CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Characteristics of Ping River water and Ang Keaw Reservoir water

The summary of the characteristics of raw waters from Ping River and Ang Keaw Reservoir are presented in Table 4.1.

Table 4.1 Characteristics of raw waters from Ping River and Ang Keaw Reservoir.

Parameters	Raw water sources	
	Ping River	**Ang Keaw Reservoir**
pH	7.74±0.04	7.59±0.23
Temperature (C^{o})	24.4±0.5	23.1±0.3
Conductivity (µS/cm)	221.5±15.7	73.0±1.9
Turbidity (NTU)	87.4±5.0	18.9±1.2
Alkalinity (mg/l CaCO3)	85.5±4.9	33.0±3.2
DOC (mg/l)	2.24±0.09	3.06±0.08
UV-254 (cm-1)	0.0556±0.0043	0.0711±0.0034
SUVA (L/mg-m)	2.48±0.09	3.04±0.02

As shown in Table 4.1, the average pH and alkalinity values of Ping River water and Ang Keaw Reservoir were 7.74, 7.59 and 87.4 mg/l CaCO$_3$, 33.0 mg/l CaCO$_3$, respectively. It can be noticed that pH of two raw water sources was nearly neutral whereas alkalinity of Ang Keaw Reservoir was slightly low. In order to prevent pH drop by alkalinity consuming during coagulation/flocculation process, the conventional water coagulation that utilize alum (aluminum sulfate) as coagulant was generally required the additional alkalinity in case of low alkalinity raw water. As stated previously, PACl are synthetic polymers dissolved in water and finally react to form insoluble aluminium poly-hydroxides. Solutions of PACl are not as acidic as alum; consequently they do not tend to decrease the pH as much as an equivalent amount of alum. Therefore, PACl was induced as coagulant without pH adjustment in this study. pH of all water samples was monitored and summarized in Appendix A.

Interestingly, the significant turbidity different between Ping River water and Ang Keaw Reservoir water must be exhibited the different appropriate condition for DOM removal through the in-line coagulation combined with ceramic membrane. The high amount of solid contained in Ping River water (>80 NTU) and the case of low turbidity water (turbidity of Ang Keaw Reservoir water <20 NTU) may have affected to the aggregates (flocs) formation in the coagulation/ flocculation process that was proposed in the next topic. Turbidity values of all water samples were monitored and summarized in Appendix A.

4.2 Correlation between THMFP and DOM surrogate parameters

As mention earlier, Dissolved Organic Matter (DOM) was the term used to describe the complex mixture of various compounds with widely different chemical properties. The parameters utilized to identify character and quantity of DOM was non-specific parameters such as DOC, UV-254, SUVA, FEEM, and THMFP. Consequently, it was not practical to analyze individual chemical compound of DOM by individual parameter.

This section was aimed at considering in the correlation between THMFP as dependent variable and other DOM surrogate parameters (DOC, UV-254, SUVA, and FEEM Intensity) as independent variable in order to allow one of this parameter to be used for THMFP prediction. Data of raw water and filtrate water by In-line coagulation combined with ceramic membrane were induced to evaluate the correlation coefficients in this study.

The correlations and correlation coefficients between THMFP and other DOM surrogate parameters obtained in these experiments were illustrated in Figure 4.1 and Figure 4.2. The overall correlations were summarized in Table 4.2.

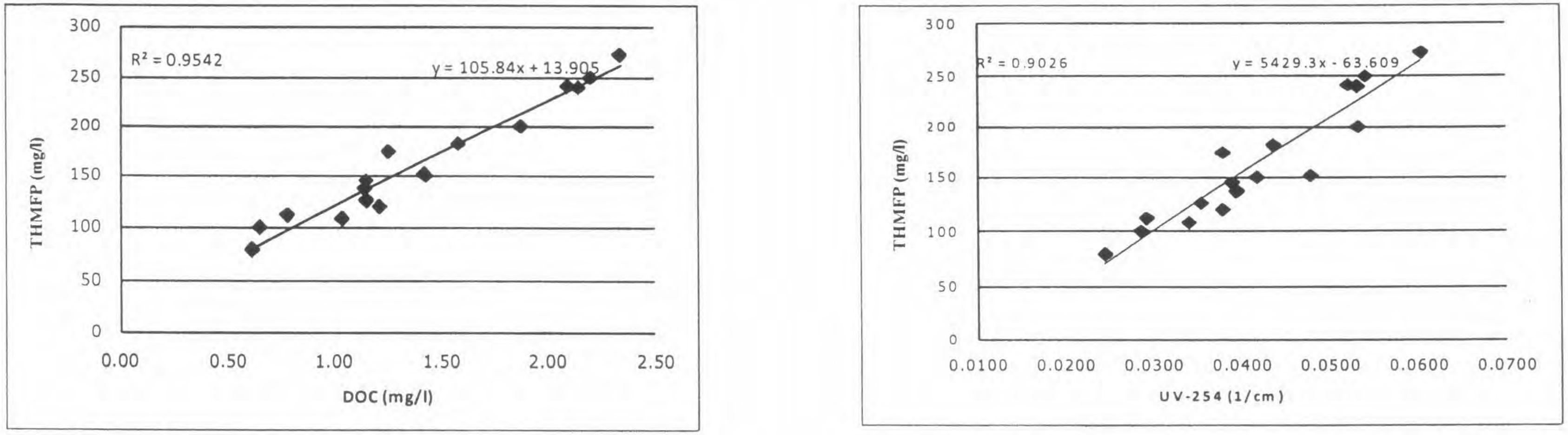
Referring to the regression analysis, AWWA (1993) had been recognized that the correlation levels were divided in four categories as an $R^2 > 0.9$ was considered a good correlation, $0.7 < R^2 < 0.9$ a moderate correlation, $0.5 < R^2 < 0.7$ a fair correlation and $R^2 < 0.5$ a poor correlation. For the considerably poor correlation ($R^2 < 0.5$), regression analysis was not performed, hence, the slope and intercept for the equation were not accepted.

As can be seen from Table 4.2, a good correlation was found in regression analysis of THMFP and DOC and of THMFP and UV-254 from Ping River water which R^2 values were 0.9542 and 0.9026, respectively, and from Ang Keaw Reservoir water which R^2 values were 0.9457 and 0.9625, respectively.

The correlation coefficient of the regression analysis of THMFP and SUVA and of THMFP and FEEM intensity obtained from Ping River water were 0.7351 and 0.7845, respectively, which classified as moderate correlation.

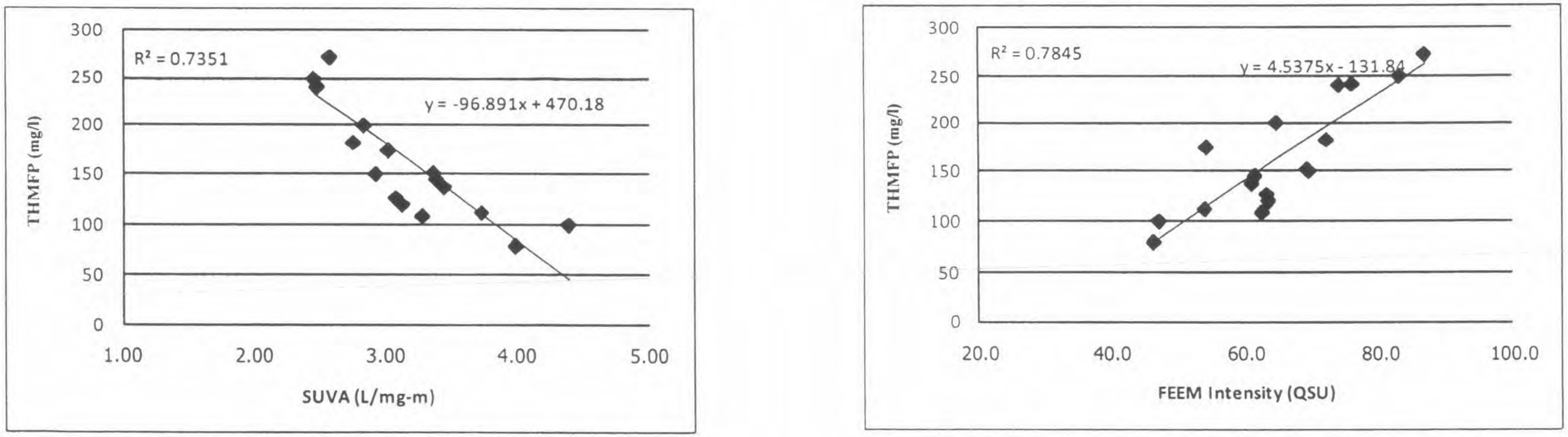
The correlation coefficient of the regression analysis of THMFP and SUVA obtained from Ang Keaw Reservoir water was 0.5808. These relationships could be classified as fair correlation, while the correlation coefficient of the regression analysis of THMFP and FEEM intensity was 0.8525 which classified as moderate correlation.

