CHAPTER 4

RESULTS AND DISCUSSION

For describing the data obtained from this study, the following results and discussion for each particular topic are separately presented as follows:

4.1 Characteristic of raw water

So as to describe the characteristics of raw water from Aung-Keaw and Mae-Hia reservoirs, pH, turbidity, alkalinity, UV-254, TOC, DOC, THMs and THMFP were determined for understanding the physical and chemical qualities as well as the quantity of surrogates for NOMs in raw water (Appendix B).

The Characteristics of raw water in Aung-Keaw and Mae-Hia reservoirs investigated between October 2002 and February 2003 are depicted in Table 4.1. Based on the results in Table 4.1 it showed that the pH values of both Aung-Keaw and Mae-Hia raw water was 6.5 on average which was neutral and the desired pH for water treatment process was 7±0.5, thus it was simple for utilizing it as raw water supply. Relatively low alkalinity in both of raw water sources of about 35 mg/L as $CaCO_3$ were observed, as a results, sufficient alkalinity may be added in water during coagulation since alkalinity must be destroyed in the reaction with coagulant to produced floc.

Turbidity, or the cloudiness of water, was caused by multiple factors such as clay, silt, fine organic and inorganic matter, soluble colored organic compounds, plankton, and other microscopic organisms. The average values of turbidity of 36.6 and 24.8 NTU in Aung-Keaw and Mae-Hia reservoirs were observed, respectively. The results showed that raw water from both reservoirs was not clear enough in comparison with Thai drinking standard of 5 NTU, (Notification of the Ministry of Industrial of Industry, No. 332, B.E, 2521), and the raw water from these sources may not be good enough for direct utilization as potable water and household water supply.

Generally, THMFP, TOC and DOC could be considerably used as surrogate parameters for NOMs. The average values of TOC were 2.61 mg/L and 2.05 mg/L, whereas those of DOC were 0.48 mg/L and 0.41 mg/L for Aung-Keaw and Mae-Hia reservoirs, respectively. With regard to UV-254, UV is represented as the organic compounds that are aromatic or that have conjugated double bonds absorb light in the ultraviolet at wave length 254 nm, thus the UV-254 absorbance is also a well known surrogate parameter for creating THM. The average of UV-254 of 0.1277 and 0.1447 were also measured for Aung-Keaw and Mae-Hia raw water, respectively. As the results of such NOMs surrogate parameters found in water samples, it could be stated that natural organic compound may contain in raw water of both reservoirs.

By contrast, THMs was not detected, this may be due to the fact that available chlorine and halogen compounds may not contain in raw water leads to no reaction with NOMs to form THMs, but THMFP were found due to it was determined under the conditions of 7 days reaction time with excess chlorine demand about 3-5 mg/L. Therefore, THMFP of average 253.32 μg/L and 251.52 μg/L were measured in Aung-Keaw and Mae-Hia untreated water, respectively.

Table 4.1 The characteristics of raw water in Aung-Keaw and Mae-Hia reservoirs between October 2002 and February 2003

Parameters	Raw water in Aung-Keaw reservoir				Raw water in Mae-Hia reservoir			
	No. of sampling	Range of values	Average value	Standard deviation	No. of sampling	Range of value	Average value	Standard deviation
pH	15	6.2- 6.7	6.5	± 0.14	15	6.3-6.9	6.5	± 0.15
Turbidity (NTU)	15	8.1-80.4	36.6	± 24.74	15	5.6-45.8	24.8	± 12.52
Alkalinity (mg/L as $CaCO_3$)	15	27.8-40.7	32.9	± 3.40	15	25.7-42.9	34.0	± 4.55
UV absorbance at 254 nm. (1/cm)	15	0.1097-0.2738	0.1277	± 0.01	15	0.0962-0.2038	0.1447	± 0.03
TOC (mg/L)	10	2.01-5.24	2.61	± 1.11	10	3.60-1.77	2.05	± 0.25
DOC (mg/L)	10	0.37-1.67	0.48	± 0.09	10	0.18-0.65	0.41	± 0.16
THMs (µg/L)	15	0.0	0.0	-	15	0.0	0.0	-
THMFP (µg/L)	5	218.1-285.7	253.32	± 30.38	5	220.7-272.5	251.52	± 19.31

4.2 THMs and THMFP in water supply from actual plant waterworks

The aim of this study was to determine THMs and THMFP in water supply produced from actual plants of selected small waterworks.

Table 4.2 showed the THMs and THMFP including other characteristics of water supply produced from the actual plants of Aung-Keaw and Mae-Hia waterworks between October 2002 and February 2003 (Appendix B).

As can be seen in Table 4.2, THMs in produced water of average at 60.0 μg/L and 62.5 μg/L while those of THMFP of 40.3 μg/L and 46.4 μg/L, were investigated from Aung-Keaw and Mae-Hia waterworks, respectively. THMs occurred in produced water supply due to the use of chlorine in chlorination process in actual plants and chlorine can react with NOMs in water from THMs. As stated previously that at the time being, the recommended concentration or permissible level of THMs in drinking water by Thai's agency were not available, thus THMs Maximum control level (MCL) of 80 μg/L proposed by USEPA was considerably utilized as the standard criteria for THMs in this study. The results obtained showed that THMs in actual plant waterworks were averagely lower than such THMs standard. It could be indicated that coagulation and filtration process in the selected small waterworks could produce water supply that was considerably safe for drinking from problematic THMs.

TOC, DOC and UV-254 were also determined in the produced water supply. The relatively low value of these NOMs surrogated parameters were obtained comparing to those obtained in raw water as mentioned earlier in section 4.1. The result corresponded to that of THMs, which could be explained by the reason that treatment process by PACl coagulation could reduce NOMs satisfactorily.

The results of THMFP were also similar to those of other NOMs surrogates and THMs. The all above - mentioned results could be used to present that there were the correlation among TOC, DOC, UV-254 and THMFP for representing as NOMs surrogates.

With the reference to pH, turbidity and alkalinity in water supply from both of actual plant waterworks as shown in Table 4.2, good quality of water supply in term of pH, turbidity and alkalinity which were meet the Thai drinking water standard could be produced in such small waterworks.

In addition, based on the results discussed in the characteristics of raw water and the performances of water treatment process of Aung-Keaw and Mae-Hia case studies were not significant different.

Table 4.2 The THMs and THMFP including characteristic of water supply produced from the actual plants of Aung-Keaw and Mae-Hia waterworks between October 2002 – February 2003

Parameters	Aung-Keaw waterwork				Mae-Hia waterwork			
	No. of sampling	Range of values	Average value	Standard deviation	No. of sampling	Range of values	Average value	Standard deviation
THMs (µg/L)	15	37.4-84.3	60.0	± 14.75	15	35.2-106.4	62.5	± 19.23
THMFP (µg/L)	5	35.2-46.9	40.3	± 4.58	5	31.5-52.3	46.4	± 4.7
TOC (mg/L)	10	0.27-3.86	1.8	±1.24	10	0.35-2.60	1.4	± 0.92
DOC (mg/L)	10	0.1-0.97	0.5	± 0.27	10	0.50-0.14	0.3	± 0.17
UV absorbance at 254 nm. (1/cm)	15	0.0543-0.0862	0.0702	± 0.01	15	0.0585-0.0957	0.0745	± 0.01
pH	15	6.5-7.1	6.7	± 0.18	15	6.5-7.1	6.8	± 0.16
Turbidity (NTU)	15	0.14-0.56	0.4	± 0.21	15	0.2-0.8	0.6	± 0.52
Alkalinity (mg/L as $CaCO_3$)	15	15.0-26.1	18.5	± 4.26	15	34.8-15.0	23.7	± 7.26

