River were 5.57, 3.50, and 2.73 NTU, respectively. From the obtained results, the raw water in Aung-Keaw Reservoir was not adequately clear to allow for direct utilization as potable water (Notification of the Ministry of Industry, No.332, 1978). However, turbidity or the cloudiness of raw water caused by multiple factors such as clay, silt, fine organic and inorganic matter, and was expected to be removed during coagulation.

As stated previously, UV represents the organic compounds that are aromatic or that have a conjugated double bond, which bonds to the absorbed light in ultraviolet at wave length 254 nm. Moreover, UV-254 is also a well-known DOM surrogate parameter for creating THMs (Edzwald, Becker, and Wattier, 1985; Eaton, 1995). The average values of UV-254 were 0.1085, 0.0496, and 0.0244 cm<sup>-1</sup> whereas the average values of SUVA were 4.62, 2.45, and 1.39 L/mg-m for water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River, respectively. In particular, SUVA was also used as an index of aromaticity. SUVA values of less than about 3 L/mg-m signify water containing mostly non-humic material. SUVA values of 4 to 5 L/mg-m are typical of waters containing primarily humic material (Edzwald and Van Benschoten, 1990). In regard to the UV-254 and SUVA values, it can be stated that water samples from Mae-Kuang Reservoir, and Mae Sa River mostly contain non-humic material while the water sample from Aung-Keaw Reservoir mostly contain humic material.

TOC and DOC are commonly used as the primary surrogate parameters for measuring the concentration of DOM in natural water. The average values of TOC

were 2.43, 2.11, and 1.81 mg/L for Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River, respectively. The average values of DOC of about 2.35, 2.02, and 1.76 mg/L were obtained from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River, respectively. It indicated that TOC and DOC of reservoir waters were slightly higher than that of river water.

The DOC/TOC ratio is used to describe the phase of organic matter in the raw water. In cases of relatively high DOC/TOC ratios, the organic matter in water is present in soluble form. In case of relatively low DOC/TOC, the organic matter is present in suspended form. The DOC/TOC ratios of 0.97, 0.96, and 0.97 were observed from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River, respectively. Therefore, organic matter in water sources mainly occurred in soluble form. The values of DOC/TOC ratios were relatively high because the pore size of filter papers that was used in this study was bigger than the used in other research. According to the previous research, DOC is defined as organic compounds that were filtered through 0.45  $\mu\text{m}$  cellulose acetate membrane. In this study, organic compounds that were filtered through a 0.7  $\mu\text{m}$  GF/F filter were defined as DOC. The reason for changing the pore size and type of filter paper from 0.45  $\mu\text{m}$  cellulose acetate membrane to 0.7  $\mu\text{m}$  GF/F was to prevent the leaking of organic matter from cellulose acetate membrane into the water sample. Moreover, the 0.7  $\mu\text{m}$  GF/F can be combusted to eliminate organic contaminant from filter paper at 550 °C for 2 hours before using in the filtration process.

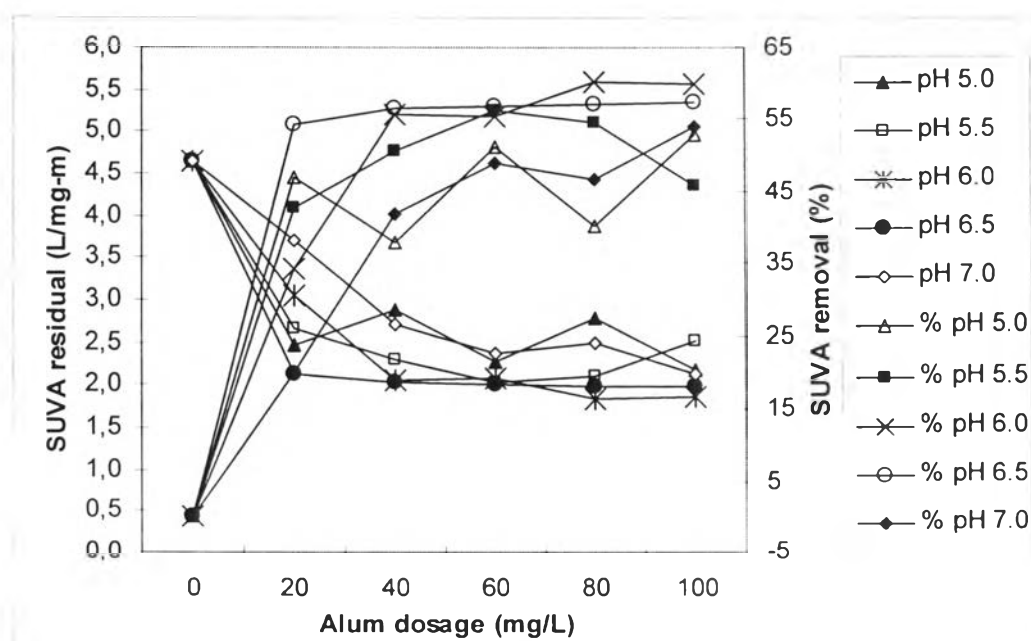
According to the slightly high level of DOM in raw water, the reaction between DOM and chlorine in the disinfection process may occur and create the carcinogens, THMs and other substances. The coagulation process, therefore, was performed in this study in order to remove DOM prior to chlorination.

#### **4.2 Reduction of SUVA by alum coagulation**

As shown in Figure 4.1, alum coagulation of 20 mg/L at a controlled pH of 6.5 could promptly reduced SUVA in the supernatant from Aung-Keaw Reservoir by approximately 54.2 percent. When comparing this value with a maximum SUVA

reduction of approximately 60.3 percent that occurred at alum dosages of up to 80 mg/L and a controlled pH of 6.0, only a 5 percent difference in reduction of SUVA was observed. Therefore, alum coagulation at 20 mg/L and a controlled pH of 6.5 could be used to reduce SUVA from Aung-Keaw Reservoir water.

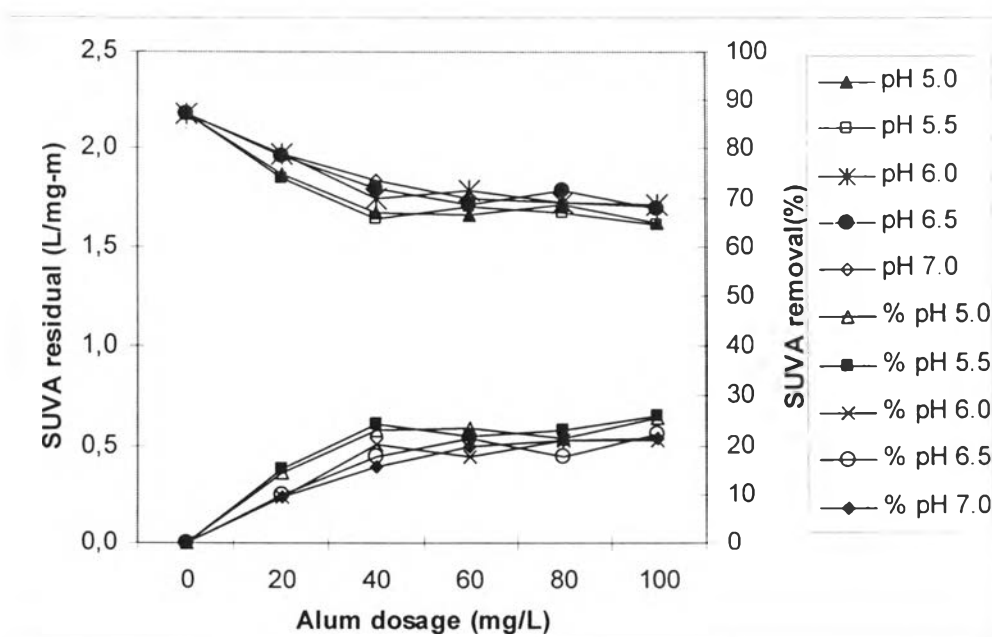
As can be seen from in Figure 4.2, the SUVA value was gradually reduced from an average value of about 2.182 L/mg-m to approximately 1.837 L/mg-m by a 40.0 mg/L dosage of alum and a controlled pH of 7.0. This condition reduced SUVA in raw water from Mae-Kuang Reservoir to about 20.0 percent while the maximum SUVA reduction of about 25.9 percent occurred at an alum dosage of 100.0 mg/L and a controlled pH of 5.5. An approximate increase of only 5.0 percent increasing in SUVA reduction when the alum dosage was raised to 100 mg/L and pH was adjusted to a low level of 5.5. When considering the SUVA values at the same pH, the SUVA values in the supernatant were significantly similar. On the contrary, when considering SUVA values at the same alum dosage, the SUVA values in supernatant were significantly different. Therefore, a 40.0 mg/L of alum dosage and a controlled pH of 7.0 could be utilized to reduce SUVA from Mae-Kuang Reservoir water.



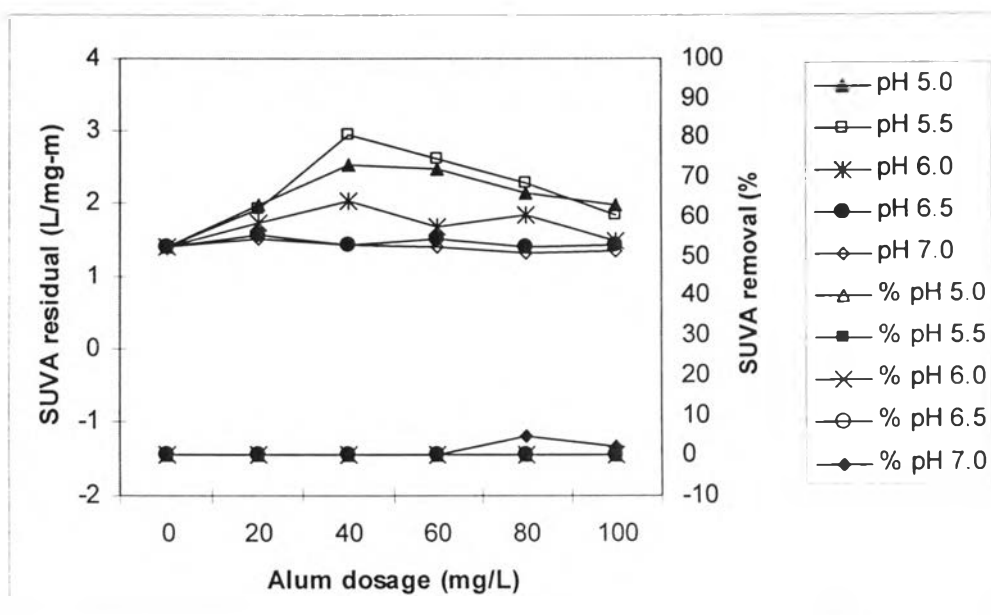
**Figure 4.1:** Residual SUVA and percentage of SUVA removal of the coagulated water from Aung-Keaw Reservoir as a function of alum dosages at different controlled pH.

From Figure 4.3, SUVA in raw water from Mae-Sa River was not reduced by alum dosage. Due to low levels of SUVA of less than 2 L/mg-m, alum coagulation could not reduce SUVA in the raw water from Mae-Sa River.

As mentioned earlier, SUVA represented the level of aromaticity, and the optimal reduction of SUVA could be used to represent the reduction of aromatic compounds. The comparison between optimal condition of SUVA and DOC reduction, which is presented in the next section was required in order to select the appropriate condition for SUVA, and DOC reduction.



**Figure 4.2:** Residual SUVA and percentage of SUVA removal of the coagulated water from Mae-Kuang Reservoir as a function of alum dosages at different controlled pH.



**Figure 4.3:** Residual SUVA and percentage of SUVA removal of the coagulated water from Mae-Sa River as a function of alum dosages at different controlled pH.