From the relationships obtained, it was indicated that the suitable DOM surrogate parameter that could be used to predict the quantity of THMFP in raw water and filtrate water by In-line coagulation combined with ceramic membrane of Ping River water and Ang Keaw Reservoir water was DOC and UV-254. However, SUVA, and FEEM intensity were also considerably acceptable to predict THMFP.



a.) Correlation between THMFP and DOC

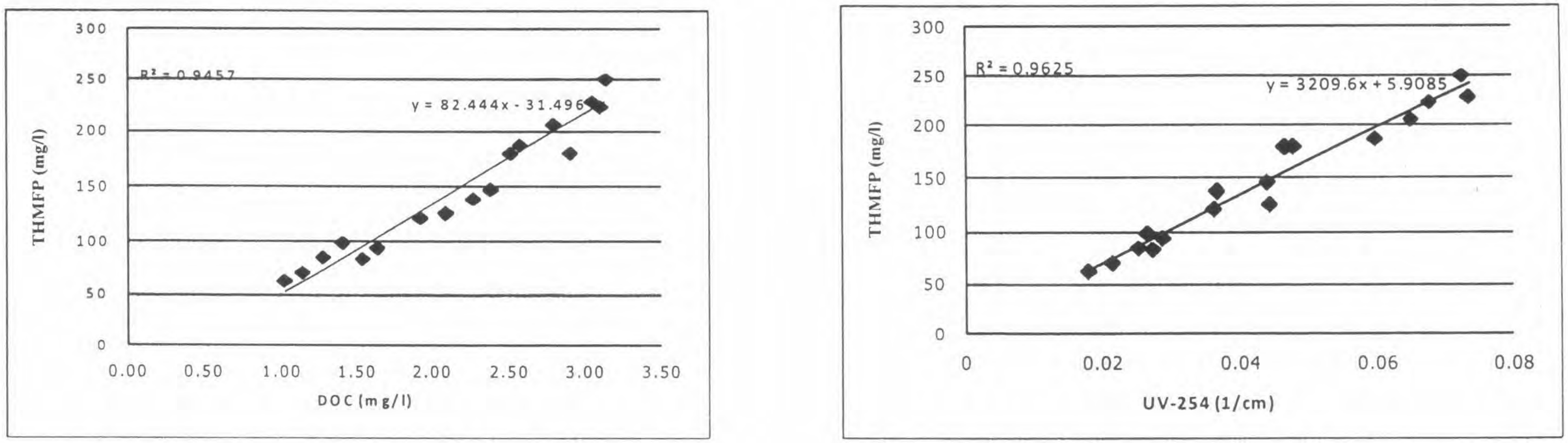
b.) Correlation between THMFP and UV-254



c.) Correlation between THMFP and SUVA

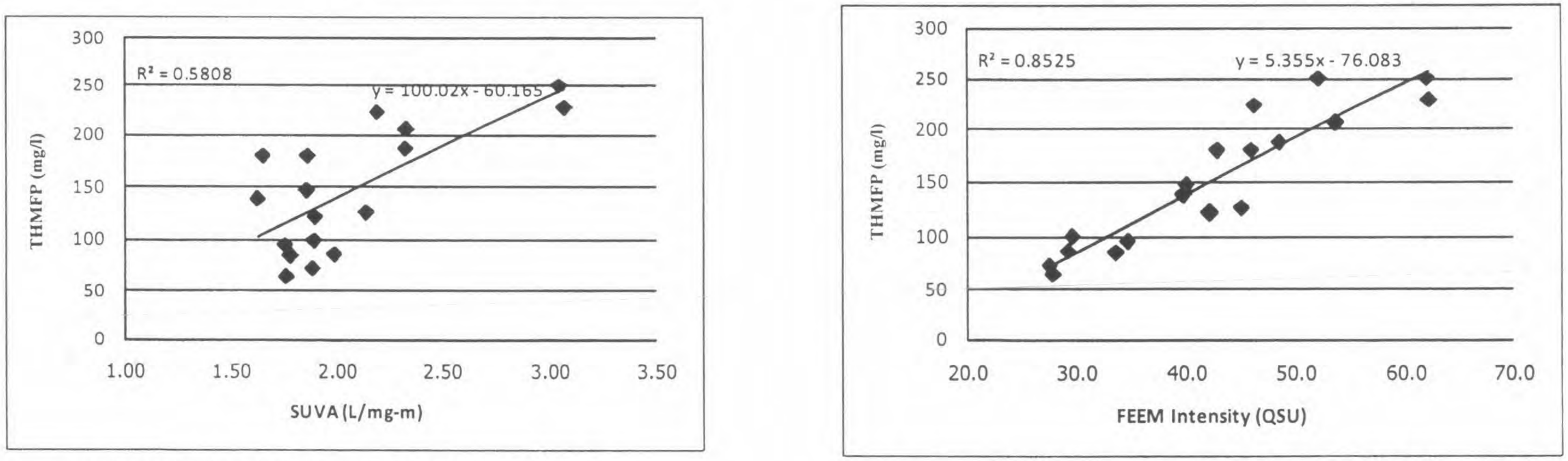
d.) Correlation between THMFP and FEEM Intensity

Figure 4.1 Correlation between THMFP and DOM surrogate parameters of raw water and filtrate water by In-line coagulation combined with ceramic membrane from Ping River water



a.) Correlation between THMFP and DOC

b.) Correlation between THMFP and UV-254



c.) Correlation between THMFP and SUVA

d.) Correlation between THMFP and FEEM Intensity

Figure 4.2 Correlation between THMFP and DOM surrogate parameters of raw water and filtrate water by In-line coagulation combined with ceramic membrane from Ang Keaw Reservoir water

Table 4.2 Correlation between THMFP and DOM surrogate parameters

Water Sources	Independent Variables	R^2	Equations	Remarks
Ping River	DOC	0.9542	THMFP =105.84(DOC)+13.905	Good correlation
	UV-254	0.9026	THMFP =5429.3(UV-254)-63.609	Good correlation
	SUVA	0.7351	THMFP =-96.891(SUVA)+470.18	Moderate correlation
	FEEM Intensity	0.7845	THMFP =4.5375(FEEM)-131.84	Moderate correlation
Ang Keaw Reservoir	DOC	0.9457	THMFP =82.444 (DOC)-31.496	Good correlation
	UV-254	0.9625	THMFP =3209.6(UV-254)+5.9085	Good correlation
	SUVA	0.5808	THMFP =100.02(SUVA)-60.165	Fair correlation
	FEEM Intensity	0.8525	THMFP =5.355(FEEM)-76.083	Moderate correlation

Note: - Dependent variable for all equations was THMFP
- N = 17 (Data include of raw water and filtrate water by In-line coagulation combined with ceramic membrane)

4.2 The removal of DOM surrogates (DOC, UV-254, and SUVA)

This section was aimed at considering in twofold. Firstly, it was to compare the DOM removal by the conventional coagulation-flocculation process with various PACl dose (PACl dose of 1.5, 2.0, 2.5, and 3.0 mg/l Al) and the In-line coagulation combined with ceramic membrane with the same PACl dose variation as Jar Test experiment. Secondly, The comparison among the DOM removal by In-line coagulation combined with 1.0 μm, MF and UF with PACl dose of 1.5, 2.0, 2.5, and 3.0 mg/l Al were evaluated in order to select suitable alternatives to UF membranes for the effective removal of DOM, as the 1.0 μm and MF have much higher permeability, without significantly sacrificing DOM removal efficiency.

4.2.1 DOC removal

The average value of DOC observed in water samples from Ping River and Ang Keaw Reservoir were 2.24 and 3.06 mg/l, respectively. The DOC results of all experiments were summarized in Table 4.3.

As can be seen in Figure 4.3 and Figure 4.4, the optimal PACl dose for Ping River water was 2.5 mg/l Al and the highest removal of Ang Keaw Reservoir water was at 3.0 mg/l Al observed by Jar Test experiments. However, DOC removal of Ang Keaw Reservoir water trend to increase at PACl dose over 3.0 mg/l Al; therefore, the optimal dose may at some more over 3.0 mg/l Al. DOC removal by Jar Test exhibited low percentage, it may attribute to the fact that DOC remaining in the supernatant have been due to the flocs have not grown proper enough to settle down under gravity and some organic particles have not been adsorbed onto the aluminum flocs.