4.3 Proper pH in PACl Coagulation for THMFP reduction in Jar-Test experiments

Since the principal factors affecting the coagulation of water are pH and coagulant dosages, the selection of pH and coagulant dosage require the use of coagulation studies in laboratory. The laboratory technique of the Jar-Test is usually used to determine the proper pH value and optimum dosage of coagulant. In this experimental series, raw water samples from Aung-Keaw and Mae-Hia reservoirs were studied in Jar-Test apparatus under the conditions of different pH ranged from 6 to 10 and at various PACl dosages between 0.5 and 5 mg/L. After a given time of Jar-Test, the stirring was ceased and the floc formed was allowed to settle. Then the supernatant samples were filtered by 1.12 μm GFC prior to determine THMFP and TOC, whereas the samples were filtered through 0.45 μm cellulose acetate membrane before DOC and UV-254 measurements. All filtered samples were defined as coagulated water. As can be seen in Figures 4.1, 4.2, 4.3 and 4.4 are the experimental results of the above-mentioned Jar-Test series. THMFP in coagulated water and percent reduction of THMFP versus various pH of each different PACl dosage experiments are demonstrated. Nearly all PACl dosages for Aung-Keaw water, it was appeared that the best conditions of PACl coagulation for THMFP reduction were at the pH values of 7. Similarly, the proper pH values of most PACl dosages for Mae-Hia, were also at the pH values of 7. Hence, it could be conclusively stated that coagulation by using PACl as coagulant aimed at THMFP reduction would be recommended to operate under the condition of proper pH value of 7 (The profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at pH in the range of 6 to 10 can be seen in Appendix C). This is similar to the results for turbidity removal of Penitsky and Edzwald (1999) which was presented that the optimum turbidity removal by PACl coagulation was achieved at about pH 7.

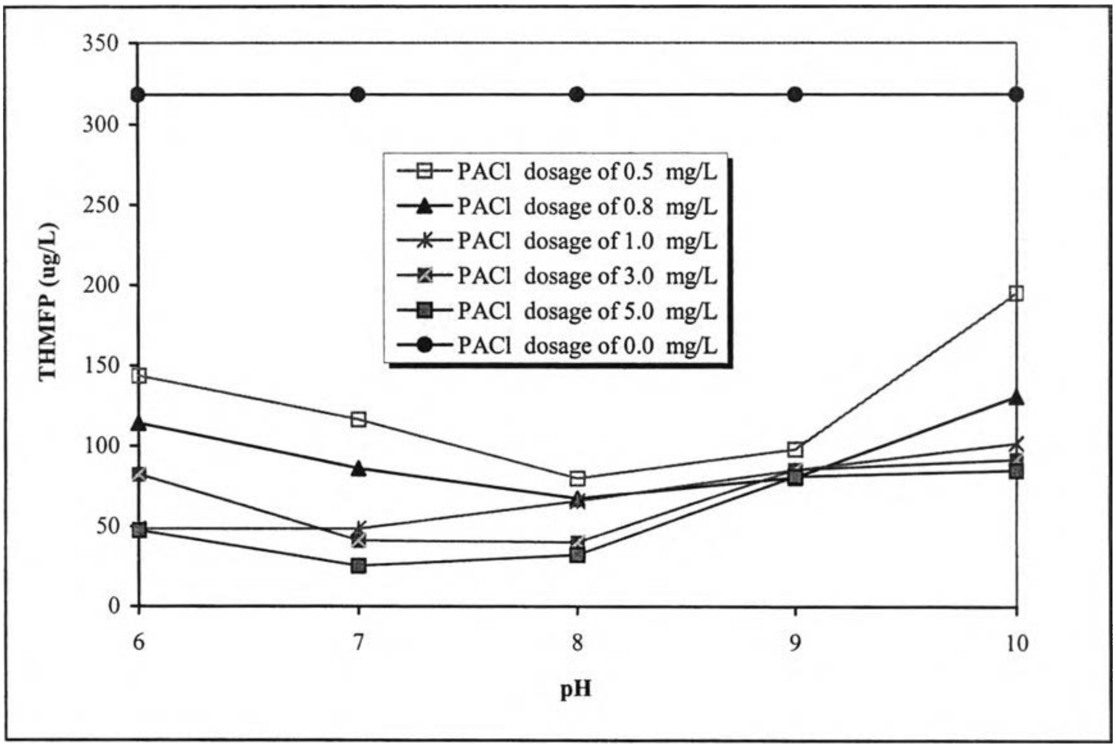

Figure 4.1 THMFP in coagulated water versus pH at different PACl dosages for Aung-Keaw water

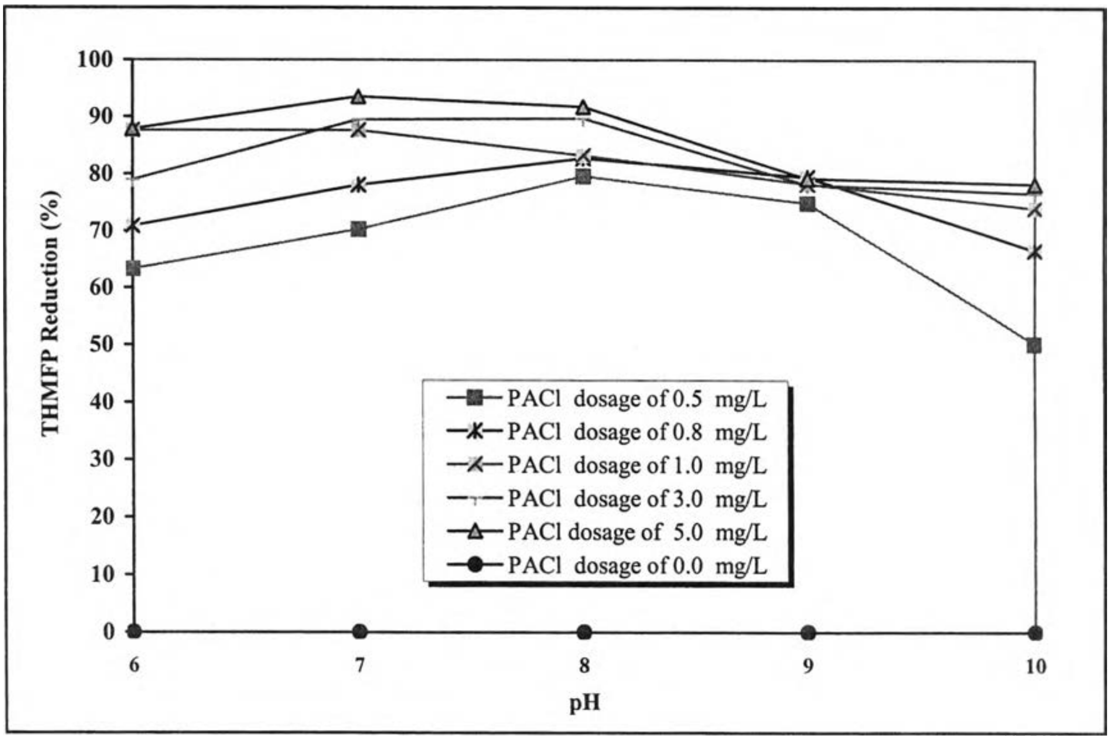

Figure 4.2 Percent reduction of THMFP versus pH at different PACl dosages for Aung-Keaw water