#### 4.3 Optimal condition for DOC removal by alum coagulation

As shown in Figure 4.4, alum coagulation of 60 mg/L at a controlled pH of 5.5 could promptly remove DOC in the supernatant from Aung-Keaw Reservoir by approximately 59.0 percent. When comparing this value with maximum DOC removal of about 64.7 percent, which occurred at alum dosages of up to 100 mg/L and controlled pH of 5.5, it was found that only a 5 percent difference in removal of DOC was observed. Therefore, alum coagulation at 60 mg/L of alum dosage and a controlled pH of 5.5 could remove DOC from Aung-Keaw Reservoir water.

From Figure 4.5, about 2.402 mg/L of DOC in raw water from Mae-Kuang Reservoir was promptly reduced to 1.252 mg/L by 40.0 mg/L of alum dosage and a pH value of 6.0. At this condition, the removal of 47.9 percent of DOC from the supernatant was observed. In comparison, the maximum DOC removal in the supernatant was about 56.2 percent at an alum dosage of 80 mg/L and a pH of 5.0. Only an 8 percent difference in reduction of DOC was observed. This result indicates that an alum dosage of 40 mg/L and a controlled pH of 6.0 could be appropriately used to reduce DOC from Mae-Kuang Reservoir water.

As shown in Figure 4.6, alum coagulation of 40.0 mg/L at a controlled pH of 6.0 could promptly remove DOC in the supernatant from Mae-Sa River by approximately 61.3 percent. In comparison with maximum DOC removal in the supernatant which was approximately 69.1 percent at alum dosages of up to 100 mg/L and a controlled pH of 5.0. It was shown that the percent reduction of these two conditions were slightly different. These results indicated that alum coagulation at a dosage of 40 mg/L and a controlled pH of 6.0 could be used to reduce DOC from raw water.

The optimal conditions of alum coagulation in raw water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River were observed at dosage of 60 mg/L with a pH of 5.5, a dosage of 40 mg/L with a pH of 6.0, and a dosage of 40 mg/L with a pH of 6.0, respectively.

The optimal condition of alum coagulation of DOM removal has been demonstrated to occur at pH values of between 5.0 and 6.0 (White, Thompson, Harrington et al., 1997). Similarly, in this study, the optimal pH for raw waters from Aung-Keaw Reservoir, Mae-Kuang Reservoir and Mae-Sa River were also in range of between 5.0 and 6.0.

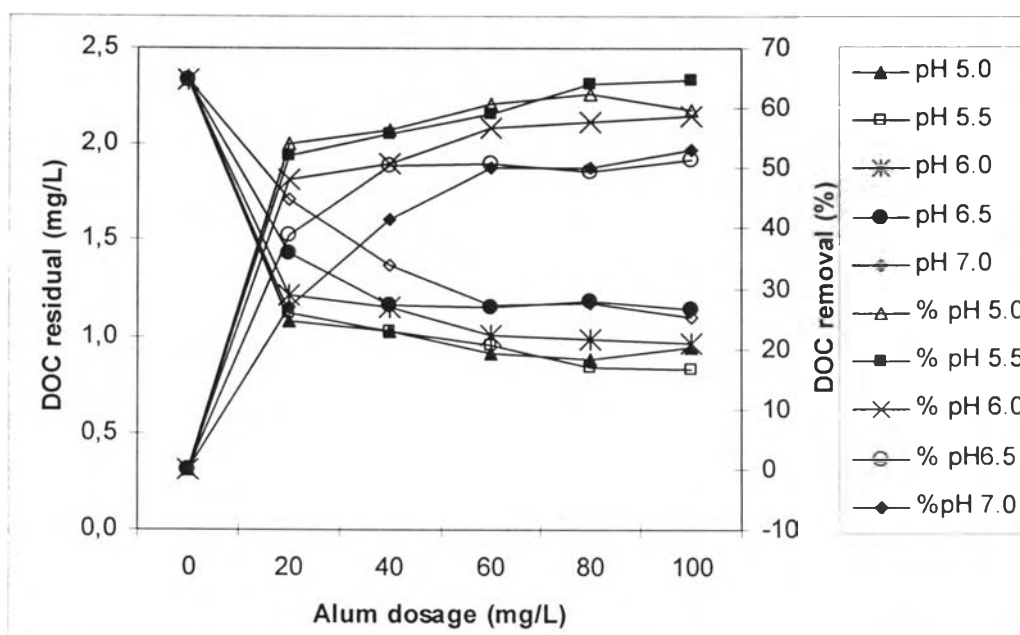
The main mechanism of alum coagulation for removing DOM in raw water was the absorption of DOM onto aluminum hydroxide floc. According to the complexity of DOM components in raw water, some organic compounds were affinity to absorb onto the floc whereas the other organic compounds dissolved in raw water. As can be seen in Figures 4.4 to 4.6, although alum dosage was increased the residual DOC concentration in supernatant remained in a steady state. The residual SUVA values were also steady. It indicated that the remaining DOM in the raw water was more likely to dissolve in raw water. Due to the studied of Amy, Sierka, Bedessem et al. (1992) and Randtke (1988), it was found that alum coagulation reduced humic substances (hydrophobic) and high molecular weight organic matters better than non-humic substances (hydrophilic) and low molecular weight organic matters. Therefore, the remaining organic compounds might be non-humic substances or low molecular weight organic matters.

Enhanced coagulation according to USEPA (1998) is presented in Table 2.10. In cases of the DOC in raw water at between >2.0-4.0 mg/L and an alkalinity of about 0-60 mg/L as CaCO<sub>3</sub>, the water treatment process was required to remove 40 percent of DOC. Water samples from Aung-Keaw Reservoir and Mae-Kuang Reservoir have the DOC and alkalinities that fall into this range. DOC reduction at optimal condition could be achieved at more than 40 percent. Therefore, in this study organic matter in raw water from Aung-Keaw Reservoir and Mae-Kuang Reservoir was removed. In cases of raw water from Mae-Sa River, which has DOC values of less than 2 mg/L, there was no reduction requirement for this condition.

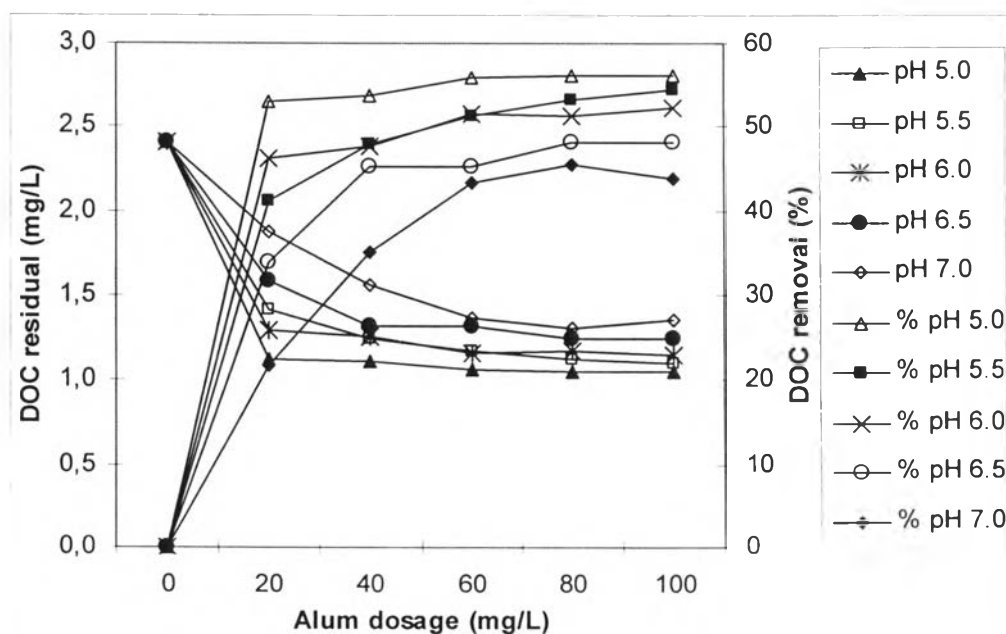
Temperature is not expected to significantly influence the extent to which organics are removed. (Randtke, 1988). In this study, the raw waters temperatures ranged from 19 to 24 °C. Knocke, West, and Hoein (1986) stated that in cases of temperature varying from 2 to 22 °C in the coagulation process, the efficiency of TOC removal was not significantly affected. In this study, the obtained result showed no difference in DOC removal.

Finally, the conclusion in this part could be drawn that the optimal condition for DOC removal could be also used to reduce SUVA. Moreover, as previously known, DOC represented the nature of DOM including humic and non-humic material. Therefore the optimal condition was selected from DOC removal to conduct further experiments.

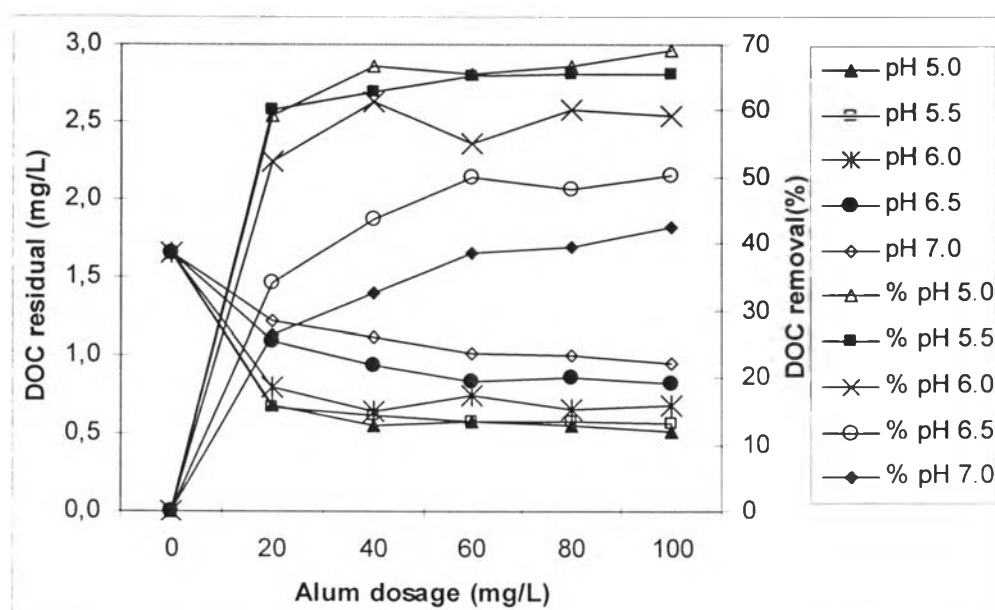




**Figure 4.4:** Residual DOC and percentage of DOC removal in the coagulated water of Aung-Keaw Reservoir as a function of alum dosages and different controlled pH.