The DOC removal by 1.0μm, MF and UF without coagulant from Ping River water were 2.5%, 10.4%, and 19.7%, respectively and Ang Keaw Reservoir water were 1.3%, 11.0%, and 15.5%, respectively as illustrated in Figure 4.3 and Figure 4.4. According to these very low DOC removal results obtained, it can be stated that the 1.0μm, MF and UF ceramic membrane filtration that relies on the sieving mechanism alone could not be sufficient to reduce DOC, according to the size distribution of

Dissolved Organic Matters (DOMs) are in range $10^{-0.5}$-10^{-3}µm (Amy *et al.*, 1987; AWWA, 1993) that allowed a tiny amount of DOM ,which has particle size larger than ceramic membrane pore size 1.0 µm, 0.1 µm, and 0.01 µm, rejected by membrane pores.

The DOC removal efficiency by Jar Test with PACl dose of 1.5, 2.0, 2.5, and 3.0 mg/l Al of both raw water sources exhibited low DOC removal (20.6-38.7% of Ping River and 27.4-46.4% of Ang Keaw Reservoir) when compared with In-line coagulation prior membrane filtration. It was suspected that DOC removal by In-line coagulation in all PACl doses combined with 1.0 µm ceramic membrane from Ping River water were significantly lower than that by Jar Test in all PACl dose. These results obtained can be indicated that the detention time of flocs formation inside 7-meters–nylon tube prior 1.0µm ceramic membrane may not enough to form the flocs size larger than 1.0 µm (The detention time values for In-line coagulation were summarized in AppendixA). Therefore, the longer detention time was required for the flocculation process of in-line coagulation prior 1.0 µm ceramic membrane in case of low turbidity water (the average turbidity of Ang Keaw Reservoir raw water is 19.6 NTU) in order to enhance the flocs forming efficiency.

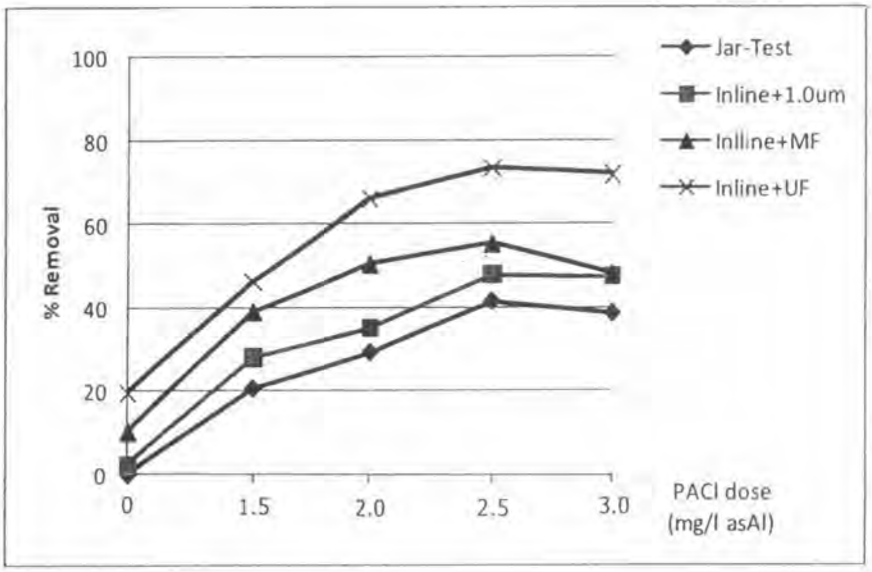


Figure 4.3 DOC removals by Jar Test and In-line coagulation combined with ceramic membrane from Ping River water

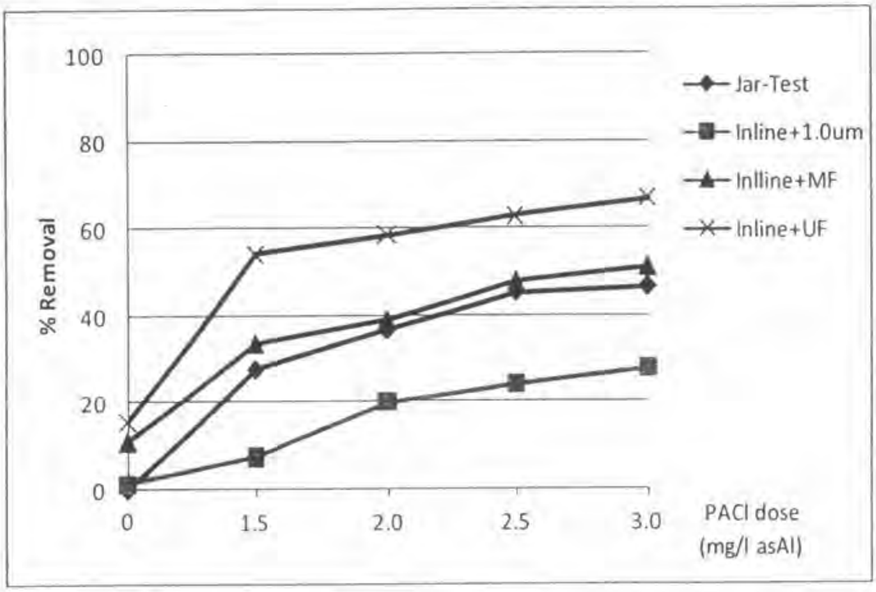


Figure 4.4 DOC removals by Jar Test and In-line coagulation combined with ceramic membrane from Ang Keaw Reservoir water

DOC removal of Ping River water and Ang Keaw Reservoir water by In-line coagulation combined with 1.0 μm with various PACl dose were in range 28.1%-47.8% and 7.5%- 27.8%, respectively. The results obtained were lower than 50% DOC removal. This could be implied that In-line coagulation combined with 1.0 μm was inadequate condition to remove DOC from Ping River water and Ang Keaw Reservoir water.

The differences of DOC removals by In-line coagulation combined with MF and that with UF at the optimal PACl dose of each water sources (at PACl dose of 2.5 and 3.0 mg/l Al for Ping River water and Ang Keaw Reservior water, respectively), were 18.1% and 15.5% for Ping River water and Ang Keaw Reservior water, respectively. Although the DOC removal efficiency of In-line coagulation combined with UF was significantly higher than that with MF, MF has much higher permeability than UF. From the fact that the higher filter permeability, the higher filtrate flow rate (The filtrate flow rate data in this study were concluded in Appendix A). The keys to select the appropriate membrane pore size for practical operation were the filtrate quality and filtrate quantity that depend up on the utilizable purpose. However, this section could be concluded that In-line coagulation at PACl dose of 2.5 mg/l Al combined with UF was the most achievable condition for DOC removal in

Ping River water (73.8% removal) and In-line coagulation at PACl dose of 3.0 mg/l Al combined with UF was the most achievable condition for DOC removal in Ang Keaw Reservoir water in this study (66.6%).

4.2.2 UV-254 removal

The UV-254 results of all experiments were summarized in Table 4.3. The UV-254 removals were illustrated in Figure 4.5 and 4.6 for Ping River water and Ang Keaw Reservior water, respectively.

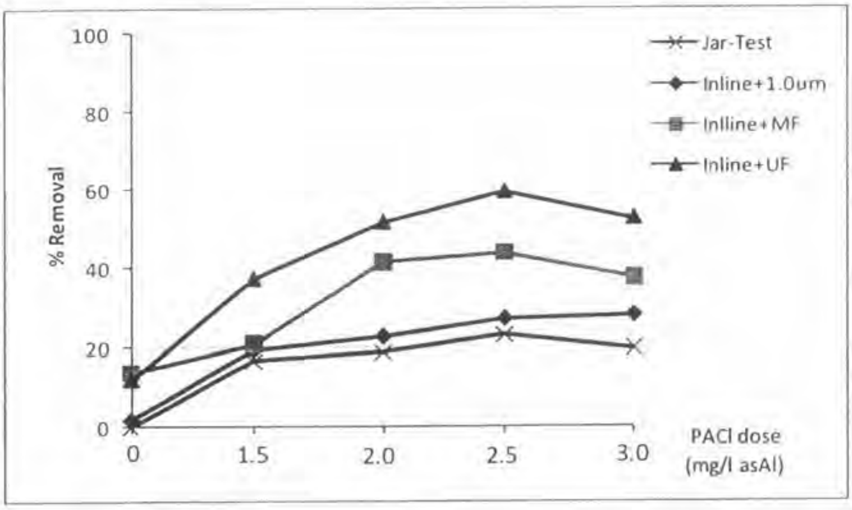


Figure 4.5 UV-254 removals by Jar Test and In-line coagulation combined with ceramic membrane from Ping River water