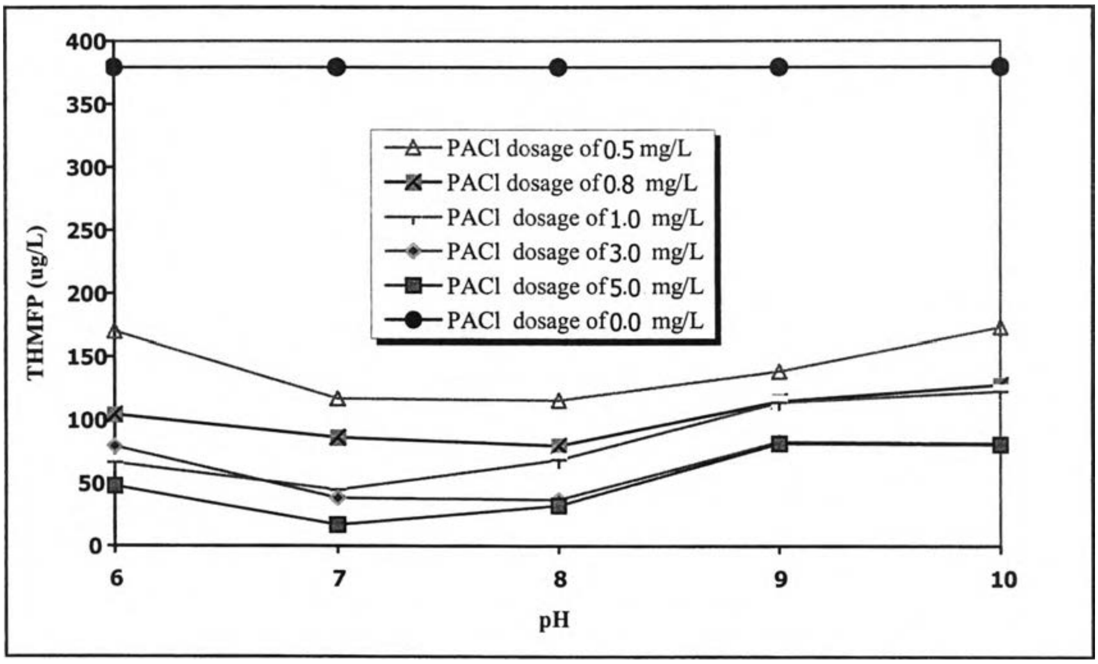

Figure 4.3 THMFP in coagulated water versus pH at different PACl dosages for Mae-Hia water

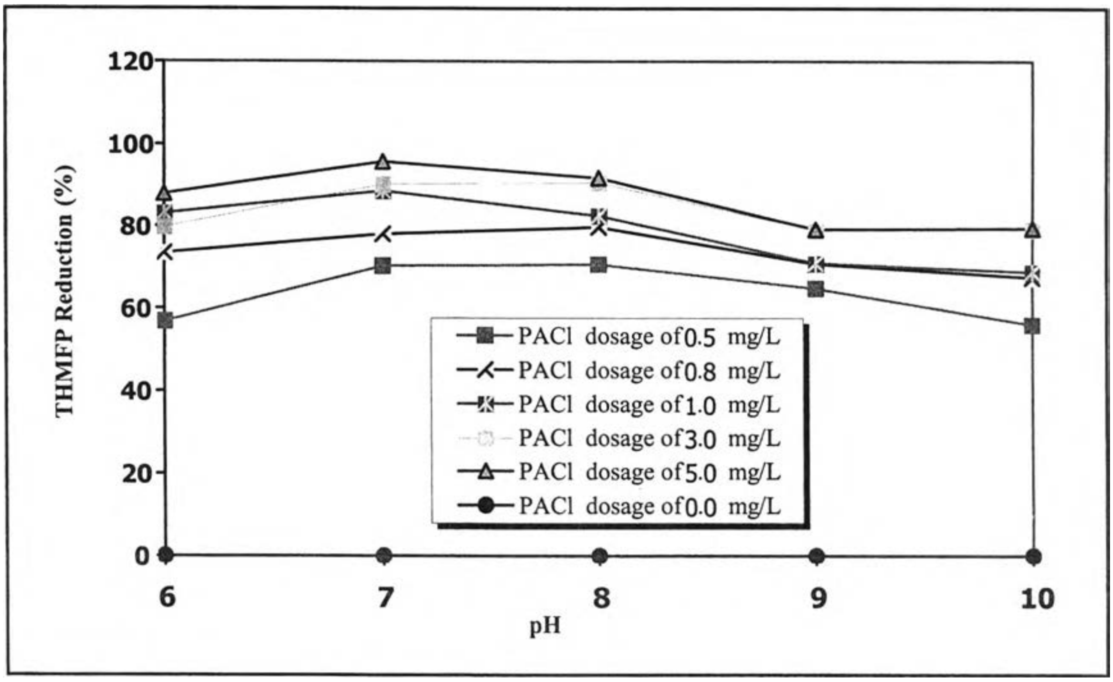

Figure 4.4 Percent reduction of THMFP versus pH at different PACl dosages for Mae-Hia water

4.4 The performance of PACl coagulation on THMFP reduction

According to the investigation on THMFP reduction in coagulated water by different dosages of PACl between 0 and 5 mg/L and at the variation of pH ranged from 6 to 10 as discussed previously in section 4.3, it has already concluded that the proper pH value for PACl coagulation was at 7. Although, the profiles of THMFP in coagulated water and percent reduction of THMFP obtained from all experimental runs for both Aung-Keaw and Mae-Hia water were presented in Figure 4.5 to 4.9 and Figure 4.10 to 4.14, respectively, the results obtained at the proper pH of 7 for both of water sources as shown in Figure 4.6 and 4.11 were only used for discussion the performance of PACl coagulation on THMFP reduction. As can be seen in Figure 4.6 and 4.11, it was found that THMFP reduction of about 70% at PACl dosage of 0.5 mg/L for both Aung-Keaw and Mae-Hia water were noticed whereas the increment of THMFP reduction efficiency to the maximum value of about 95% required the PACl dosage to be as high as 5 mg/L. THMFP could be sharply removed from 392.0 and 329.0 μg/L to approximately 116.5 and 169.7 μg/L within the short range of PACl adding from 0 to 0.5 mg/L. By contrast, after PACl dosage of 0.5 μg/L up to 5.0 mg/L THMFP gradually reduced until reaching to nearly constant concentration (minimum level) of about 16.9 and 70.1 μg/L for Aung-Keaw and Mae-Hia water sources, respectively (Appendix C). This is attributed to the reason that natural organic matter of higher apparent molecular weight (AMW) containing much in water was mostly reduced the beginning of dosing PACl from 0 to 0.5 mg/L while the remaining lower AMW organic matter, which was more difficult to be removed by coagulation, could be gradually removed at each step of PACl adding.

With regard to the species of trihalomethanes, including $CHCl_3$ (Chloroform) and $CHCl_2Br$ (Bromodichloromethane) and $CHClBr_2$ (Dibromochloromethane) and $CHBr_3$ (Bromomethane), those usually could be occurred in water due to disinfection which is accomplished almost solely by chlorination in small rural waterworks, therefore, the above-mentioned four forms of THMs were also expected to be observed in this study.

From the results as appeared in Table 4.3, it could be noted for both of raw water sources, Chloroform and Bromodichloromethane formation potentials were only two species of THMFP observed in this study. The main THMFP species in Aung-Keaw and Mae-Hia raw water was Chloroform ($CHCl_3$) of about 96.8 % while Bromodichloromethane ($CHCl_2Br$) was found as few as approximately 3.2 %. The reason used to explain this phenomenon is that halogen atom of disinfectant compound used in this study was Cl (without Br, F and I) and it was assumed that only a small amount of Br atom (without F and I) was present in raw water, hence, Chloroform ($CHCl_3$) and Bromodichloromethane ($CHCl_2Br$) formation potential were the only THMs species being found during the course of this research. Furthermore, as can be draw from the Figures 4.6 and 4.11 which demonstrate the most appropriate pH of PACl coagulant, it was interesting to note that Chloroform ($CHCl_3$) formations potential was significantly reduced from 379.3 μg/L to 116.5 μg/L and from 318.6 μg/L to 169.7 μg/L by using PACl dosage of 0.5 mg/L, for Aung-Keaw and Mae-Hia water, respectively. Addtitionally, all of the small amount of Bromodichloromethane ($CHCl_2Br$) in raw water as mentioned earlier was also removed at the same PACl dosage of 0.5 mg/L for both Aung-Keaw and Mae-Hia cases.