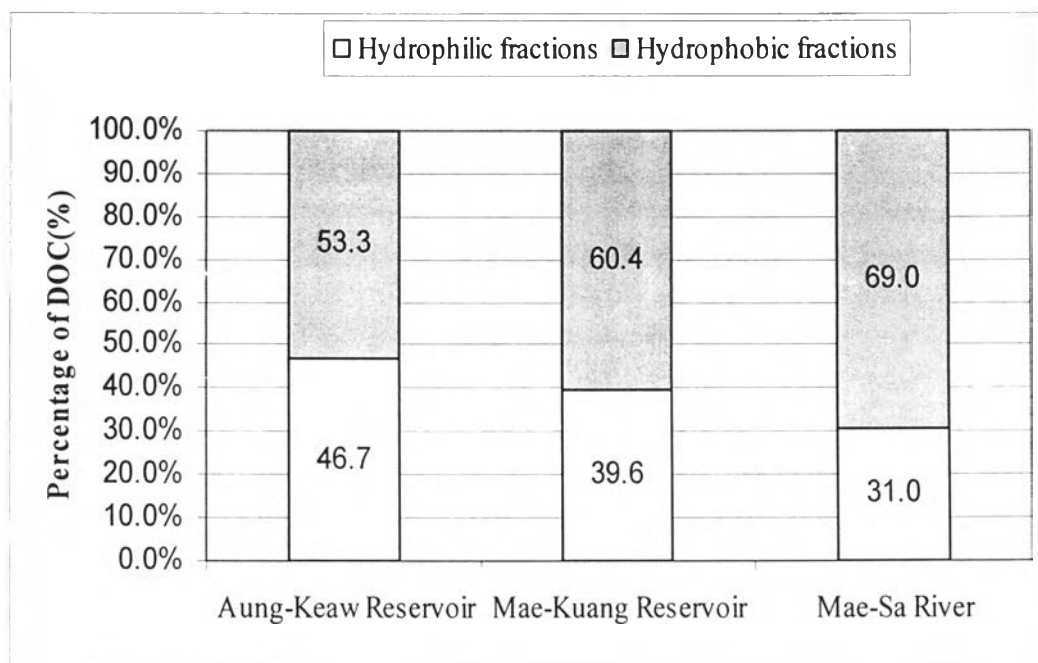
**Figure 4.5:** Residual DOC and percentage of DOC removal in the coagulated water of Mae-Kuang Reservoir as a function of alum dosages and different controlled pH.



**Figure 4.6:** Residual DOC and percentage of DOC removal in the coagulated water of Mae-Sa River as a function of alum dosages and different controlled pH.

#### 4.4. Mass distribution of DOM in terms of DOC in raw waters and coagulated water.

DOM can be separated into hydrophilic (non-humic substance) and hydrophobic (humic substance) fractions. The percentage distributions of hydrophilic and hydrophobic fractions are shown in Figure 4.7. Hydrophilic fractions in raw water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa river were 46.7, 39.6, and 31.0 percent by weight of total DOC, respectively, whereas hydrophobic fractions in raw water from Aung-Keaw Reservoir, Mae-Kuang, and Mae-Sa River accounted for 53.3, 60.4, and 69.0 percent by weight of total DOC, respectively. The results show that the hydrophobic fraction was the major DOM in all three sources of natural water. The obtained results implied that hydrophobic DOMs in the three sources of natural waters were considerably higher than the hydrophilic DOMs. Finally, it can be implied that the three sources of natural water were contaminated with humic and fulvic acid or with high molecular weight organic matters.



**Figure 4.7:** Hydrophilic and hydrophobic dissolved organic matter fractions in term of DOC in raw water.

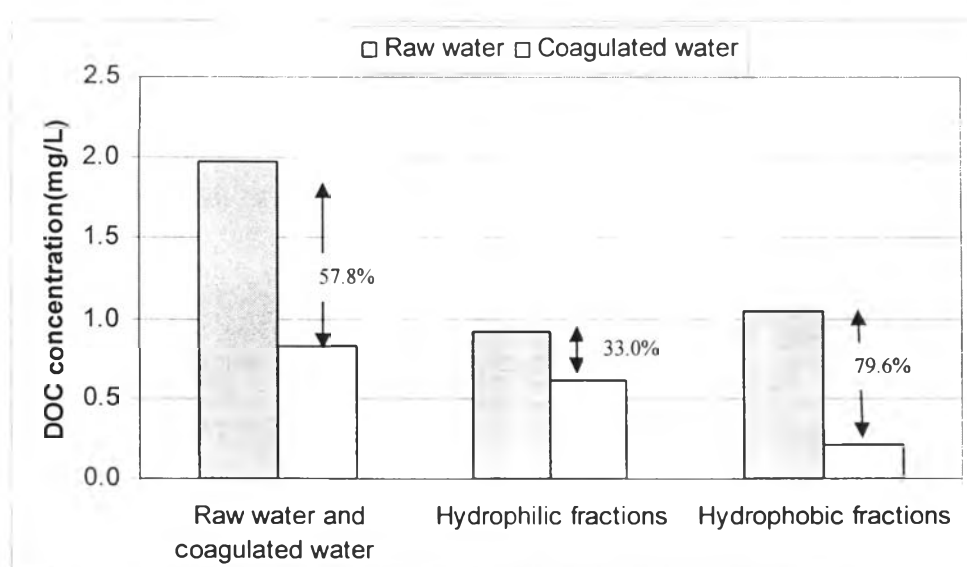
As can be seen in Figure 4.8, alum coagulation at optimal condition could be used to remove DOC from raw water of Aung-Keaw Reservoir by about 57.8 percent in terms of DOC concentration. More detailed consideration of results from the raw water from Aung-Keaw Reservoir show that 33.0 percent in terms of DOC concentration by alum coagulation at optimal condition of the hydrophilic fraction was removed whereas about 79.6 percent of the hydrophobic fraction was removed.

From figure 4.9, 41.2 percent of DOC in raw water from Mae-Kuang Reservoir was removed by alum coagulation at optimal condition. In terms of organic fraction, 27.6 percent in terms of DOC concentration of the hydrophilic fraction was removed about whereas approximately 50.2 percent of the hydrophobic fraction was removed.

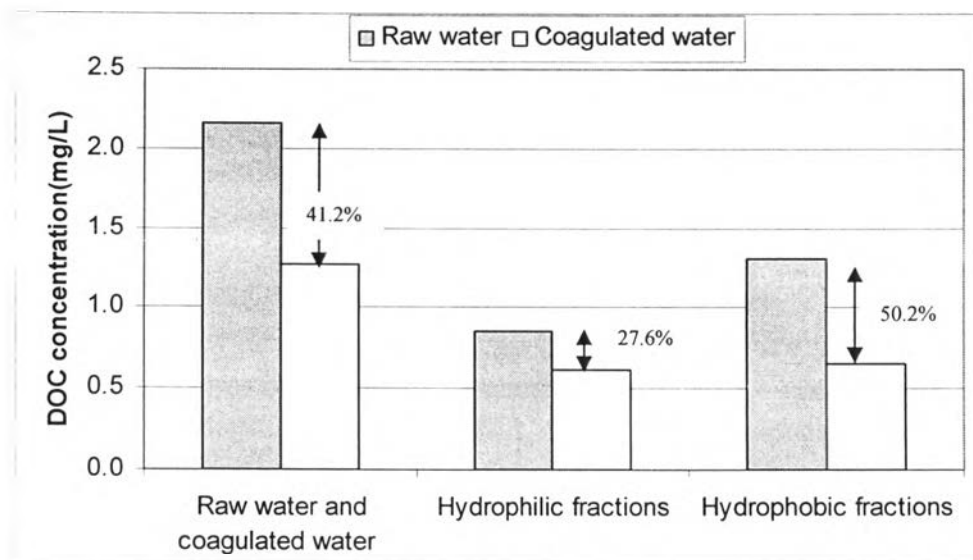
As shown in Figure 4.10, alum coagulation at optimal condition removed DOC in raw water from Mae-Sa River by about 70.8 percent in terms of DOC concentration. 50.9 percent in terms of DOC concentration of the Hydrophilic fraction in raw water from Mae-Sa River was removed whereas the hydrophobic fraction was reduced by about 79.9 percent. From the obtained results, it is notified that the

hydrophobic fraction could be easily removed by alum coagulation, while the hydrophilic fraction was slightly difficult to remove by alum coagulation. The highest value of hydrophobic fractions removal was observed from Mae-Sa River.

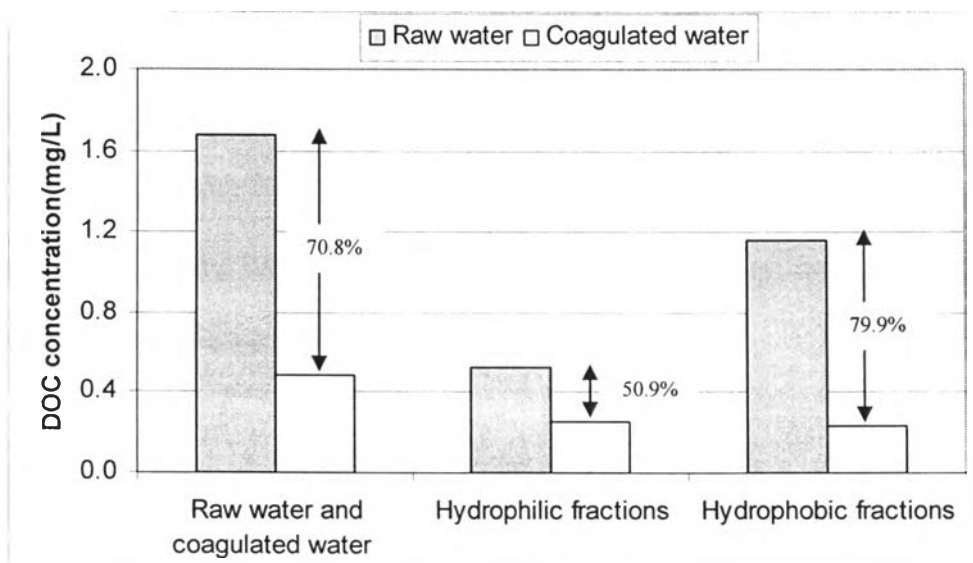
According to studies by Amy, Sierka, Bedessem et al. (1992) and Randtke (1988), alum coagulation reduced humic substances (hydrophobic) and high molecular weight organic matters better than non-humic substances (hydrophilic) and low molecular weight organic matters. Similarly, in this study, hydrophobic fractions in raw waters from the three natural water sources were removed more easily than hydrophilic fractions by alum coagulation at optimal condition.



**Figure 4.8:** Hydrophilic and hydrophobic dissolved organic matter fractions in term of DOC in raw water and coagulated water from Aung-Keaw Reservoir.



**Figure 4.9:** Hydrophilic and hydrophobic dissolved organic matter fractions in term of DOC in raw water and coagulated water from Mae-Kuang Reservoir.



**Figure 4.10:** Hydrophilic and hydrophobic dissolved organic matter fractions in term of DOC in raw water and coagulated water from Mae-Sa River.

The mass distributions of DOC in raw waters and coagulated waters are presented in Table 4.2. The percentages of difference between DOC mass before fractionation and DOC mass after fractionation in raw water from Aung-Keaw Reservoir, Mae-Kuang Reservoir and Mae-Sa River were -9.2, +4.7, and +8.4 percent, respectively, whereas the percentages of difference between DOC mass before and after fractionation in raw water and in coagulated water were -9.8, +7.1, and +8.9 percent, respectively. According to Day., (1991) and Croue, Martin, Simon et al. (1993), the tolerance ranges of fractionation mass balance were between 10 and 15 percent and between 8 and 12 percent, respectively. In cases of surplus, it can be stated that the organic substance in Milli-Q water during the cleaning process could be adsorbed into the resin and eluted in the eluted process. This was the reason why the mass of DOC after fractionation was higher than that of before fractionation. In negative cases, it came from the effectiveness of the elution. Some organic matters still absorbed on the resin.