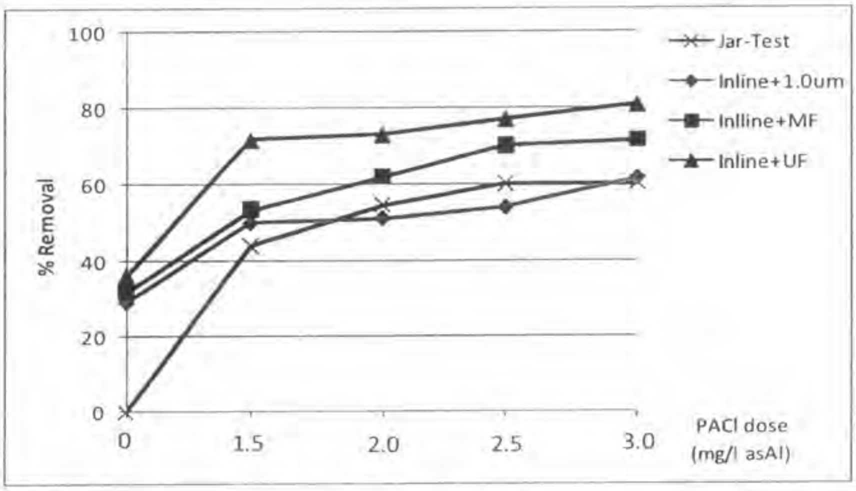


Figure 4.6 UV-254 removals by Jar Test and In-line coagulation combined with ceramic membrane from Ang Keaw Reservoir water

As mentioned 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 wavelength 254 nm. Moreover, UV-254 is well-known DOM surrogate parameter for creating THMs (Eaton *et al.*, 1995).

As illustrated in Figure 4.5, the In-line coagulation with various PACl dose combined with 1.0 μm, MF, and UF reduced UV-254 by 19.3-28.0%, 20.9-43.7%, and 37.3-59.4%, respectively from Ping River water. Their results showed that the water from Ping River could not reduced UV-254 sufficiently by In-line coagulation with various PACl dose combined with 1.0 μm and MF (UV-254 removal lower than 50%). The moderate UV-254 removal was by In-line coagulation with 2.5 mg/l Al combined with UF that exhibited the percent removal about 60%. For the UV-254 removal of Ang Keaw Reservoir water as presented in Figure 4.6, the In-line coagulation with various PACl dose combined with 1.0 μm, MF, and UF reduced UV-254 by 49.9-61.5%, 53.5-71.4%, and 71.7-80.9%, respectively. The % UV-254 reduction in Ang Keaw Reservoir water was very high compared with that in Ping River water. It may refer that the ability to remove aromatic compounds was better than aliphatic compounds in Ang Keaw Reservoir water comparing with that in Ping River water.

4.2.3 SUVA removal

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 indicated the presence of organic matter of lower average molecular weight (AMW) with more fulvic character. SUVA values of 4-5 L/mg-m are typical of waters containing primarily humic material (Edzwald and Van Benschoten, 1990). As the SUVA values demonstrated in table 4.1, the average SUVA values observed were 2.50 and 3.04 L/mg-m of Ping River water and Ang Keaw Reservoir water, respectively. It can be stated that Ping River water mostly contains non-humic material while Ang Keaw Reservoir water mostly contains humic material. This suggests that the aromatic organic content which was more humic-like in character and higher AMW contained in Ang Keaw Reservoir water could be treated more effectively than the aromatic organic, fulvic-like and lower in AMW found in Ping River water.

As shown in Figure 4.7, the SUVA removal of Ang Keaw Reservoir water that mostly contains humic material was achieved by PACl coagulation process. In case of Ping River water, SUVA value was not reduced by Jar Test and In-line coagulation combined with ceramic membrane that utilized PACl as coagulant. Moreover, SUVA of Ping River water trended to increase after the coagulation by PACl. It was suspected that the UV-insensitive fraction in Ping River water could be easily removed by coagulation process that using PACl as coagulant; therefore, the remaining dissolved organic matter in the treated water was mainly composed of more UV-sensitive fractions that provided a high relative index of DOC humic content. This hypothesis referred to UV-sensitive and UV-insensitive fraction that classified organic substances in DOCs on the basis of their ability to adsorb light in the UV range (Tambo, 1989). McKnight *et al.* (1994) proposed that the UV-sensitive fraction was mostly hydrophobic or aromatic in nature.

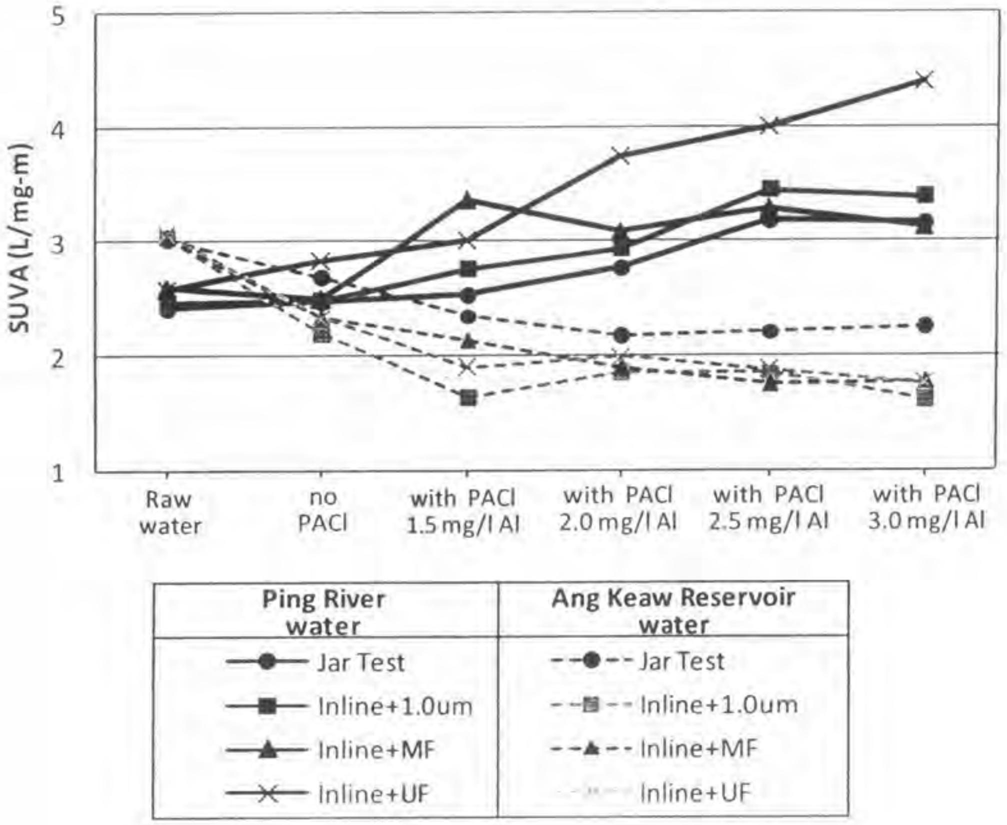


Figure 4.7 SUVA values of Ping River water and Ang Keaw Reservoir water treated by Jar Test and In-line coagulation combined with ceramic membrane