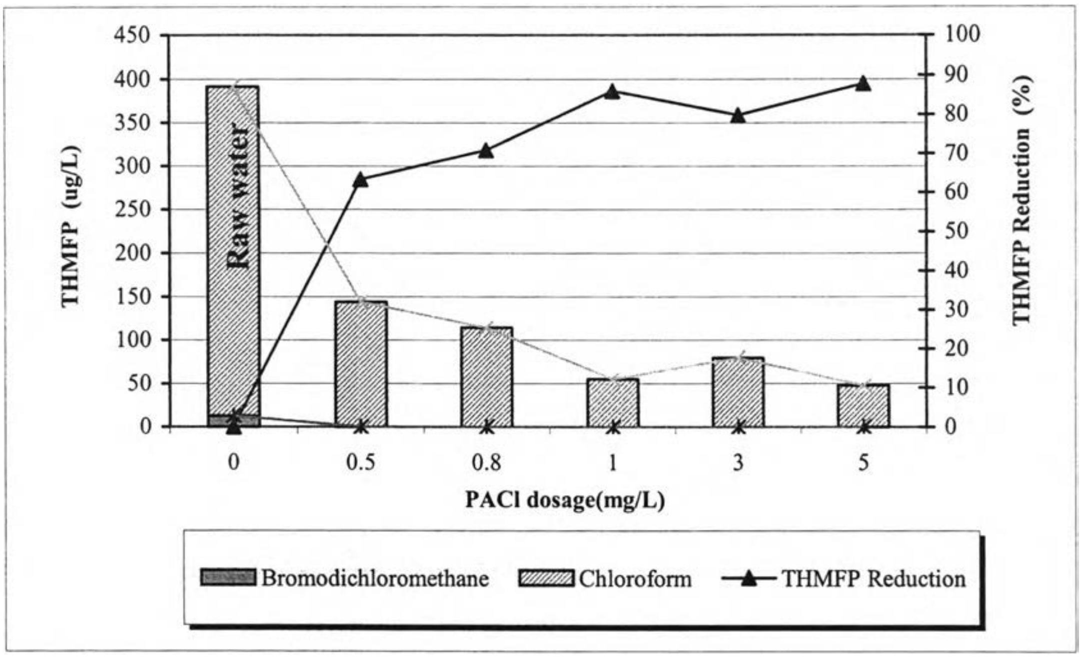

Figure 4.5 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 6 for Aung-Keaw water source

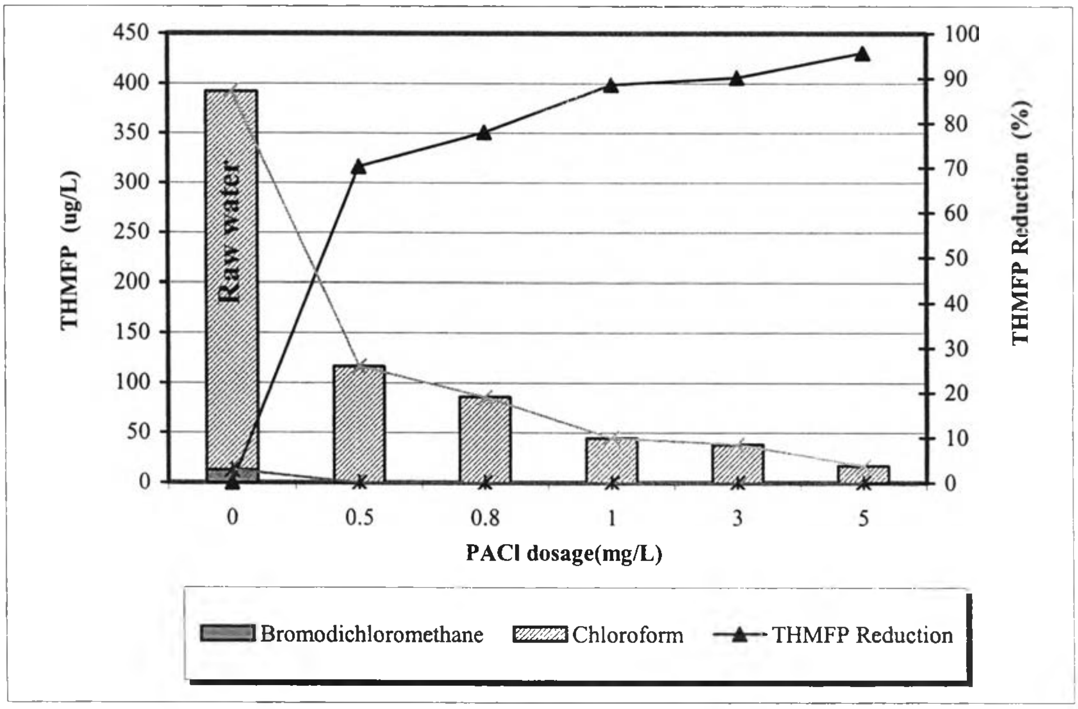

Figure 4.6 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 7 for Aung-Keaw water source (The most suitable pH THMFP reductions by PACl coagulation as previously discussed in section 4.3)

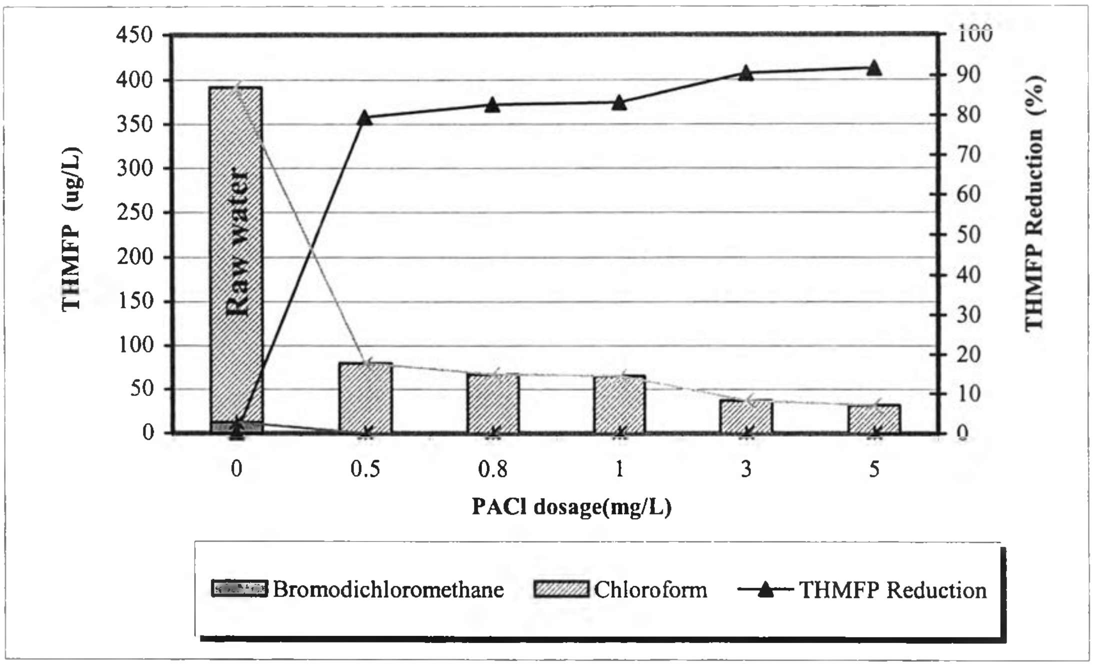

Figure 4.7 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 8 for Aung-Keaw water source