**Table 4.2:** Mass distribution of DOM in raw water and coagulated water

Source of Raw waters	Parameters	Fractionation									
		Raw water					Coagulated water				
		HPL <sup>1</sup>	HPB <sup>2</sup>	HPL+HPB	Total <sup>3</sup>	percent diff <sup>4</sup>	HPL <sup>1</sup>	HPB <sup>2</sup>	HPL+HPB	Total <sup>3</sup>	percent diff <sup>4</sup>
Aung-Keaw Reservoir	DOC (mg/L)	0.922	1.052	1.974	2.173	-9.2	0.618	0.215	0.833	0.924	-9.8
	DOC (mg)	9.22	10.52	19.74	21.73	-9.2	6.18	2.15	8.33	9.24	-9.8
Mae-Kuang Reservoir	DOC (mg/L)	0.858	1.308	2.166	2.107	+4.7	0.621	0.652	1.273	1.230	+7.1
	DOC (mg)	4.19	6.38	10.57	10.28	+4.7	3.10	3.26	6.36	6.150	+7.1
Mae-Sa River	DOC (mg/L)	0.521	1.157	1.678	1.588	+8.4	0.256	0.233	0.489	0.470	+8.9
	DOC (mg)	2.65	5.88	8.52	8.07	+8.4	1.28	1.16	2.44	2.35	+8.9

<sup>1</sup>HPL=Hydrophilic fraction, <sup>2</sup>HPB=Hydrophobic fraction, <sup>3</sup>Total of DOC before fractionation, <sup>4</sup> percentdiff= $((\text{Total}-(\text{HPL}+\text{HPB}))/\text{Total})\times 100$

#### **4.5 Reduction of trihalomethane formation potential by alum coagulation.**

As can be seen from Table 4.3, THMFP value of raw water from Aung-Keaw Reservoir was 403.12  $\mu\text{g/L}$  while a THMFP of 146.00  $\mu\text{g/L}$  was observed from coagulated water. From Figure 4.14 the optimal condition for alum coagulation reduced THMFP by about 63.8 percent by weight of total THMFP.

With more detailed consideration, THMFP values of hydrophobic and hydrophilic fractions of raw water were 162.30 and 275.09  $\mu\text{g/L}$ , respectively while THMFP of 92.30 and 86.60  $\mu\text{g/L}$  were observed from hydrophilic and hydrophobic fractions of coagulated water, respectively. The optimal condition could remove 43.1 and 68.5 percent of THMFP by weight of hydrophilic fraction and hydrophobic fraction, respectively.

From Table 4.3, THMFP value of raw water from Mae-Kuang Reservoir was 235.87  $\mu\text{g/L}$  while a THMFP of 142.80  $\mu\text{g/L}$  was observed from coagulated water. From the Figure 4.11 the optimal condition for alum coagulation reduced THMFP to about 39.5 percent by weight of total THMFP.

With more detailed consideration, THMFP values of hydrophobic and hydrophilic fractions of raw water were 124.61 and 156.82  $\mu\text{g/L}$ , respectively while THMFP of 96.32 and 101.22  $\mu\text{g/L}$  were observed from hydrophilic and hydrophobic fractions of coagulated water, respectively. The optimal condition removed 22.7 and 35.4 percent of THMFP by weight of hydrophilic fraction and hydrophobic fraction, respectively.

From the Table 4.3, THMFP value of raw water from Mae-Sa River was 112.36  $\mu\text{g/L}$  while a THMFP of 63.17  $\mu\text{g/L}$  was observed from coagulated water. From Figure 4.13 the optimal condition for alum coagulation reduced THMFP by about 43.8 percent by weight of total THMFP.

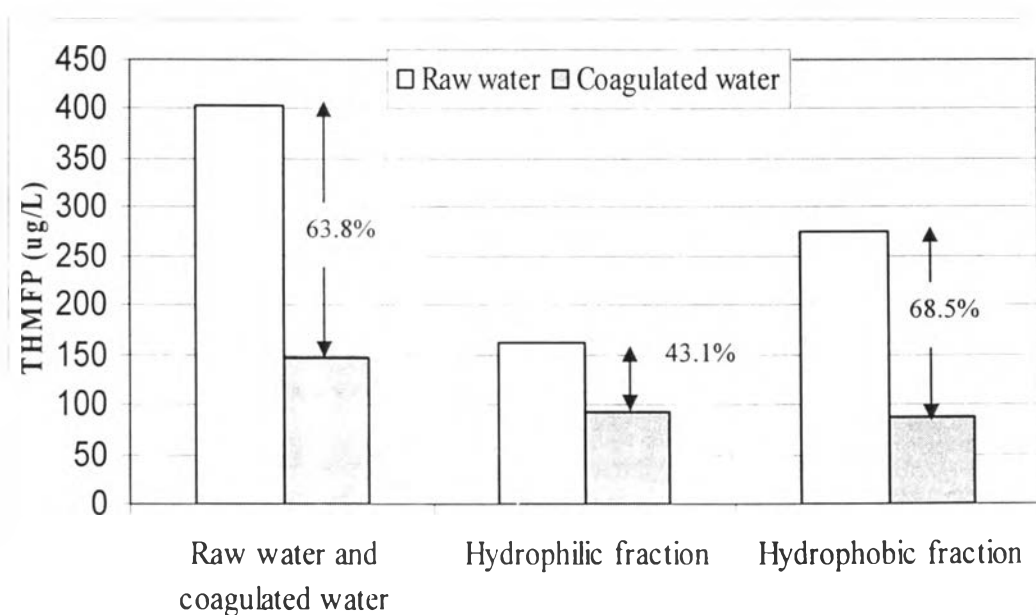
With more detailed consideration, THMFP values of hydrophobic and hydrophilic fractions of raw water were 77.00 and 62.58  $\mu\text{g/L}$ , respectively while



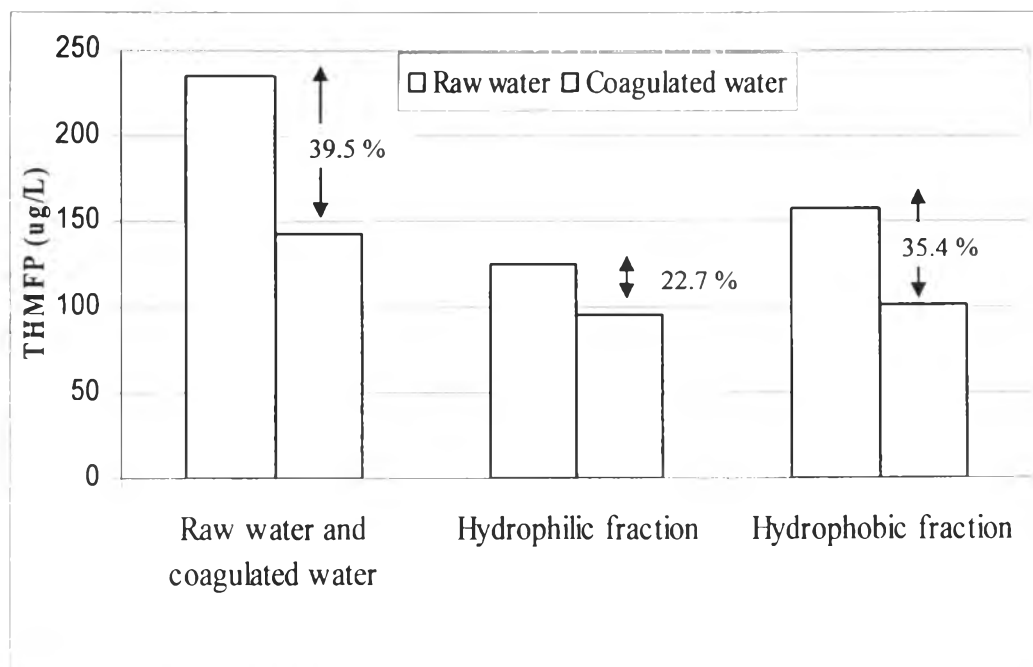
THMFP of 57.19 and 35.62  $\mu\text{g/L}$  were observed from hydrophilic and hydrophobic fractions of coagulated water, respectively. The optimal condition removed about 25.7 and 43.1 percent of THMFP by weight of hydrophilic fraction and hydrophobic fraction, respectively.

THMFP values of hydrophobic fractions in each water source were higher than THMFP values of hydrophilic fractions. Similarly, the studied by of Galapate, Baes, Ito et al. (1999) and Lin, Lin, and Hao (2000), it was found that hydrophobic fractions created THMFP higher than hydrophilic fractions. After coagulation, THMFP of hydrophobic fractions was reduced more than the THMFP of hydrophilic fractions. Due to the reduction in complexity of organic matter in fractionated water, the creation of THMFP in fractionated water was higher than the creation of THMFP in raw water and coagulated water.

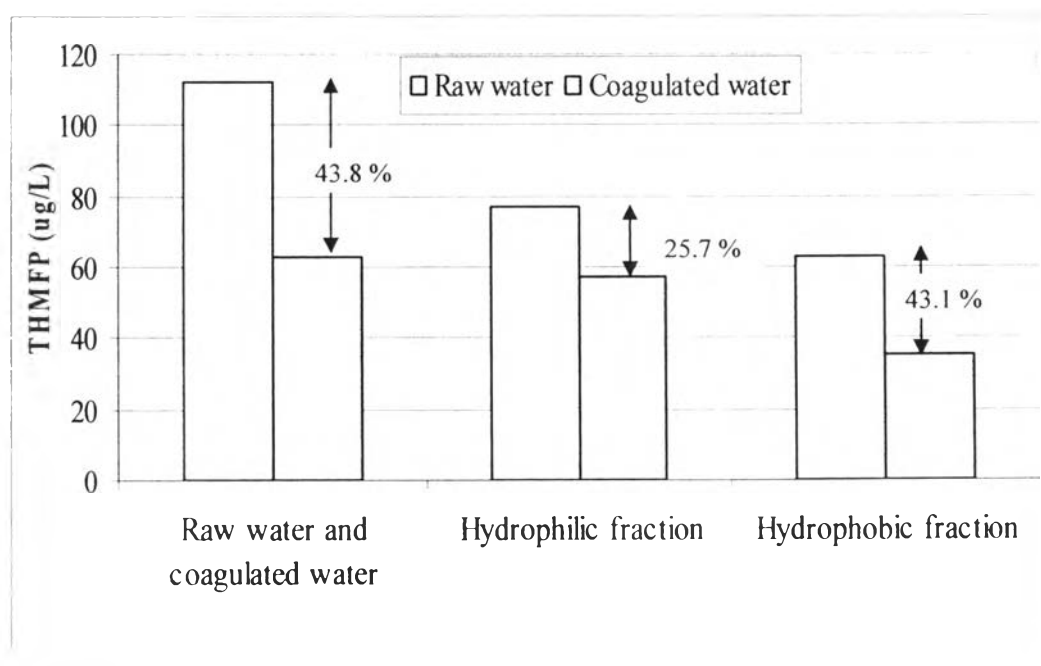
Moreover, chloroform, dichlorobromomethane, and dibromochloromethane were the THMFP species observed in this study. However, chloroform was the major THMFP species while dichlorobromomethane and dibromochloromethane were found in minority.