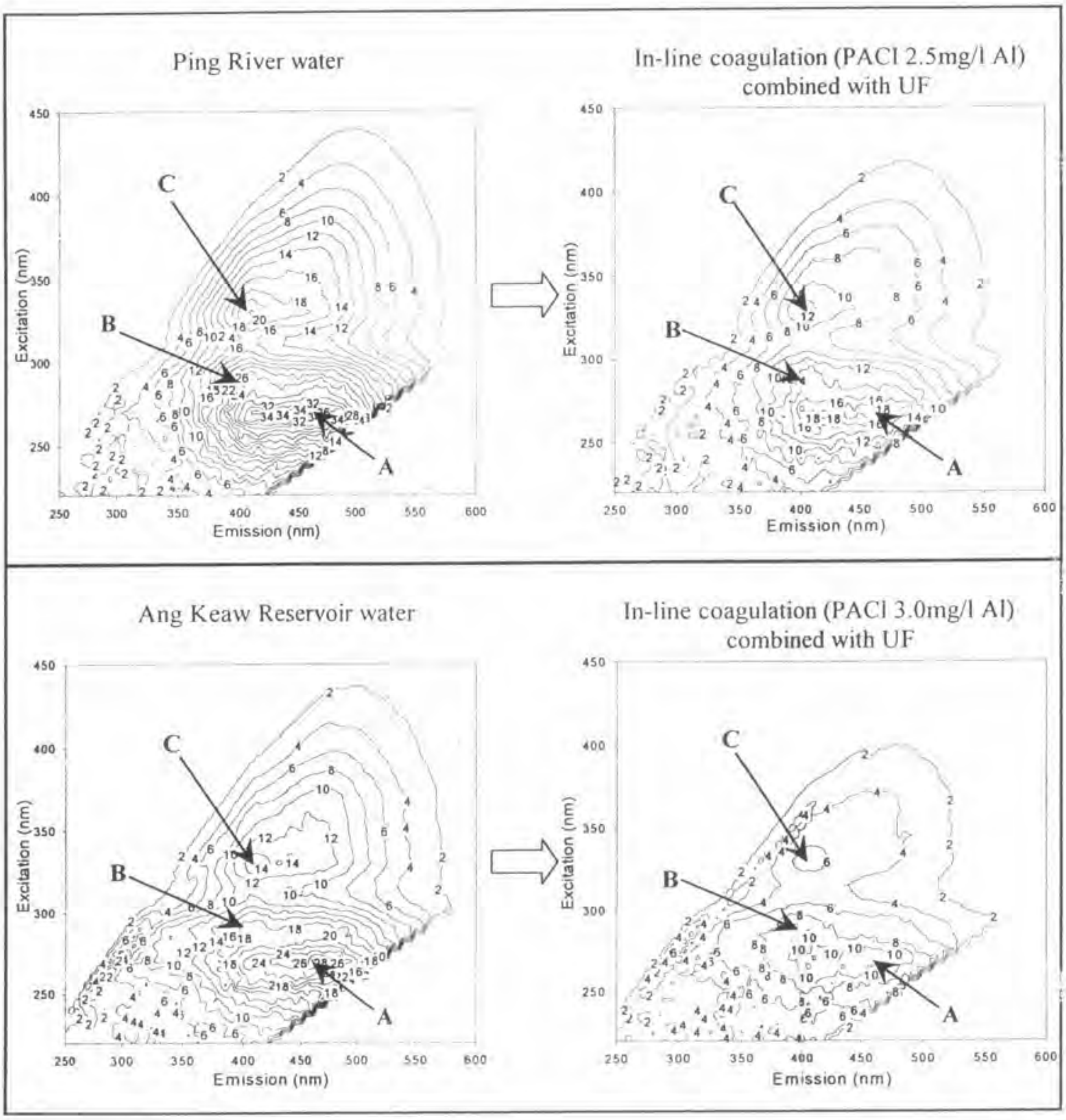
Table 4.3 DOC, UV-254, and SUVA values of raw water and treated water

Water samples	Ping River water			Ang Keaw Reservoir water		
	DOC (mg/l)	UV-254 (1/cm)	SUVA L/mg-m	DOC (mg/l)	UV-254 (1/cm)	SUVA L/mg-m
Raw water	2.17	0.0523	2.41	2.98	0.0899	3.02
Jartest with 1.5 mg/l Al	1.72	0.0437	2.53	2.16	0.0503	2.33
Jartest with 2.0 mg/l Al	1.54	0.0426	2.77	1.89	0.0408	2.16
Jartest with 2.5 mg/l Al	1.27	0.0403	3.18	1.63	0.0358	2.19
Jartest with 3.0 mg/l Al	1.33	0.0420	3.16	1.60	0.0357	2.24
Raw water	2.20	0.0540	2.45	3.14	0.0956	3.04
1.0μm	2.15	0.0531	2.48	3.10	0.0678	2.19
In-line(with 1.5 mg/l Al)+1.0μm	1.58	0.0436	2.75	2.91	0.0479	1.65
In-line(with 2.0 mg/l Al)+1.0μm	1.43	0.0418	2.93	2.51	0.0467	1.86
In-line(with 2.5 mg/l Al)+1.0μm	1.14	0.0394	3.45	2.38	0.0441	1.85
In-line(with 3.0 mg/l Al)+1.0μm	1.15	0.0389	3.38	2.27	0.0368	1.62
Raw water	2.34	0.0604	2.58	3.14	0.0956	3.04
MF	2.10	0.0521	2.49	2.79	0.0650	2.33
In-line(with 1.5 mg/l Al)+MF	1.42	0.0478	3.36	2.09	0.0445	2.13
In-line(with 2.0 mg/l Al)+MF	1.15	0.0354	3.08	1.92	0.0363	1.89
In-line(with 2.5 mg/l Al)+MF	1.04	0.0340	3.28	1.64	0.0287	1.75
In-line(with 3.0 mg/l Al)+MF	1.21	0.0378	3.12	1.54	0.0273	1.78
Raw water	2.34	0.0604	2.58	3.05	0.0936	3.07
UF	1.88	0.0532	2.83	2.58	0.0598	2.32
In-line(with 1.5 mg/l Al)+UF	1.25	0.0379	3.02	1.40	0.0265	1.89
In-line(with 2.0 mg/l Al)+UF	0.78	0.0292	3.73	1.27	0.0252	1.98
In-line(with 2.5 mg/l Al)+UF	0.61	0.0245	3.99	1.14	0.0214	1.88
In-line(with 3.0 mg/l Al)+UF	0.65	0.0286	4.39	1.02	0.0179	1.76

This section can be concluded that an appropriate condition to remove DOM considering in DOC and UV-254 removal in Ping River water and Ang Keaw Reservior water would be the In-line coagulation (with PACl dose of 2.5 mg/l Al and 3.0 mg/l Al, respectively) combined with UF ceramic membrane. The reduction of organic matter significantly indicating rejection of DOM not only by the pore size exclusion, but also other separation mechanisms such as adsorption onto the membrane surface, adsorption onto particles in the cake layer or sieving as a result of physical constriction of the membrane pores due to irreversible fouling as indicated by other investigators (Nuray *et al.*, 2008).

4.3 DOM characterization and DOM removal efficiency by FEEM

Examples of FEEM peaks obtained from this study were demonstrated in Figure 4.8. From all the water samples, a total of three fluorescent peaks were detected at (A) 270 nmEx/ 450-470 nmEm, (B) 290 nmEx/400-415 nmEm, and (C) 330 nmEx/400-415 nmEm.



Ping River water

In-line coagulation (PACl 2.5mg/l Al) combined with UF

Ang Keaw Reservoir water

In-line coagulation (PACl 3.0mg/l Al) combined with UF

Figure 4.8 Examples of FEEM peaks reduction at peak position A, B, and C in the contour graphs with 2 QSU contour interval

These three fluorescent peaks were categorized into regionV which represented humic-like substance in the boundaries of the FEEM peak created by Chen *et al.* (2003), as shown in Figure 4.9. Literature recommended the potential origins of fluorescent spectra as summarized in Table 4.4. Humic and fulvic acid-like substances were mostly found in natural water that related to peaks A, B, and C presented in this study.

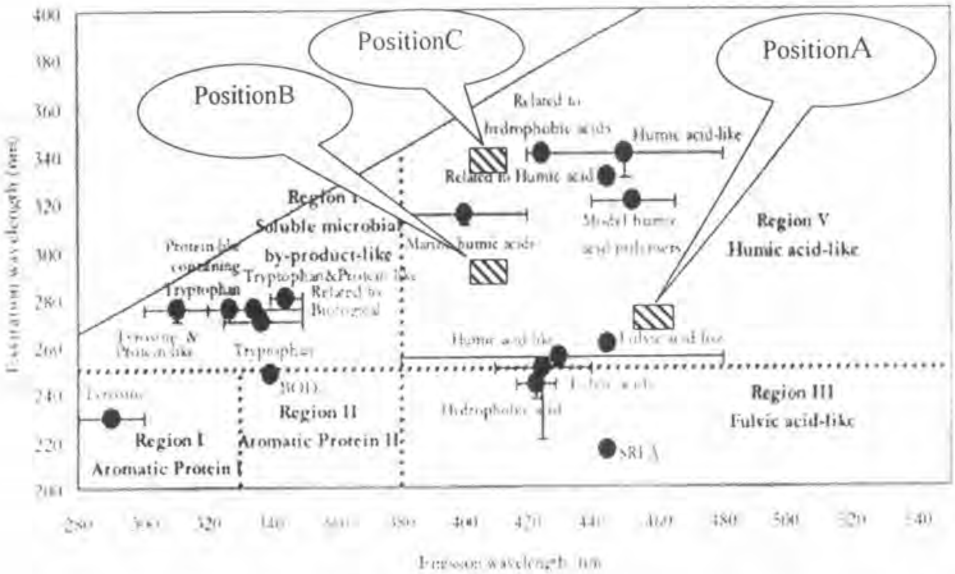


Figure 4.9 Position A, B, and C marked on the boundaries of FEEM peaks defined excitation and emission wavelength for five regions created