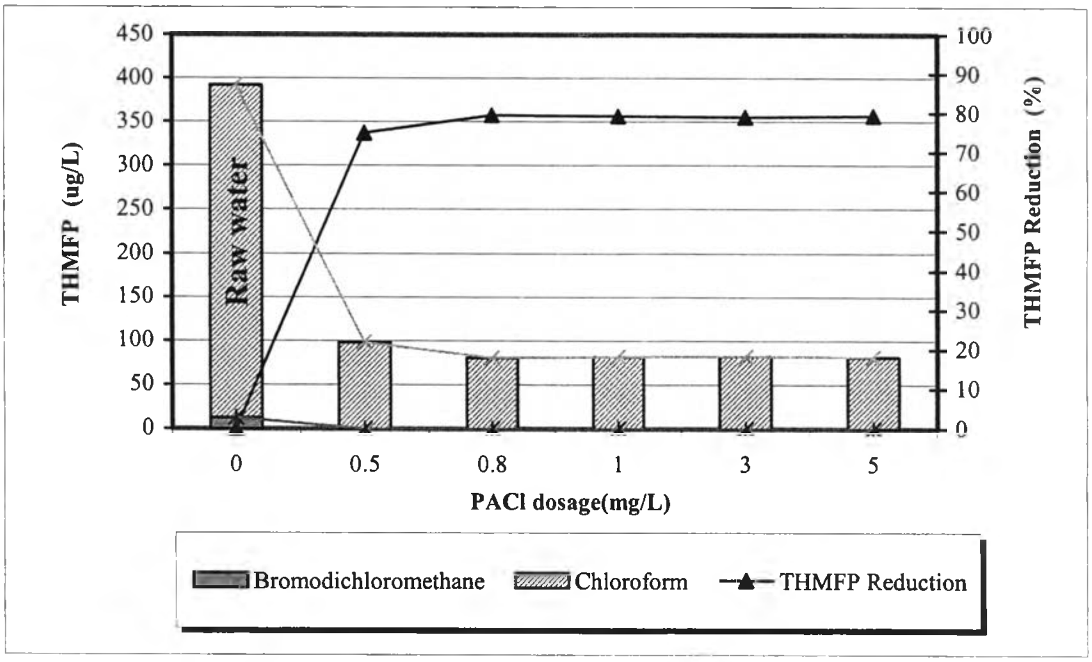

Figure 4.8 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 9 for Aung-Keaw water source

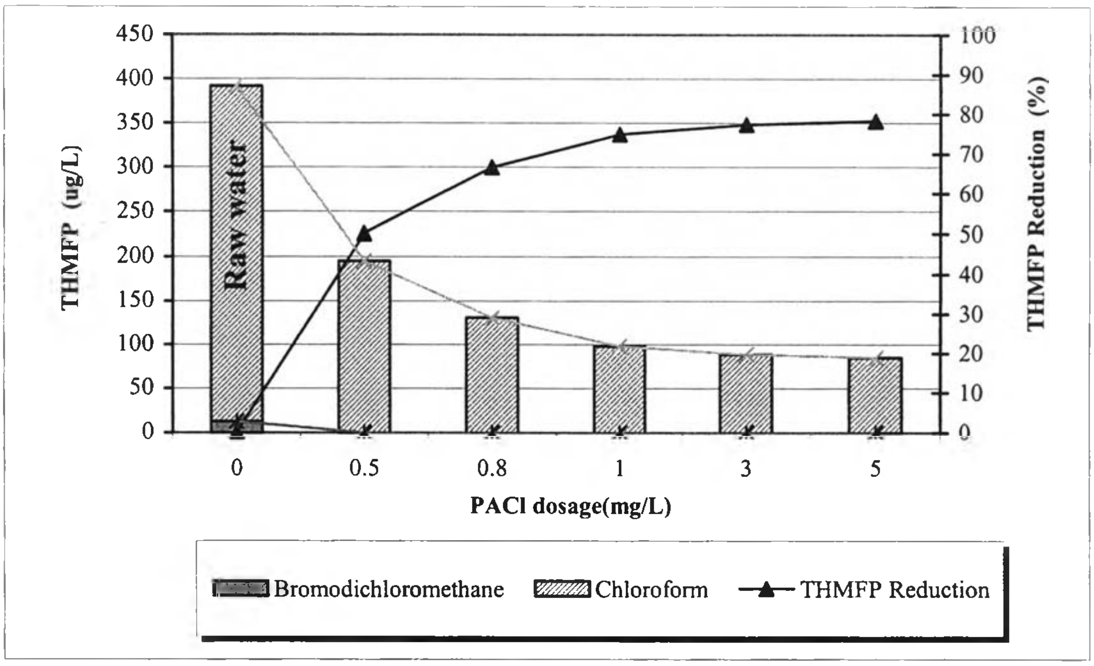

Figure 4.9 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 10 for Aung-Keaw water source

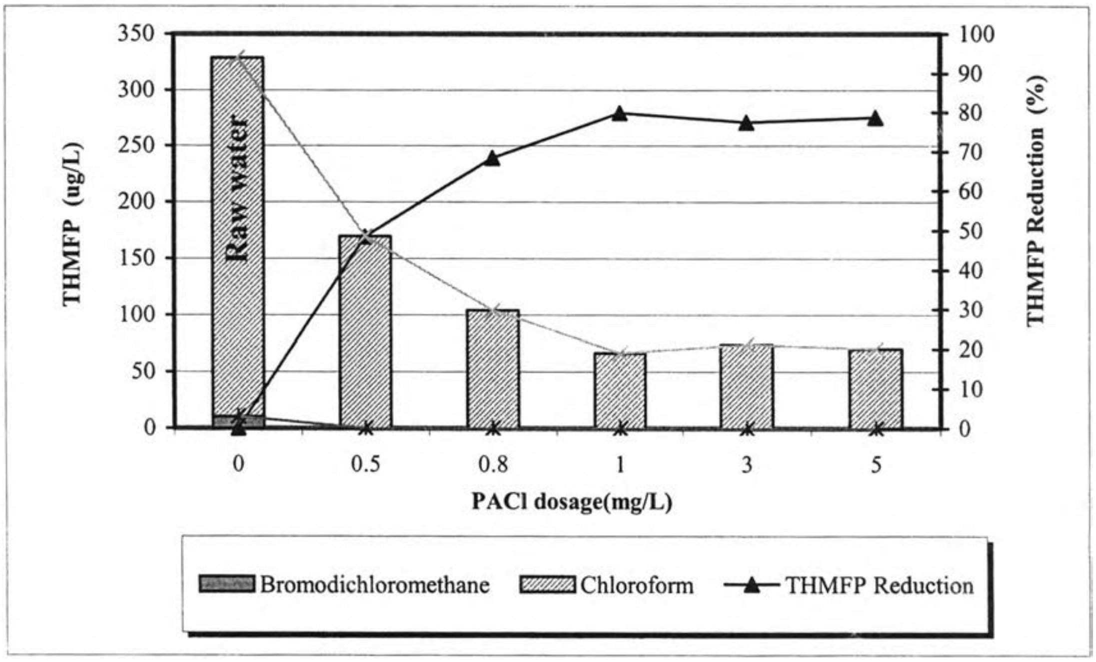

Figure 4.10 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 6 for Mae-Hia water source

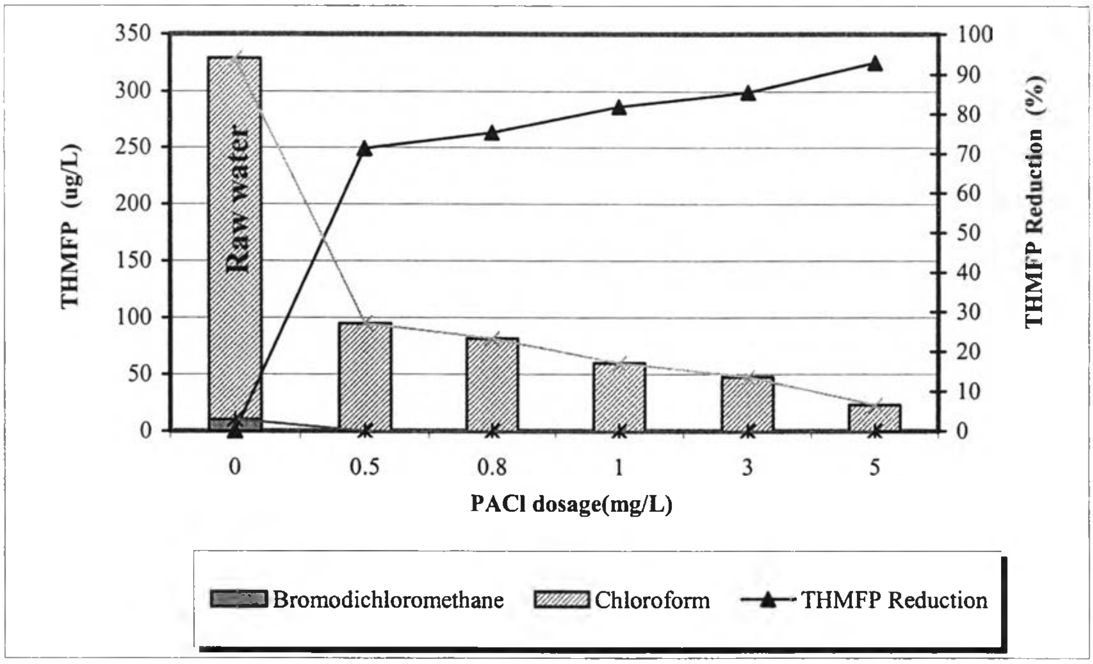

Figure 4.11 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 7 for Mae-Hia water source (The most suitable pH THMFP reductions by PACl coagulation as previously discussed in section 4.3)