**Figure 4.11:** THMFP of raw water, coagulated water, and their fractionated water from Aung-Keaw Reservoir.



**Figure 4.12:** THMFP of raw water, coagulated water, and their fractionated water from Mae-Kuang Reservoir.



**Figure 4.13:** THMFP of raw water, coagulated water, and their fractionated water from Mae-Sa River.

**Table 4.3:** THMFP values of raw water, coagulated water, and their fractionated water.

Sources	Type	Type	THMFP ( $\mu\text{g/L}$ )			
			Chloroform	Bromodichloromethane	Chlorodibromomethane	THMs
Aung-Keaw Reservoir	Raw water	Total	371.88	20.13	11.10	403.12
		Hydrophilic	137.00	13.70	11.30	162.30
		Hydrophobic	257.70	4.70	12.50	275.09
	Coagulated water	Total	125.60	15.00	5.00	146.00
		Hydrophilic	71.70	12.62	7.96	92.30
		Hydrophobic	73.50	4.33	8.80	86.60
Mae-Kuang Reservoir	Raw water	Total	213.58	15.38	6.90	235.87
		Hydrophilic	107.94	13.00	3.66	124.61
		Hydrophobic	142.16	0.00	2.20	156.82
	Coagulated water	Total	122.14	11.99	8.65	142.80
		Hydrophilic	77.76	11.63	6.92	96.32
		Hydrophobic	95.39	0.00	0.00	101.22
Mae-Sa River	Raw water	Total	93.60	11.65	7.01	112.36
		Hydrophilic	69.00	8.00	0.00	77.00
		Hydrophobic	62.58	0.00	0.00	62.58
	Coagulated water	Total	53.13	8.42	1.57	63.17
		Hydrophilic	47.24	8.35	1.66	57.19
		Hydrophobic	35.62	0.00	0.00	35.62

#### 4.6 Specific THMFP

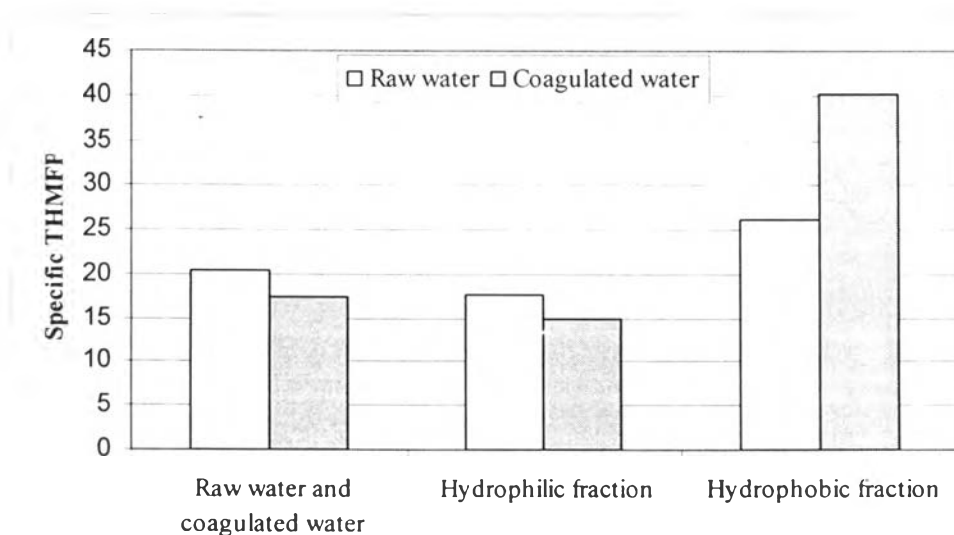
The specific THMFP was the ratio between THMFP and DOC of each water sample. Specific THMFP provides an indication of the potential of the organic carbon in water to react with chlorine to form THMs.

As can be seen from Figure 4.14, which presents the specific THMFP of water samples from Aung-Keaw Reservoir, the specific THMFP of raw water was lower than the specific THMFP of its hydrophobic fraction, while the specific THMFP of raw water was higher than that of its hydrophilic fraction. In the case of coagulated water, the value of specific THMFP of the hydrophobic fraction was also higher than that of coagulated water before fractionation and its hydrophilic fraction. Therefore, it can be stated that the hydrophobic fraction in water from Aung-Keaw Reservoir was slightly more reactive with chlorine to form THMs.

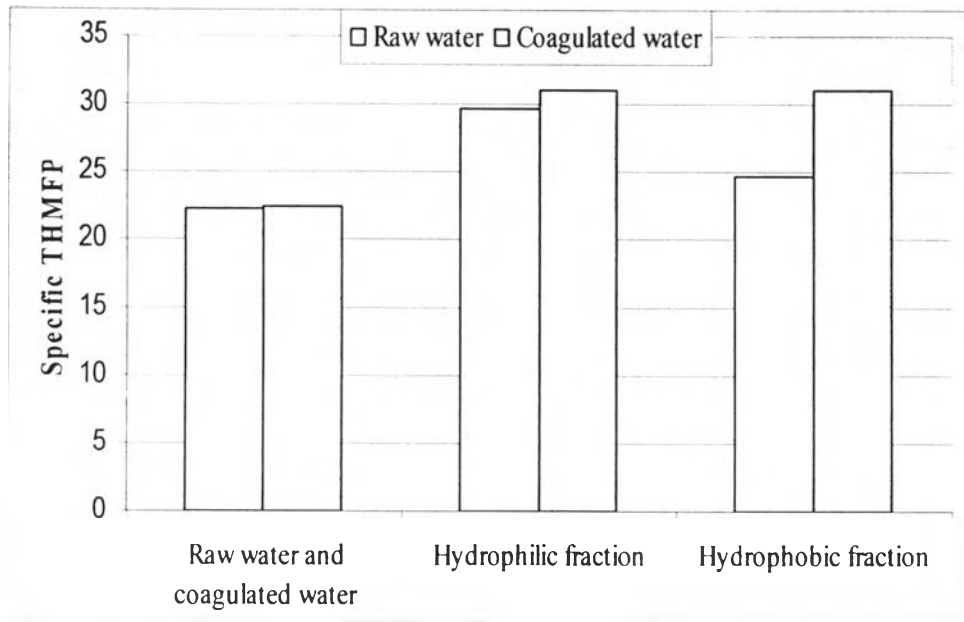
From Figure 4.15, which shows the specific THMFP of water samples from Mae-Kuang Reservoir, the value of specific THMFP of raw water was less than the specific THMFP of its hydrophobic fraction and its hydrophilic fraction. The result from coagulated water showed that the value of specific THMFP of coagulated water was also lower than its hydrophobic and hydrophilic fractions. Therefore, it can be stated that water samples after the fractionation process were slightly more reactive with chlorine to form THMs.

As can be seen from Figure 4.16, which presents the specific THMFP of water samples from Mae-Sa River, the specific THMFP of raw water was higher than the specific THMFP of its hydrophobic fraction while the specific THMFP of raw water was lower than that of its hydrophilic fraction. In the case of coagulated water, the value of the specific THMFP of the hydrophilic fraction was also higher than that of coagulated water and its hydrophobic fraction. Therefore, it can be stated that the hydrophilic fraction in water from Mae-Sa River was slightly more reactive with chlorine to form THMs.

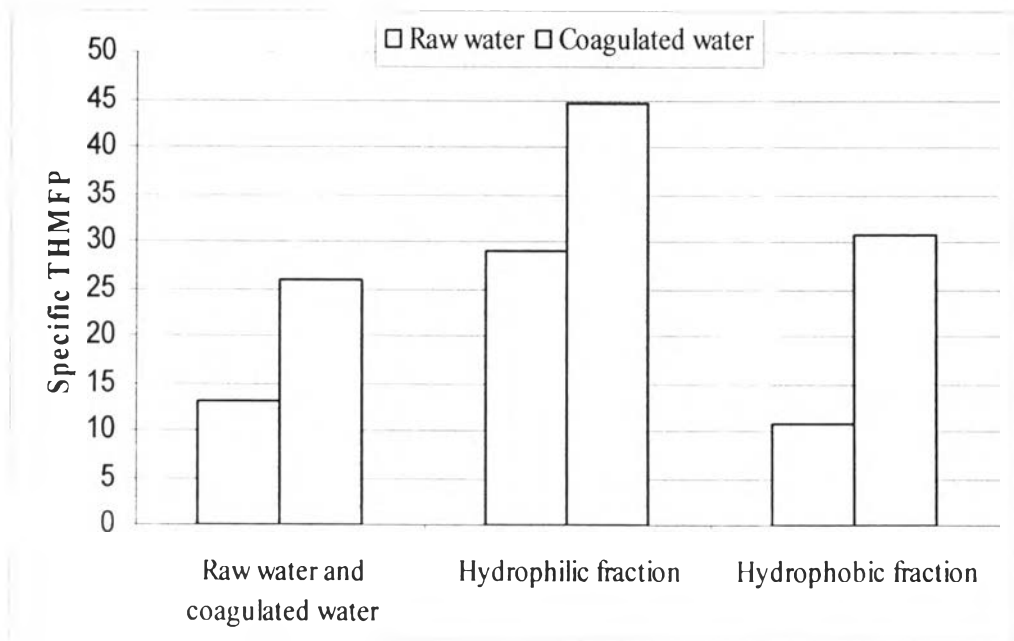
After alum coagulation, the hydrophobic fractions from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River were slightly more reactive with chlorine to form THMs. It might be due to the fact that the coagulation process largely removed DOC in terms of its hydrophobic fractions and therefore the hydrophobic fraction in coagulated water could be present in a low level. However, at this low level, the hydrophobic fraction, which was slightly more reactive with chlorine, still reacts with chlorine to form THMs. Moreover, the hydrophilic fractions from Mae-Kuang Reservoir and Mae-Sa River were also slightly more reactive with chlorine to form THMs. It might be due to the fact that the coagulation process could not remove the hydrophilic fraction. Therefore, the hydrophilic fractions still reacted with chlorine to form THMs



**Figure 4.14:** Specific THMFP of raw water, coagulated water, and their fractionated water from Aung-Keaw Reservoir.



**Figure 4.15:** Specific THMFP of raw water, coagulated water, and their fractionated water from Mae-Kuang Reservoir.



**Figure 4.16:** Specific THMFP of raw water, coagulated water, and their fractionated water from Mae-Sa River.

#### **4.7 Changes of EEM signatures of total hydrophilic and hydrophobic fractions in raw water and coagulated water.**

EEM signatures of raw water, coagulated water, and their hydrophilic and hydrophobic fractions from Aung-Keaw and Mae-Kuang Reservoir, and Mae-Sa River are presented in Figures 4.17, 4.18, and 4.19, respectively.

The EEM signatures were determined by using EEM spectra of water samples that were subtracted with EEM spectra of Milli-Q water. As previously known, the fluorescent intensity at 1 ppb of quinine sulfate was equal to 1 quinine sulfate unit (QSU). The EEM results are presented in the contours interval of 2 QSU because at this contour interval, it is very clear for observation of the EEM peaks.

As can be seen from Figure 4.17, 4.18, and 4.19, two broad lines are present in the EEM signatures. These lines were created from the emission of water at different excitation wavelengths. However, the level of fluorescent intensities depends upon the level of organic substances in the water. In cases of high organic content in water the high value of fluorescent intensities are observed, whereas in cases of low organic content, low values of fluorescent intensities are obtained.

As can be seen in Figure 4.17, which presents EEM signatures of raw water, coagulated water, and their hydrophilic and hydrophobic fractions of water from Aung-Keaw Reservoir, raw water exhibited EEM peaks at 260 nm/460 nm (Excitation / Emission) and 310 nm/400 nm while coagulated water also exhibited two peaks at these same positions. However, as can be seen in Table 4.4 which presents fluorescent intensities at peak position of raw waters, coagulated waters, and their fractionated waters from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River, the fluorescent intensities of raw water were higher than that of coagulated water. It could be implied that the coagulation process could remove some portions of organic substances, which have the EEM peak position at 260 nm/460 nm (Excitation/Emission) and 310 nm/400 nm. However, coagulated water still contains organic substances that could exhibit the EEM peak at the same position

460 nm and 330 nm/ 440 nm which were the same positions as the EEM peak of raw water, while the EEM peak at the 260 nm/460 nm was observed from hydrophilic fraction.

As shown in Figure 4.18, which presents EEM of raw water, coagulated water, and their hydrophilic and hydrophobic fractions of Mae-Kuang Reservoir, raw water exhibited the EEM peaks at 260 nm/460 nm and 310 nm/400 nm whereas coagulated water also exhibited the fluorescent intensities at these same peak positions. Moreover, the fluorescent intensities of coagulated water were less than that of raw water.