The level of fluorescent intensities depends upon the level of organic substances in the water. In case of high organic content in water the high value of fluorescent intensities are observed, whereas in case of low organic content, low values of fluorescent intensities are obtained (Homklin, 2004). Musikavong *et al*.(2006) suggested that the fluorescent intensity in the QSU units of each fluorescent peak could be further utilized to determine the quantity of all fluorescent organic matters in water by adding the fluorescent intensities of all FEEM peaks. The reduction in the fluorescent organic matters could therefore be reflected by the difference in the total fluorescent intensities of the total fluorescent organic matter by Jar Test and In-line coagulation combined with ceramic membrane. Figure 4.10 and 4.11 illustrated the summation of fluorescent intensity of all FEEM peaks from all water samples to evaluate the reduction of fluorescent organic compounds in Ping River water and Ang Keaw Reservoir water through Jar Test and In-line coagulation combined with ceramic membrane. For Ping River water, it was found that 10.4-11.7%, 13.1-26.0%, 20.3-26.8% and 37.7-46.8% of the fluorescent organic compounds were reduced by Jar Test with various PACl dose, In-line coagulation with various PACl dose combined with 1.0 μm, MF, and UF, respectively. For Ang Keaw Reservoir water, it was found that 12.6-32.1%, 11.9-23.8%, and 27.3-45.8% of the fluorescent organic compounds were reduced by Jar Test with various PACl dose. In-line coagulation with various PACl dose combined with 1.0 μm, MF, and UF, respectively.

The results implied that humic acid-like substances, represented by peaks A, B, and C could be unsuccessfully remove by Jar Test and In-line coagulation combined with 1.0 μm and MF in both of raw water sources whereas In-line coagulation with PACl dose of 2.5 mg/l Al combined with UF could be moderately reduce peaks A, B, and C.

Table 4.4 Summary of the proposed mapping of FEEM regions and fluorescent DOM substances

Substances	**Excitation(nm)/ Emission(nm)**	**Sources**	**References**
Fulvic acid	350/450	Suwannee River, Peat and soil standards, IHSS	Marhaba and Kochar (2000)
	315/-437-441	Extracted from frest soil in Dando, Japan	Yamashita and Tanoue (2003)
	245/445, 320/443	Suwannee River fulvic acid (SRFA, with lower MW and high aromaticity)	Her et al. (2003)
	220/445	standard fulvic acid (SFA)	Chen et al. (2003)
	255/455, 320/450	Suwannee River fulvic acid (1S101F), IHSS	Sierre et al. (2005)
	265/475, 325/440	Elliot Soil fulvic acid (1S102F), IHSS	Sierre et al. (2005)
Humic acid	250/450	Suwannee River, Peat and soil standards ,IHSS	Marhaba and Kochar (2000)
	235-255/453-465	Commercially available humic acid, Wako	Nakajima et al. (2002)
	260/485, 330/470	Suwannee River Humic Acid (1S101H), IHSS	Sierre et al. (2005)
	270/550, 360/560	Elliot Soil Humic acid (1S102H), IHSS	Sierre et al. (2005)
	261/457, 325/452	Suwannee River humic acid (SRHA, with larger MW and high aromaticity)	Her et al. (2003)
Fulvic acid and Humic acid-like proposed	235/435, 320/430	Lake water, Japan	Komatsu et al. (2005)
	290-340/395-430	Groundwater, from Sutherland, Scotland; Derbyshire, England; Dordogne, France; Wiltshire, England	
	230/440, 340/440	Hawaiian River water	Coble et al. (1993)
	260/380-460, 350/420-480	Bulk seawater	Coble (1996)
	339/420-422	Discharge from Sewage treatment plants, England	Baker (2001)
	343/433	Discharge from Tissue mill, Northumberland, England	Baker (2002)
	320-360/400-470	Landfill leachates, England	Baker and Curry (2004)
	337/423	Natural water and Wastewater, USA	Her et al. (2003)

(Source: Janhom *et al.*, 2009)

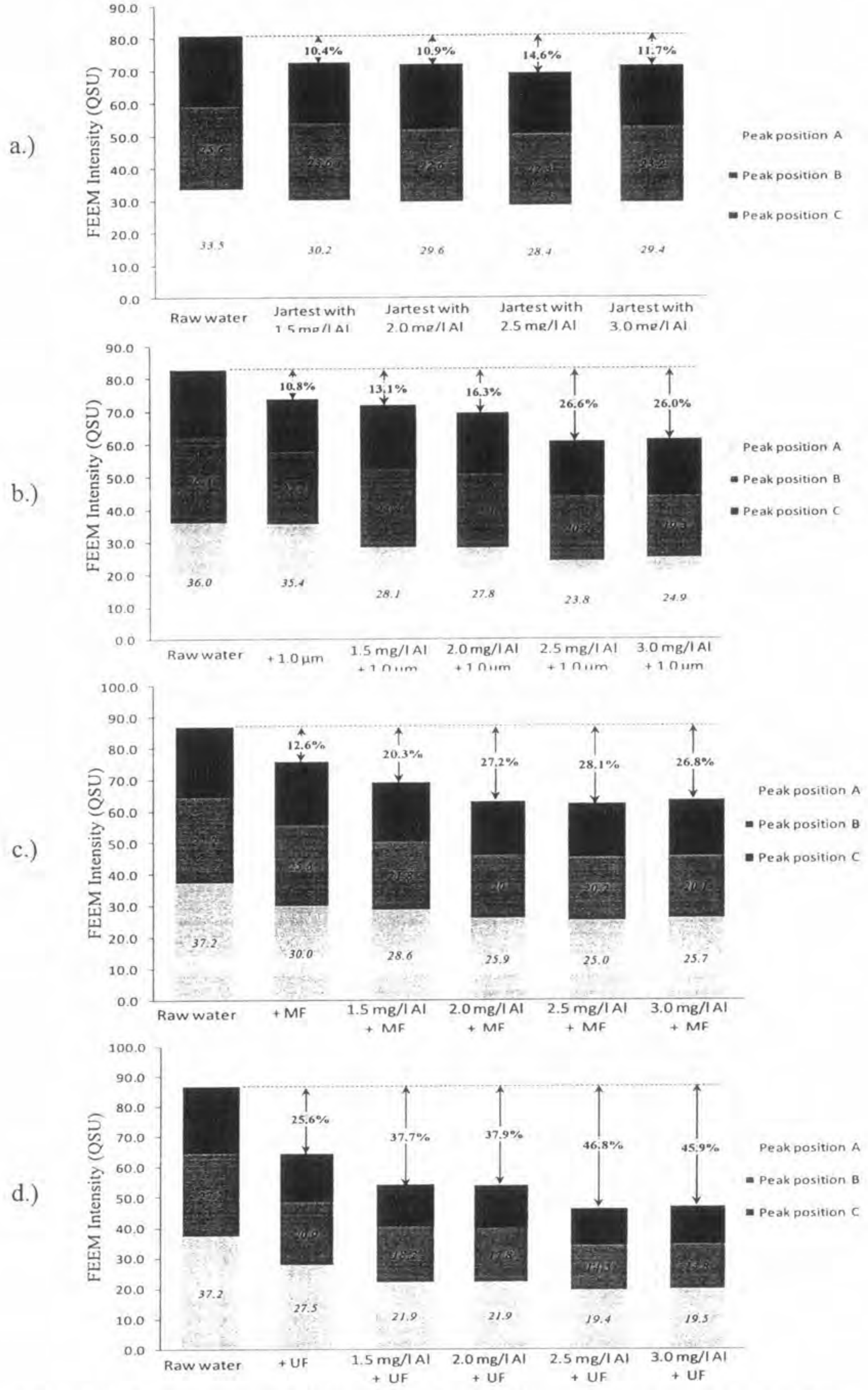


Figure 4.10 Reduction of FEEM peaks of Ping River water through a.) Jar Test, b.) In-line+1.0μm, c.) In-line+MF, and d.) In-line+UF