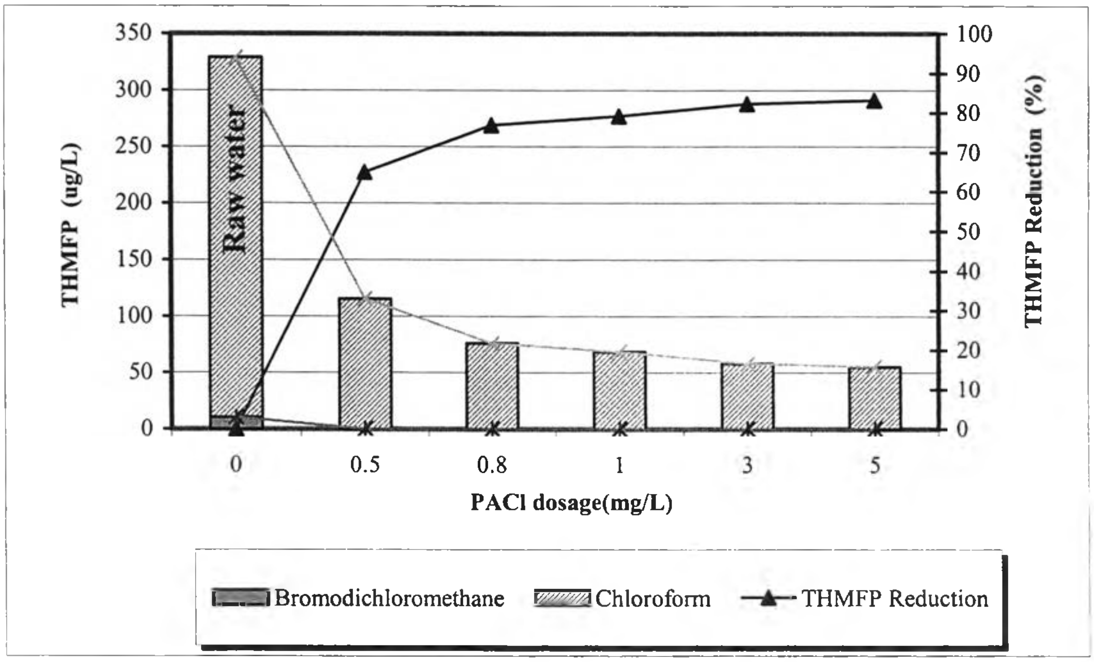

Figure 4.12 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 8 for Mae-Hia water source

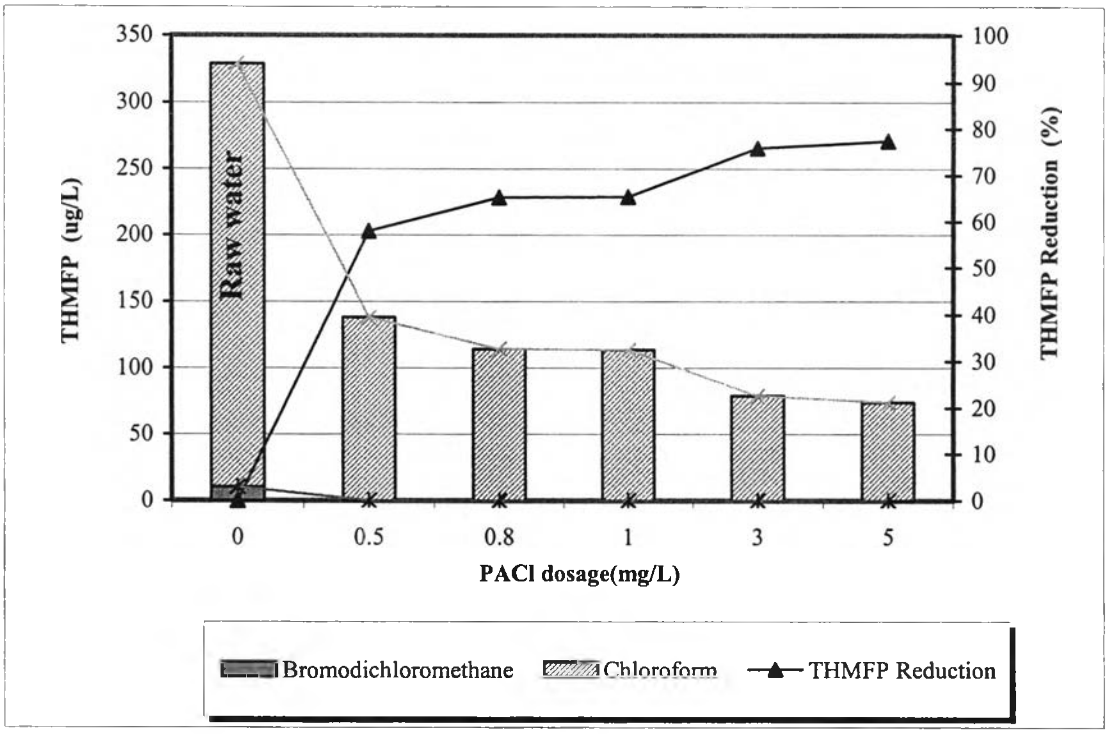

Figure 4.13 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 9 for Mae-Hia water source

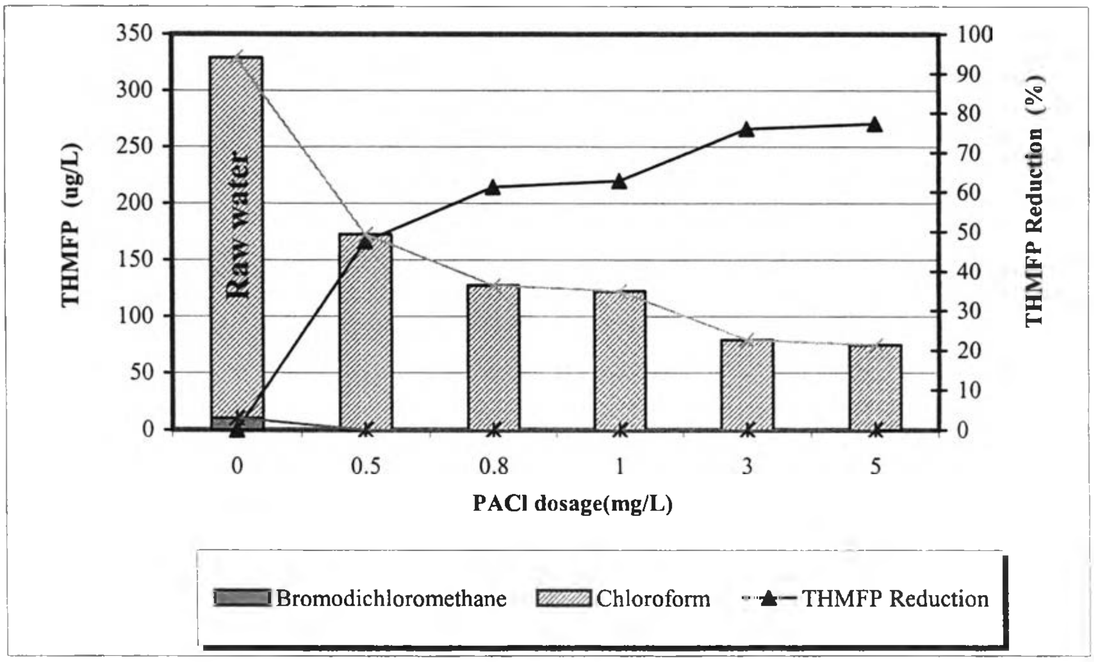

Figure 4.14 Profiles of THMFP and percent reduction of THMFP in coagulated water as a function of PACl dosages at the controlled pH of 10 for Mae-Hia water source