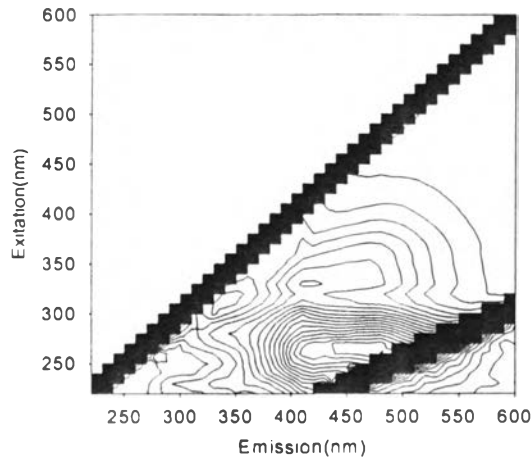
In terms of DOM fractions, hydrophobic fractions of raw water from Mae-Kuang Reservoir, which were the major DOM fractions, exhibited the EEM peaks at the 260 nm/460 nm and 310 nm/400 nm and these were similar to the EEM peak positions of raw water, while an EEM peak at 260 nm/460 nm was observed from hydrophilic fraction.

As illustrated in Figure 4.19. which presents EEM signatures of raw water, coagulated water, and their hydrophilic and hydrophobic fractions of Mae-Sa River water, raw water established the EEM peaks at 270 nm/450 nm and 340 nm/440 nm while coagulated water exhibited the EEM peaks at the same positions of raw water. In addition, the fluorescent intensities of raw water were higher than those of coagulated water.

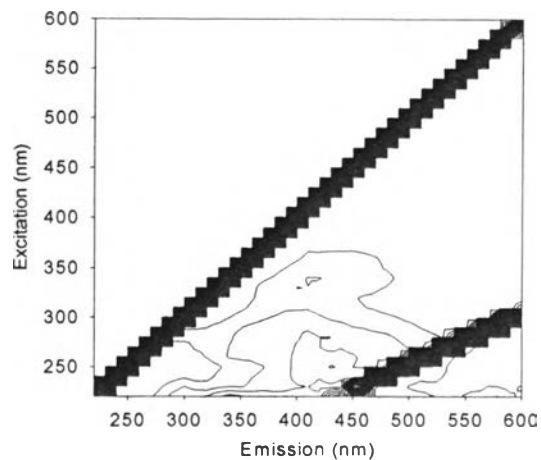
Regarding the DOM fractions, for the hydrophobic fraction of raw water, which was the major DOM fraction, there was no EEM peak exhibited. The hydrophilic fraction did also not exhibit the EEM peak.

In conclusion, it can be stated that EEM signatures could be used to monitor the major DOM fractions in water sources by determining peak position and fluorescent intensity. Moreover, the EEM of each water source was located in the same positions which were in the region of humic acid-like substances (Chen, Westerhoff, Leenheer et al., 2003). It implies that humic acid groups were the major organic compounds in the water sources.

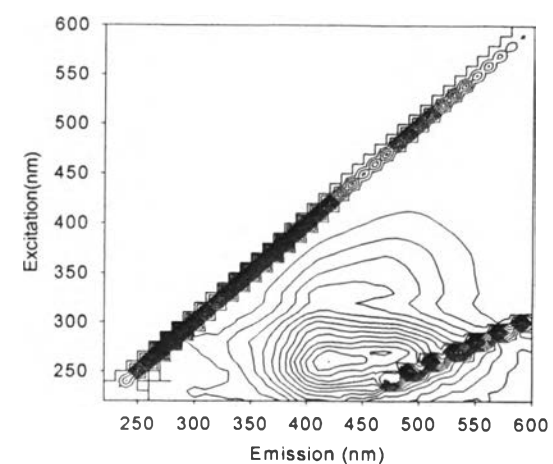




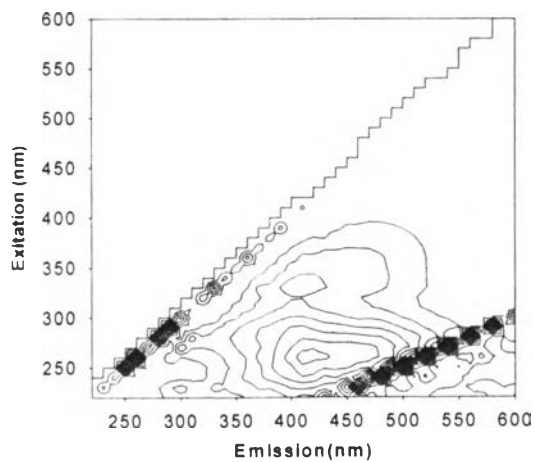
(a) Raw water



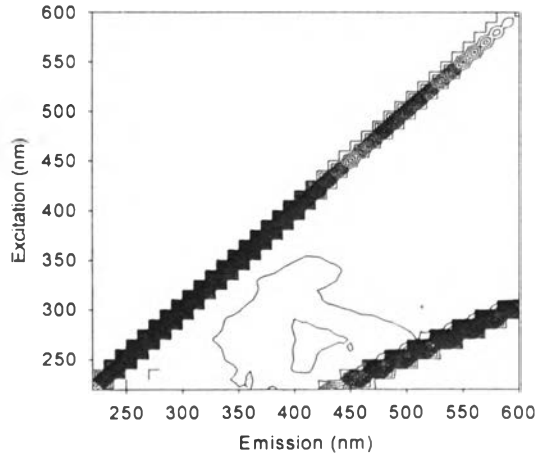
(b) Hydrophilic DOM fraction of raw water



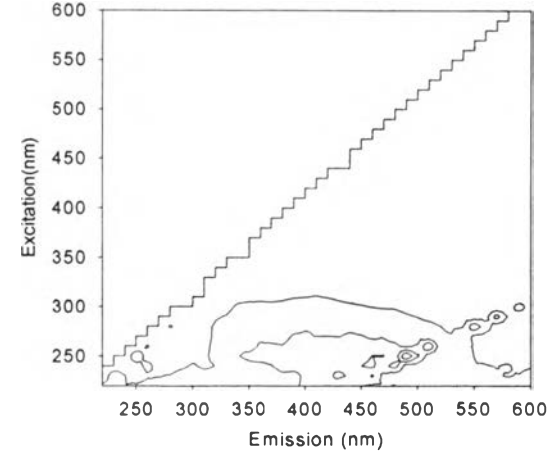
(c) Hydrophobic DOM fraction of raw water



(d) Coagulated water



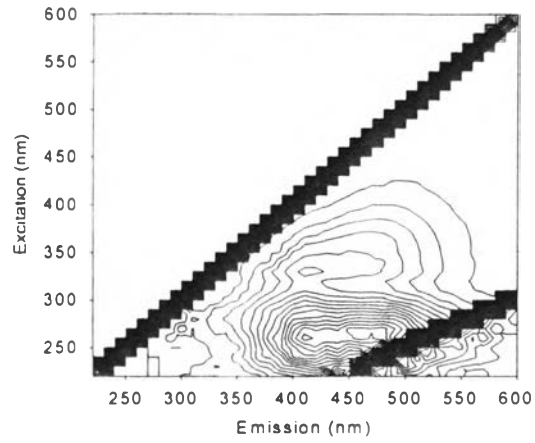
(e) Hydrophilic DOM fraction of coagulated water



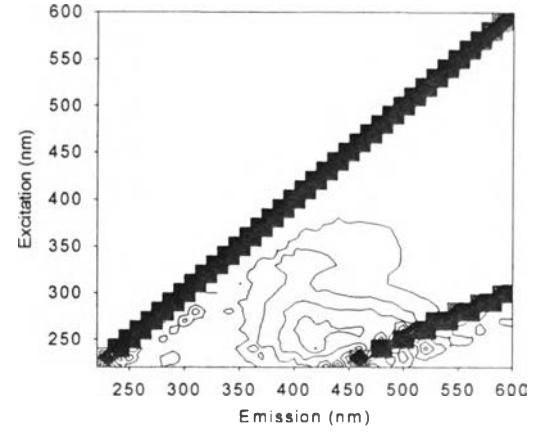
(f) Hydrophobic DOM fraction of coagulated water

**Figure 4.17:** EEM signatures of raw water, coagulated water, and their fractionated water from Aung-Keaw Reservoir

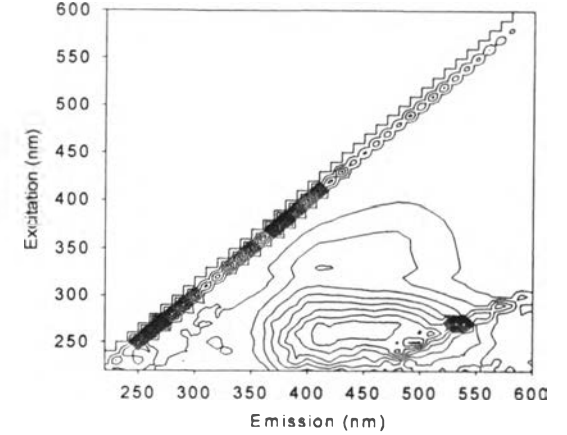
presented with contour interval of 2 QSU



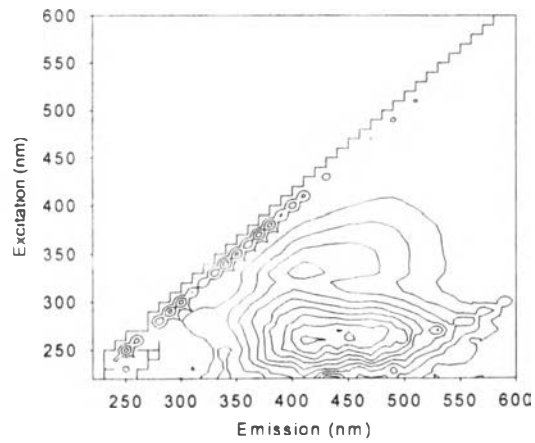
(a) Raw water



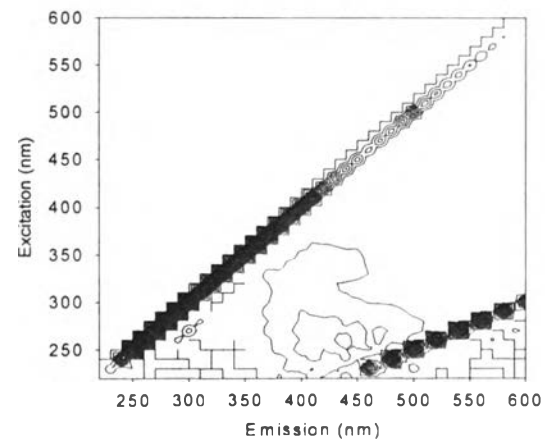
(b) Hydrophilic DOM fraction of raw water



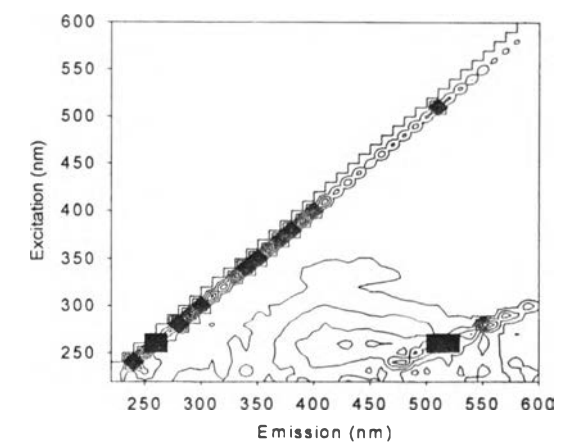
(c) Hydrophobic DOM fraction of raw water