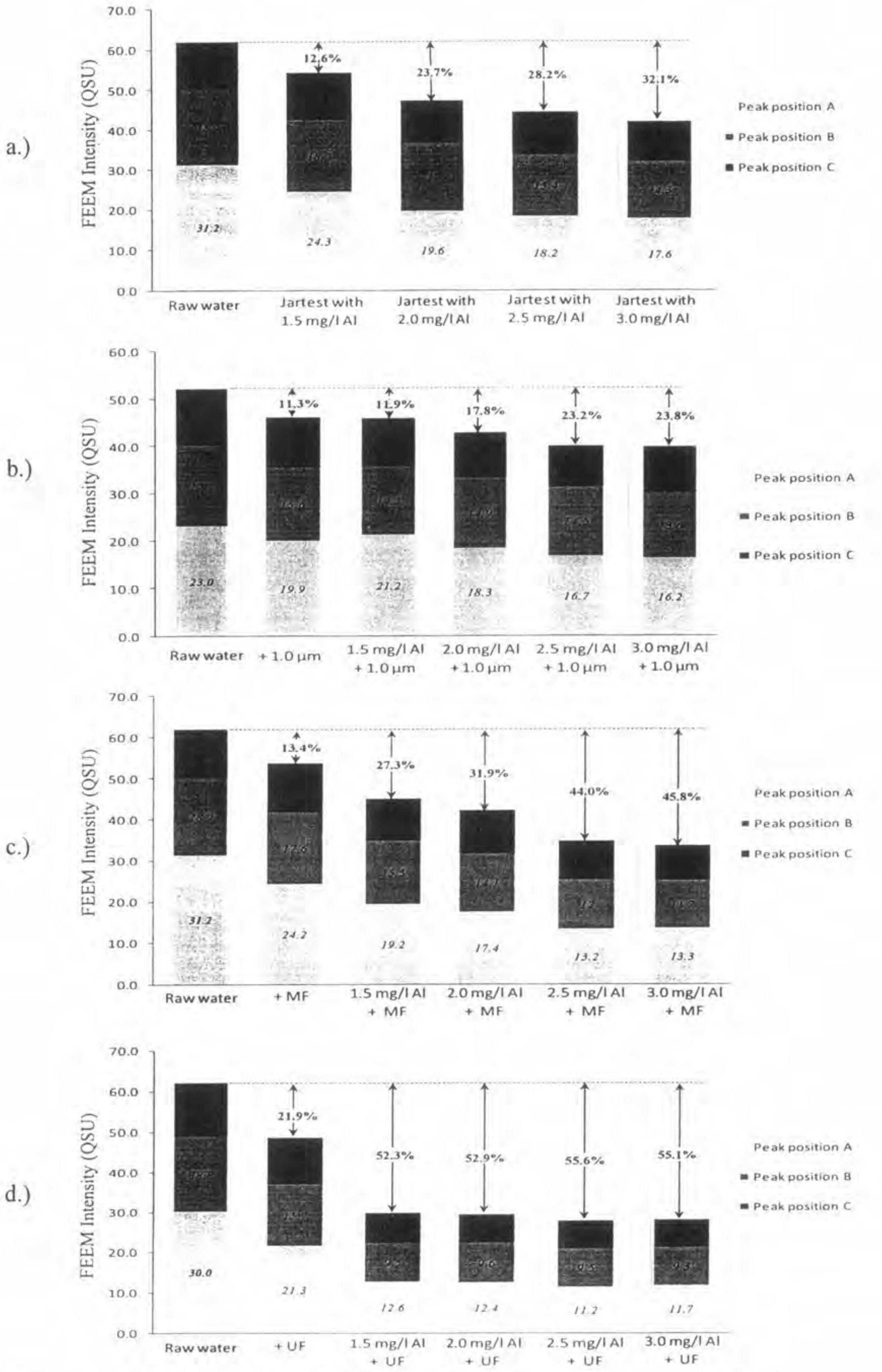


Figure 4.11 Reduction of FEEM peaks of Ang Keaw Reservoir water through a.) Jar Test,b.) In-line+1.0μm, c.) In-line+MF, and d.) In-line+UF

4.4 The removal efficiency of THMFP

THMFP has been commonly utilized to determine the THMs at the completion of the reaction condition between DOM and the excess amount of chlorine. Water with a high THMFP value could potentially form a high level of THMs. In addition, the reduction of the THMFP by water treatment processes can be used to represent the reduction of DOM, which has an active ability of forming THMs. THMFP, therefore, was considered to be an appropriate indicator and was utilized to monitor the highest possible concentrations of THMs in the water. The THMFP was determined from the summation of the Chloroform Formation Potential ($CHCl_3$-FP), Dichlorobromoform Formation Potential ($CHCl_2Br$-FP), Dibromochloroform Formation Potential ($CHClBr_2$-FP), and Bromoform Formation Potential ($CHBr_3$-FP)

THMFP removal by Jar Test and Inline coagulation combined with ceramic membrane was illustrated in Figure 4.12 for Ping River water and Figure 4.13 for Ang Keaw Reservoir water.

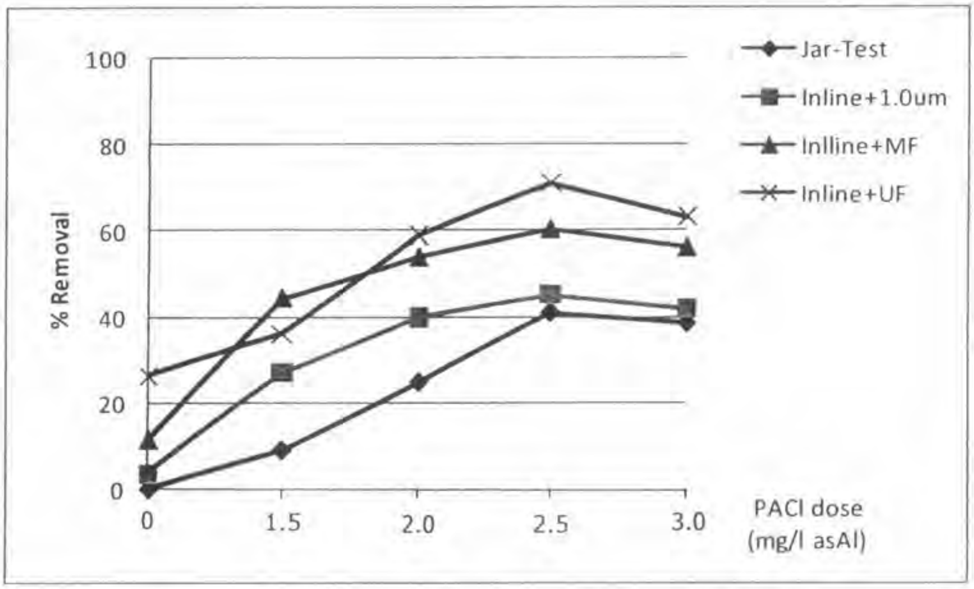


Figure 4.12 THMFP removals by Jar Test and In-line coagulation combined with ceramic membrane from Ping River water

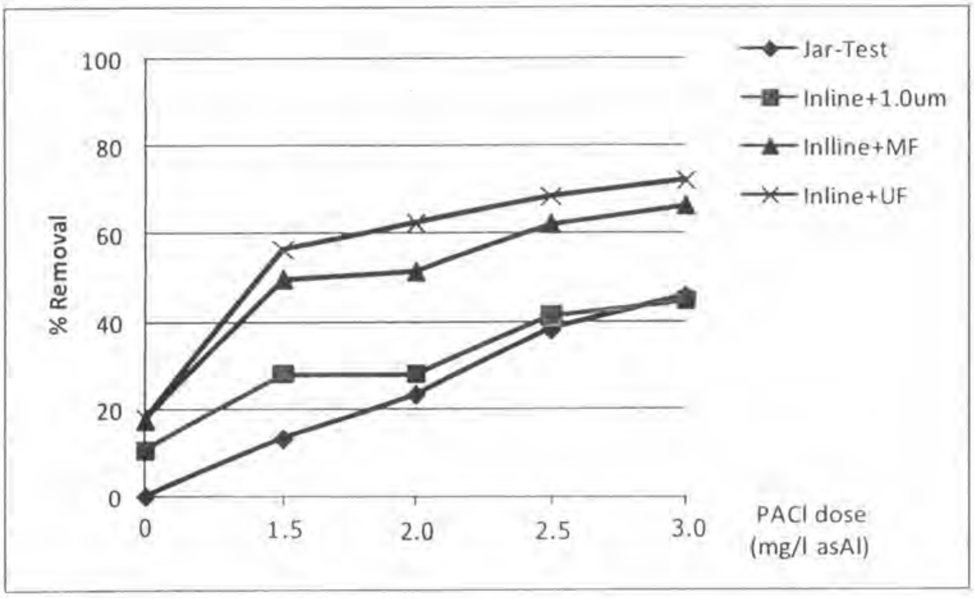


Figure 4.13 THMFP removals by Jar Test and In-line coagulation combined with ceramic membrane from Ang Keaw Reservoir water

THMFP values for all water samples and their THMFP species values were summarized in Appendix A. When considering the presence of THM species, it was found that Chloroform was the major THM species in the water samples in this study and in other water supply sources in Thailand. This observation also corresponded well with the results of previous research (Rodriguez *et al.*, 2003, Thacker *et al.*, 2002).