Table 4.3 THMFP species in raw water of Aung-Keaw and Mae-Hia reservoirs

Raw water sources	THMFP Species								Total THMFP (μg/L)
	Chloroform		Bromodichloromethane		Dibromochloromethane		Bromoform		
	Concentration (μg/L)	% of Total THMFP	Concentration (μg/L)	% of Total THMFP	Concentration (μg/L)	% of Total THMFP	Concentration (μg/L)	% of Total THMFP	
Aung-Keaw Reservoir	379.3	96.8%	12.7	3.2%	0.0	0.0	0.0	0.0	392.0 (100 %)
Mae-Hia Reservoir	318.6	96.8%	10.4	3.2%	0.0	0.0	0.0	0.0	329.0 (100 %)

4.5 Correlation between surrogates for natural organic matter (NOM) in coagulated water obtained from Jar-Test experiments.

At the present time, a number of parameter could be considered to represent a quantity of NOM. The presentation of overall matrix correlation among surrogates for NOM including THMFP, DOC, TOC and UV-254 is the objective of this section in which only the data of coagulated water are used to determine the regression and correlation coefficients.

Based on the results obtained in this research, the regression and correlation coefficients determined are demonstrated in Figure 4.15 to 4.20. In addition, the overall correlations among surrogates for NOM are conclusively presented in Table 4.4. It should be noted that in accordance with AWWA (1993) the correlation levels were divided in four categories as an R^2 > 0.9 was consider a good correlation, 0.7 < R^2 < 0.9 a moderate correlation, 0.5 < R^2< 0.7 a fair correlation and R^2 < 0.5 a poor correlation. For the considerably poor correlation (R^2 < 0.5), regression analyses were not performed; hence, the slope and intercept for the equation were not accepted.

As can be seen in Table 4.4, it could be conclusively established that THMFP and TOC was the good correlation represented by the equation of THMFP = 248.42 TOC – 62.077, with R^2 of 0.9331. The correlation between THMFP and DOC as well as DOC and TOC was considerably categorized as good level with R^2 =0.9257 and 0.9865, respectively. Unlike the earlier presentation, the unacceptable correlation of THMFP and UV-254, of DOC and UV-254 including of TOC and UV-254 were examined.

As demonstrative in aforementioned results, it could be clearly pointed out that TOC could be used to describe the quantity of THMFP since its correlation was the highest while UV-254 was not a proper parameter used to represent NOM quantity because very low values of R^2 were obtained.

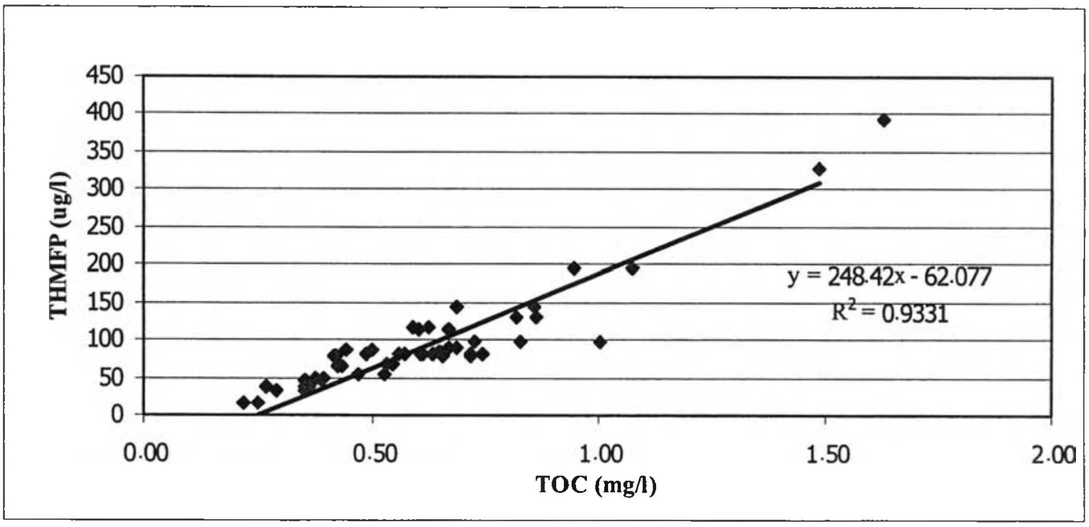

Figure 4.15 Regression and correlation coefficients between THMFP and TOC in coagulated water of both Aung-Kaew and Mae-Hia water source

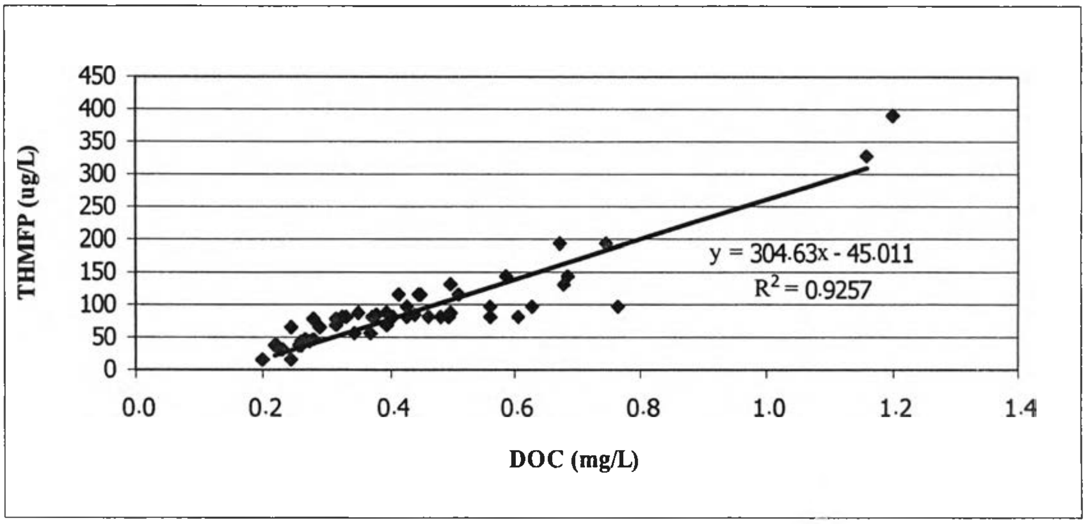

Figure 4.16 Regression and correlation coefficients between THMFP and DOC in coagulated water of both Aung-Kaew and Mae-Hia water source

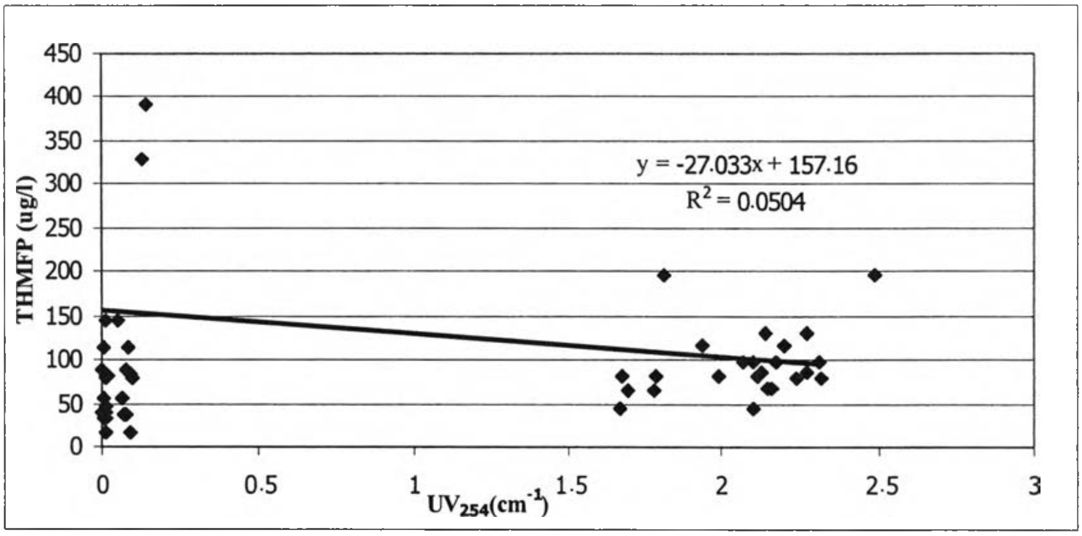

Figure 4.17 Regression and correlation coefficients between THMFP and UV-254 in coagulated water of both Aung-Kaew and Mae-Hia water source