(d) Coagulated water

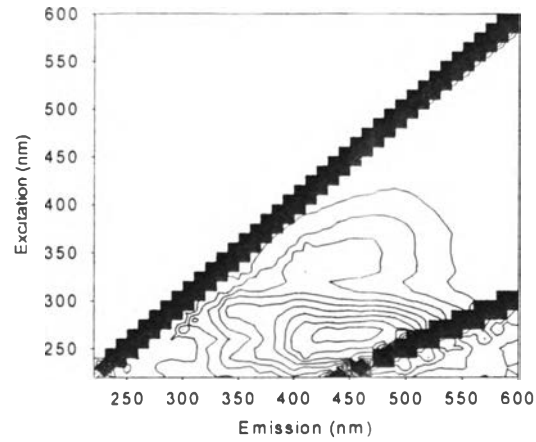


(e) Hydrophilic DOM fraction of coagulated water

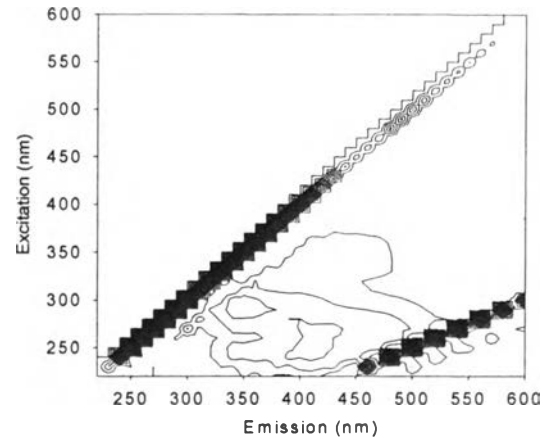


(f) Hydrophobic DOM fraction of coagulated water

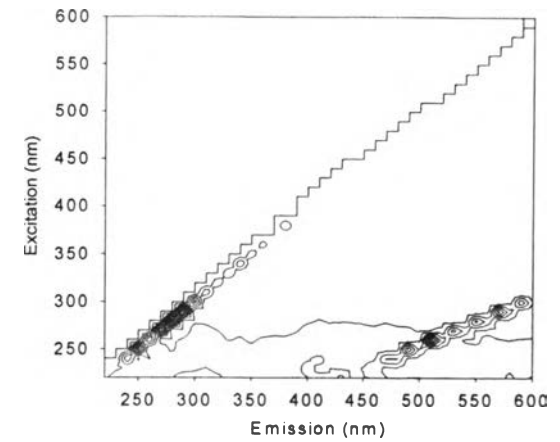
**Figure 4.18:** EEM signatures of raw water, coagulated water, and their fractionated water from Mae-Kuang Reservoir presented with contour interval of 2 QSU



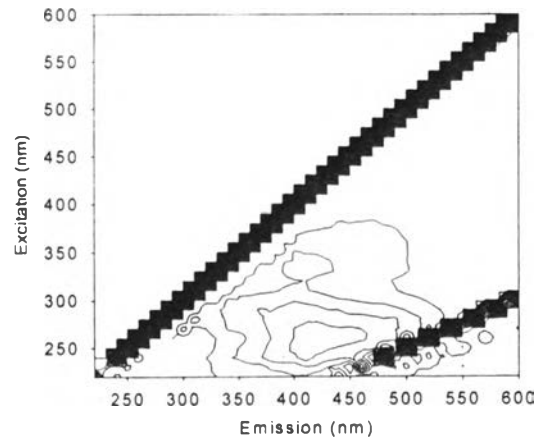
(a) Raw water



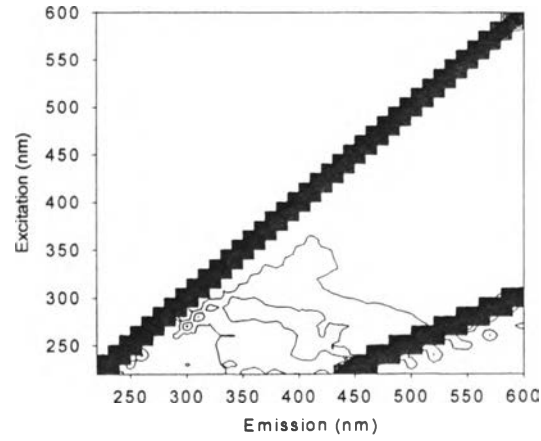
(b) Hydrophilic DOM fraction of raw water



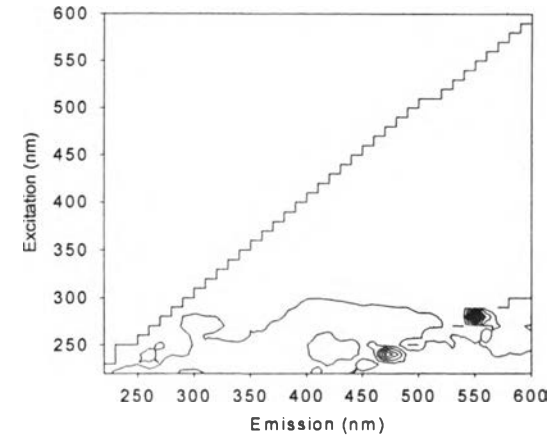
(c) Hydrophobic DOM fraction of raw water



(d) Coagulated water



(e) Hydrophilic DOM fraction of coagulated water



(f) Hydrophobic DOM fraction of coagulated water

**Figure 4.19:** EEM of raw water, coagulated water, and their fractionated water from Mae-Sa River presented with contour interval of 2 QSU

**Table 4.4.** Fluorescent intensity at peak positions of raw water, coagulated water and their fractionated water from Aung-Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River

Source	Type	Fluorescent Intensity at Peak Position (Excitation: nm/Emission: nm), QSU					
		260/460	330/440	260/460	310/400	270/450	340/440
Aung-Keaw Reservoir	Raw water	36.41	13.89				
	Hydrophilic DOM	7.40	ND.				
	Hydrophobic DOM	18.73	7.78				
	Coagulated water	13.30	5.65				
	Hydrophilic DOM	ND.	ND.				
	Hydrophobic DOM	ND.	ND.				
Mae-Kuang Reservoir	Raw water			30.84	10.71		
	Hydrophilic DOM			8.39	ND.		
	Hydrophobic DOM			17.25	5.89		
	Coagulated water			17.74	8.18		
	Hydrophilic DOM			ND.	ND.		
	Hydrophobic DOM			8.05	ND.		
Mae-Sa River	Raw water					18.93	6.85
	Hydrophilic DOM					5.57	ND.
	Hydrophobic DOM					ND.	ND.
	Coagulated water					8.20	ND.
	Hydrophilic DOM					ND.	ND.
	Hydrophobic DOM					ND.	ND.

ND. = not detectable

#### 4.8 Correlation between THMFP and DOM surrogate parameters

In general, dissolved organic matter (DOM) was the term used to describe the complex metric of organic material in natural water. As mentioned earlier, it is not practical to analyze individual chemical compounds of DOM. Consequently, DOM may be separated in terms of surrogate parameters including DOC, UV-254, SUVA and THMFP.

In this study, a number of surrogate parameters were considerably utilized to measure the quantity of DOM such as DOC, UV-254, SUVA and THMFP. From this point, the purpose of this section was to demonstrate the correlation among surrogates for DOM so as to allow one parameter such as DOC to be used as a surrogate for another parameter such as THMFP. Data of raw water and coagulated water were utilized to evaluate the correlation coefficients in this study.

According to AWWA (1993), it had been recognized that the correlation levels were divided into four categories: an  $R^2 > 0.9$  was considered 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 the considerably poor correlation ( $R^2 < 0.5$ ), regression analysis was not performed, hence, the slope and intercept for the equation were not accepted.

From the results obtained in the experiments, the correlation among surrogates for DOM were performed and the correlation coefficients determined were illustrated in Figures 4.20 to 4.23 and the overall correlation among surrogates for DOM were also conclusively demonstrated in Table 4.5.

Looking at the conclusive results as shown in Table 4.5, the THMFP was considered as the dependent variable while DOC, UV-254 and SUVA were considered as independent variables. It was found that the correlation coefficient ( $R^2$ ) of the regression analysis of THMFP and DOC and of THMFP and UV-254 of hydrophilic fractions from the results of three water sources were classified as good correlation levels which  $R^2$  values were 0.9449 and 0.9667, respectively, while the correlation

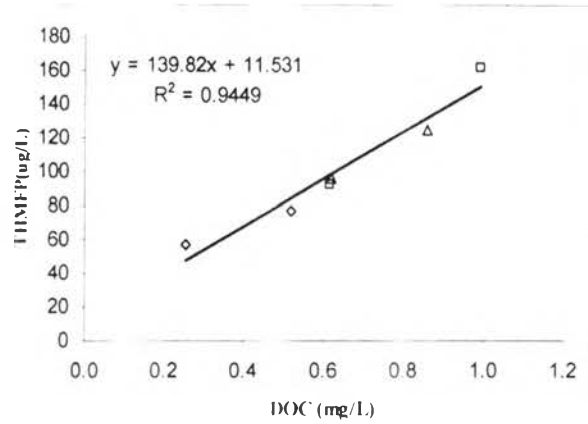
coefficient ( $R^2$ ) of the regression analysis of THMFP and SUVA was 0.7751, which classified as a moderate correlation.

The correlation coefficient of the regression analysis of THMFP and DOC and of THMFP and SUVA in hydrophobic fractions were classified as poor correlation while that of THMFP and UV-254 was 0.6739, which classified as a fair correlation.

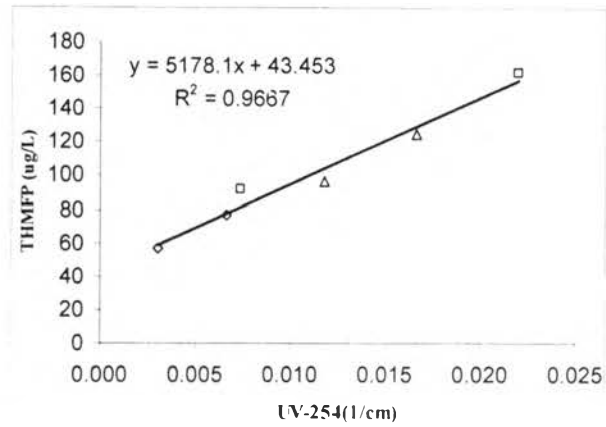
The coefficient of the regression analysis of THMFP and UV-254 and of THMFP and SUVA in raw water and coagulated water were 0.9747 and 0.9287, respectively. These relationships could be classified as good correlation, while the correlation coefficient ( $R^2$ ) of the regression analysis of THMFP and DOC was 0.5071 that classified as a fair correlation.

Finally, the correlation coefficient of the regression analysis of THMFP and DOC in raw waters, coagulated waters, and their fractionation waters of each water source was classified as fair correlation while that of THMFP and UV-254 and of THMFP and SUVA were 0.8370 and 0.8019, respectively, which classified as a moderate correlation.

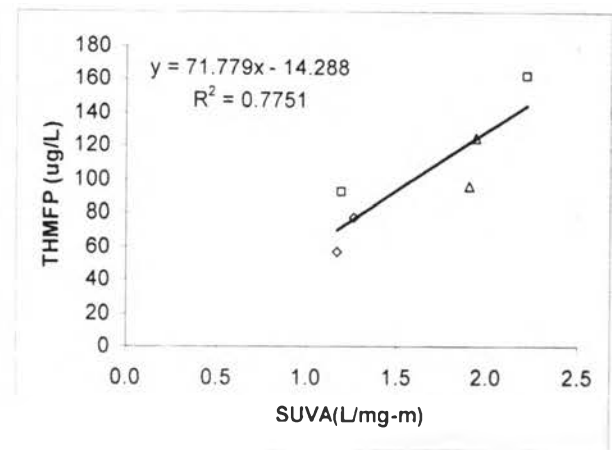
Base on the results in this study it is possible to suggest that UV-254 was the suitable DOM surrogate parameters that could be used to describe the quantity of THMFP in raw water, coagulated water, and their fractionated water from Aung Keaw Reservoir, Mae-Kuang Reservoir, and Mae-Sa River. Similarly, in study of Edzwald, and Laffin (1983), it was found that UV-254 was an excellent surrogate parameter for estimating the raw water concentrations of organic carbon and THMFP in river and reservoir waters.



(a) Correlation between THMFP and DOC



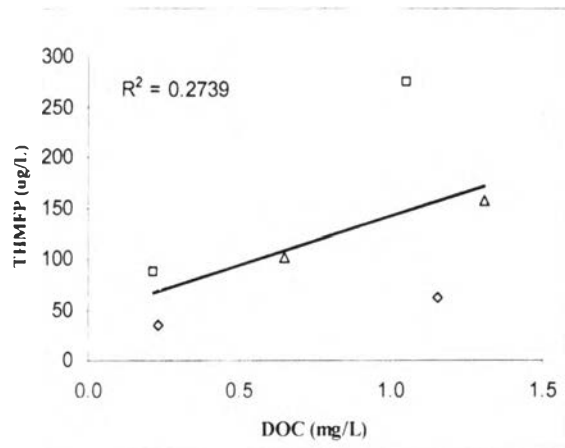
(b) Correlation between THMFP and UV-254



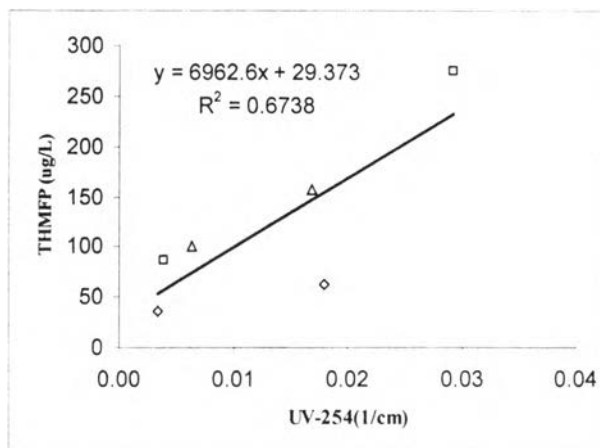
(c) Correlation between THMFP and SUVA

**Figure 4.20:** Correlation between THMFP and DOM surrogate parameters of hydrophilic fractions

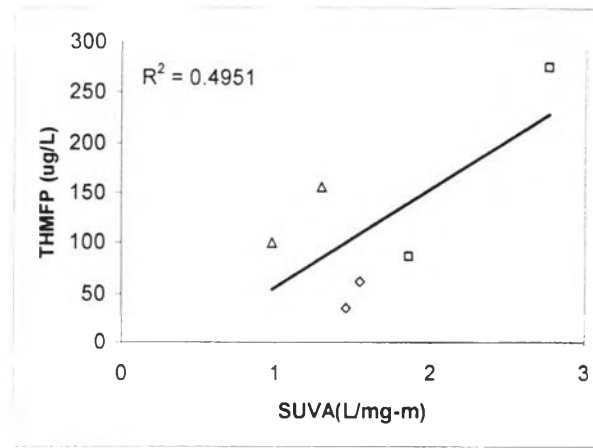
( □ = Aung-Kaew Reservoir, △ = Mae-Kuang Reservoir, and ◇ = Mae-Sa River)



(a) Correlation between THMFP and DOC



(b) Correlation between THMFP and UV-254

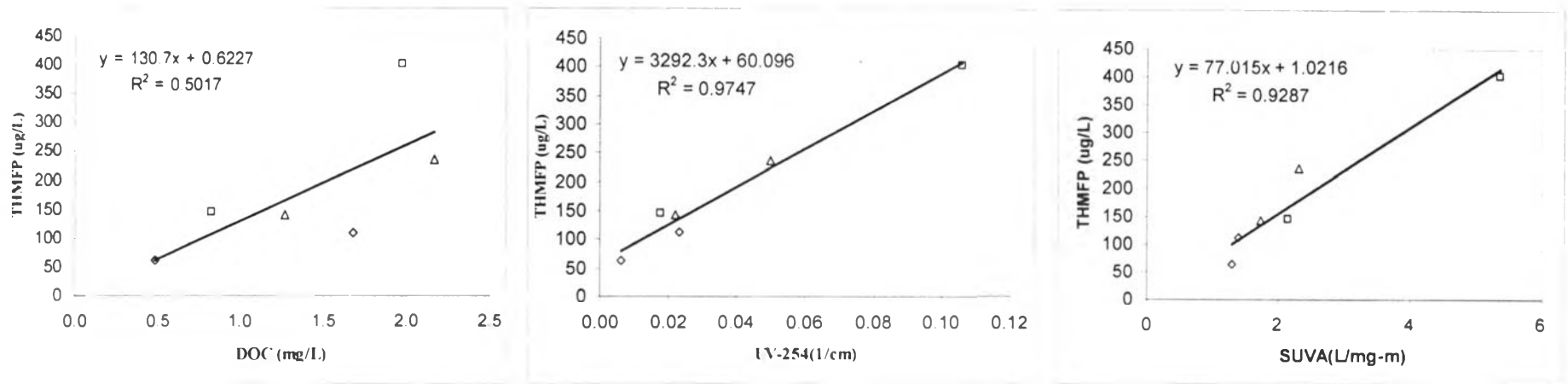


(c) Correlation between THMFP and SUVA

**Figure 4.21:** Correlation between THMFP and DOM surrogate parameters of hydrophobic fractions

(□ = Aung-Keaw Reservoir, △ = Mae-Kuang Reservoir, and ◇ = Mae-Sa River)





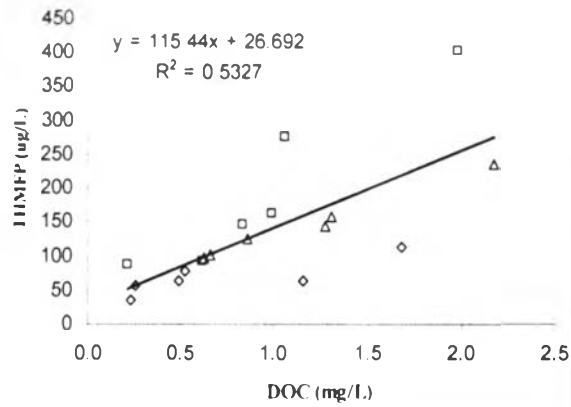
(a) Correlation between THMFP and DOC

(b) Correlation between THMFP and UV-254

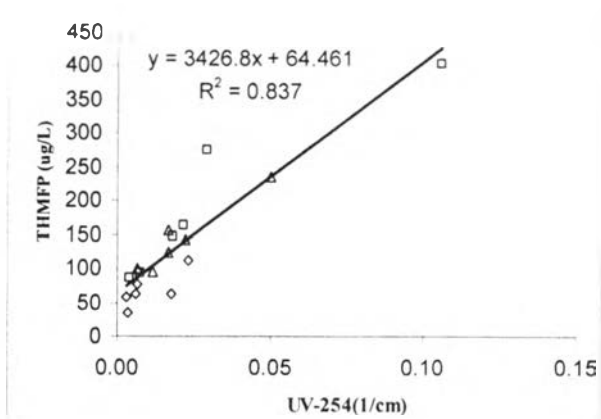
(c) Correlation between THMFP and SUVA

**Figure 4.22:** Correlation between THMFP and DOM surrogate parameters of raw waters and coagulated waters before fractionation

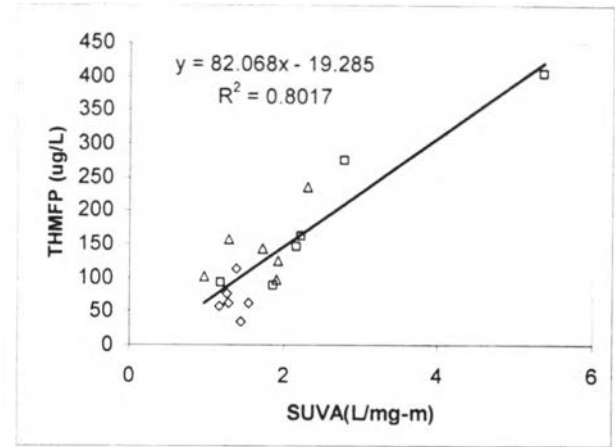
(□ = Aung-Keaw Reservoir, △ = Mae-Kuang Reservoir, and ◇ = Mae-Sa River)



(a) Correlation between THMFP and DOC



(b) Correlation between THMFP and UV-254



(c) Correlation between THMFP and SUVA

**Figure 4.23:** Correlation between THMFP and DOM surrogate parameters of raw waters and coagulated waters before fractionation and their fractionated water

( $\square$  = Aung-Keaw Reservoir,  $\triangle$  = Mae-Kuang Reservoir, and  $\diamond$  = Mae-Sa River)

**Table 4.5:** Correlation between THMFP and DOM surrogate parameters

Dependent Variable	Independent Variable	Status	N	R <sup>2</sup>	Equation	Remark
THMFP	DOC	Hydrophilic fraction in raw waters and coagulated waters	6	0.9449	Y=139.8X+11.531	A good correlation
THMFP	DOC	Hydrophobic fraction in raw waters and coagulated waters	6	0.2739	-	A poor correlation
THMFP	DOC	Raw waters and coagulated waters before fractionation	6	0.5017	Y=130.7X+0.623	A fair correlation
THMFP	DOC	Raw waters, coagulated waters, and their fractionations	18	0.5327	Y=115.4X+26.692	A fair correlation

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

**Table 4.5:** Correlation between THMFP and DOM surrogate parameters (con't)

Dependent Variable	Independent Variable	Status	N	R <sup>2</sup>	Equation	Remark
THMFP	UV-254	Hydrophilic fraction in raw waters and coagulated waters	6	0.9667	Y=5178.1X+43.453	A good correlation
THMFP	UV-254	Hydrophobic fraction in raw waters and coagulated waters	6	0.6738	Y=6962.6X+29.373	A fair correlation
THMFP	UV-254	Raw waters and coagulated waters before fractionation	6	0.9747	Y=3292.3X+60.096	A good correlation
THMFP	UV-254	Raw waters, coagulated waters, and their fractionations	18	0.8370	Y=3426.8X+64.461	A moderate correlation

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

**Table 4.5:** Correlation between THMFP and DOM surrogate parameters (con't)

Dependent Variable	Independent Variable	Status	N	R <sup>2</sup>	Equation	Remark
THMFP	SUVA	Hydrophilic fraction in raw waters and coagulated waters	6	0.7751	Y=71.8X-14.288	A moderate correlation
THMFP	SUVA	Hydrophobic fraction in raw waters and coagulated waters	6	0.4951	-	A poor correlation
THMFP	SUVA	Raw waters and coagulated waters before fractionation	6	0.9287	Y=77.0X+1.022	A good correlation
THMFP	SUVA	Raw waters, coagulated waters, and their fractionations	18	0.8017	Y=82.1X-19.285	A moderate correlation

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

#### **4.9 Application and management**

In general, groundwater and surface water were the major water resources that were utilized to produce water supply. However, the organic substances that contained in such water could create the serious problem by their reactions with chlorine because DOM was the main cause to create DBPs in disinfection process. Thus, the best way to manage and control the formation of DBP was to remove DOM from the raw water before its entering into disinfection process.

The water treatment plant consists of chemical and physical treatments that have the different efficiency for removing DOM from water. In this study, alum coagulation, which could be classified as chemical process at optimal condition could successfully remove hydrophobic and hydrophilic DOM from reservoir and river water. Moreover, when compared the obtained results with the requirement of USEPA for removing DOM from water, the results from this study could be achieved the requirement condition of USEPA. Therefore, it must be advantageous for water treatment facilities to apply the results from this study for using to operate the plant.