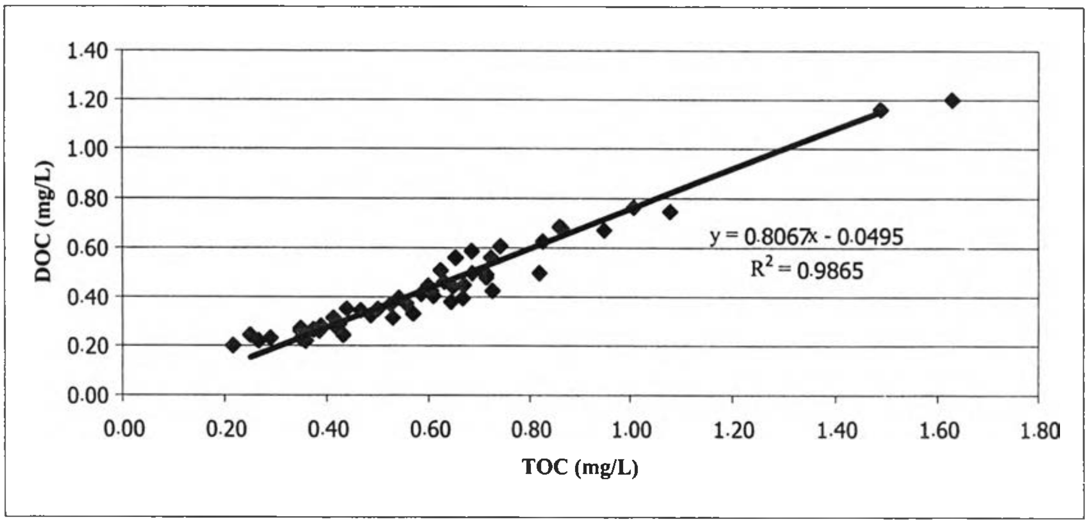

Figure 4.18 Regression and correlation coefficients between DOC and TOC in coagulated water of both Aung-Kaew and Mae-Hia water source

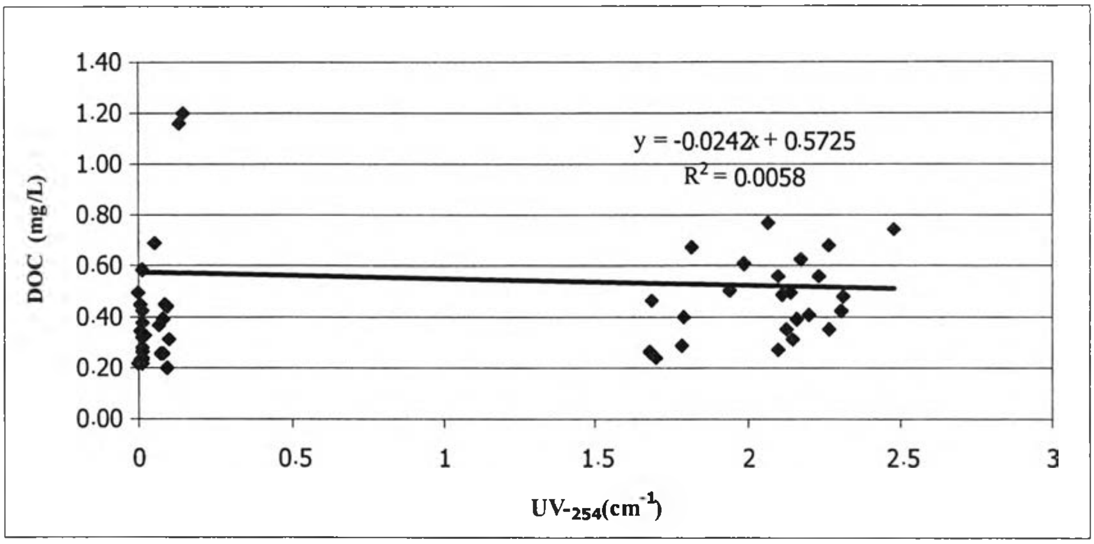

Figure 4.19 Regression and correlation coefficients between DOC and UV-254 in coagulated water of both Aung-Kaew and Mae-Hia water source

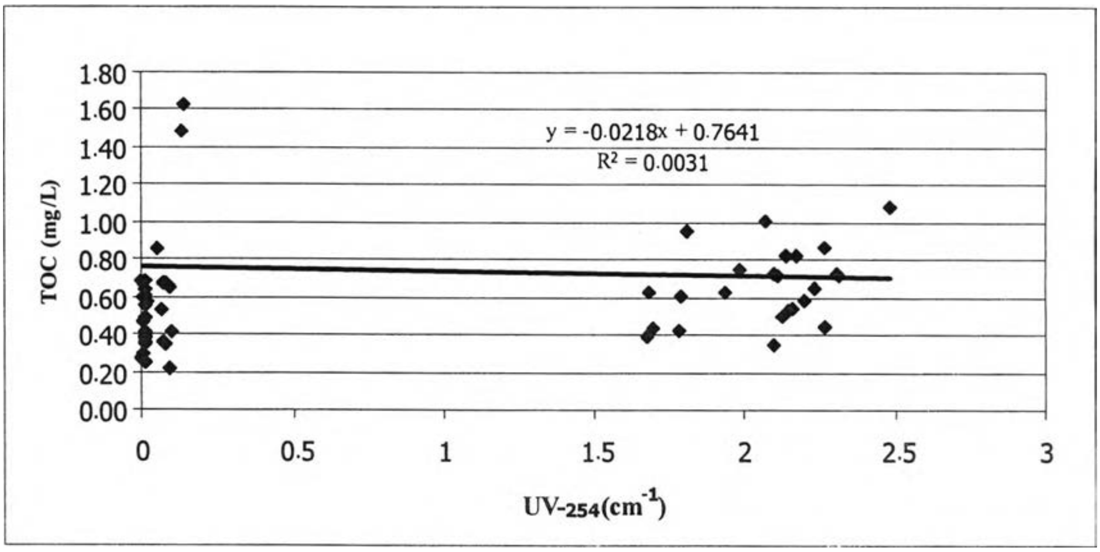

Figure 4.20 Regression and correlation coefficients between TOC and UV-254 in coagulated water of both Aung-Kaew and Mae-Hia water source

Table 4.4 Conclusive results of regression and correlation coefficients between surrogates of NOM parameters

Dependent Parameter (Y)	Independent Parameter (X)	The results obtained in this study				Remarks
		Status	n	Equation	R^2	
THMFP	DOC	Coagulated water	50	Y = 304.63X - 45.011	0.9257	A good correlation
THMFP	TOC	Coagulated water	50	Y = 248.42X - 62.077	0.9331	A good correlation
THMFP	UV-254	Coagulated water	50	Y= -27.033X + 157.16	0.0504	A poor correlation (Not accepted)
DOC	TOC	Coagulated water	50	Y = 0.8067X- 0.0495	0.9865	A good correlation
DOC	UV-254	Coagulated water	50	Y = -0.0242X + 0.5725	0.0058	A poor correlation (Not accepted)
TOC	UV-254	Coagulated water	50	Y=-0.0218x + 0.7641	0.0031	A poor correlation (Not accepted)