As can be seen from Figure 4.12, THMFP removal by Jar Test, Inline coagulation combined with 1.0μm, MF, and UF at optimum PACl dose (2.5 mg/l Al for Ping River water when considering in THMFP removal efficiency) were 41.0, 45.2, 60.4, and 71.0%, respectively.

As can be seen from Figure 4.13, THMFP removal by Jar Test, Inline coagulation combined with 1.0μm, MF, and UF at optimum PACl dose (2.5 mg/l Al for Ang Keaw Reservoir water when considering in THMFP removal efficiency) were 45.9, 44.8, 66.5, and 72.3%, respectively.

4.6 Water quality monitoring by microbial indicators

4.6.1 Total coliform and *E. coli* indicator

As stated previously, total and fecal coliforms have been used extensively for many years as indicators for determining the sanitary quality of natural water. This section was aimed to induce total coliform and *E. coli* as microbial indicators to evaluate water quality after the treatment process.

The condition of sample waters in this section was selected by considering in DOM surrogate parameters removal from previous topic. From the results obtained in topic 4.2, the appropriate PACl dose to reduce DOM surrogate parameters for In-line coagulation combined with ceramic membrane was 2.5 mg/l Al for Ping River water and 3.0 mg/l Al for Ang Keaw Reservoir water.

In order to compare the efficiency of each membrane pore size for fecal pollution reduction, total coliform and *E. coli* were detected from the filtrated Ping River waters of In-line coagulation with 2.5 mg/l Al combined with 1.0μm, MF, and UF. Similarly, total coliform and *E. coli* were detected from the filtrated Ang Keaw Reservoir waters through In-line coagulation with 3.0 mg/l Al combined with 1.0μm, MF, and UF.

Total coliform and *E. coli* detection were analyzed by single agar layer method using Chromocult Coliform agar as culture media. Triple analyzed plate counts were always done in each dilution. Salmon to red colonies and dark-blue to violet colonies were counted as total coliforms. Dark-blue to violet colonies were counted as *E.coli*. The concentration of microbes was reported as Colonies Forming Unit/ ml (CFU/ml). The detection limit in this experiment was 0.5 CFU/ml.

Total coliform and *E.coli* were used as indicators for determining the fecal pollution reduction in this experiment. Total coliform and *E.coli* was found from Ping River water in amount of 75 CFU/ml and 4 CFU/ml, respectively and from Ang Keaw

Reservoir water in amount of 500 CFU/ml and 40 CFU/ml, respectively. From the results obtained from both of two raw water sources, 1.0μm ceramic membrane and In-line coagulation combined with 1.0μm ceramic membrane could fairly remove total coliform while MF/UF ceramic membrane and In-line coagulation combined with MF/UF ceramic membrane could remove total coliform and *E.coli* completely.

According to the results, it could be concluded that the microbial quality of the water sources was poor and unacceptable for human consumption due to faecal pollution (DWAF, 1998 set the maximum limit for no risk of faecal coliforms is 0 CFU/100ml). It could be certainly suggested that the MF/UF ceramic membrane with or without cogulation as pretreatment could be efficiently used for feacal pollution treatment ;since, coliform bacteria are larger than the absolute pore size of the membranes (0.6–1.2 μm in diameter by 2–3 μm in length).

Table 4.5 Total coliform and *E.coli* results of filtrated Ping River water from In-line coagulation with 2.5 mg/l Al combined with 1.0µm, MF, and UF

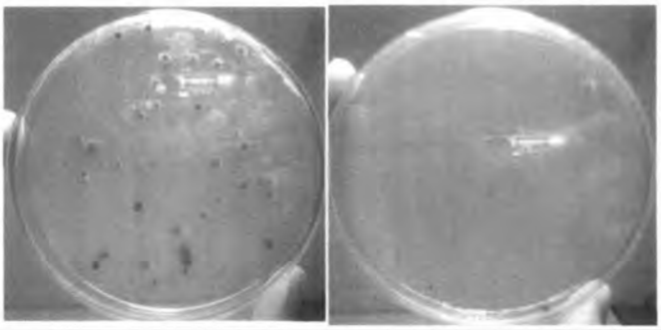
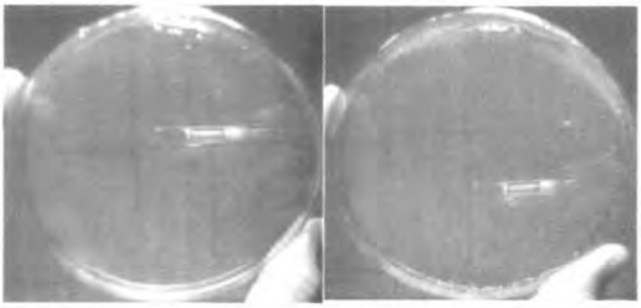
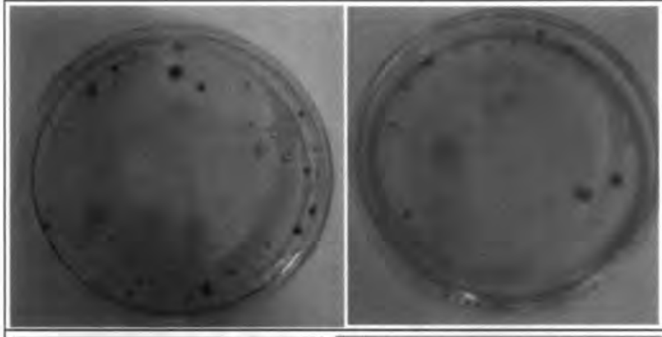
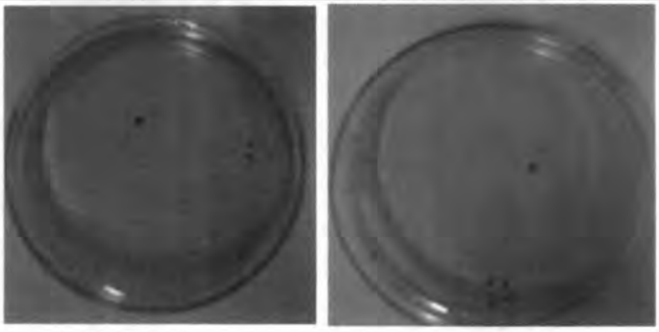
	**Raw water** *Total coliform* 71×10^0 CFU/ml 7×10^1 CFU/ml Avg. = 75 CFU/ml *E.coli* = 4 CFU/ml
	**1.0µm** *Total coliform* 3×10^0 CFU/ml 2×10^0 CFU/ml Avg. = 2.5 CFU/ml *E.coli* = -
	**2.5 mg/l Al + 1.0µm** *Total coliform* 1×10^0 CFU/ml 1×10^0 CFU/ml Avg. =1 CFU/ml *E.coli* = -
-	**MF** *Total coliform* = - *E.coli* = -
-	**2.5 mg/l Al + MF** *Total coliform* = - *E.coli* = -
-	**UF** *Total coliform* = - *E.coli* = -
-	**2.5 mg/l Al + UF** *Total coliform* = - *E.coli* = -

Table 4.6 Total coliform and *E.coli* results of filtrated Ang Keaw Reservoir water from In-line coagulation with 3.0 mg/l Al combined with 1.0μm, MF, and UF

	**Raw water** *Total coliform* 54 x 10^1 CFU/ml 46 x 10^1 CFU/ml Avg. = 500 CFU/ml *E.coli* 5 x 10^1 CFU/ml 3 x 10^1 CFU/ml Avg. = 40 CFU/ml
	**1.0μm** *Total coliform* 10 x 10^1 CFU/ml 7 x 10^1 CFU/ml Avg. = 85 CFU/ml *E.coli* = 1 x 10^1 CFU/ml 1 x 10^1 CFU/ml Avg. = 10 CFU/ml
	**3.0 mg/l Al + 1.0μm** *Total coliform* 3 x 10^0 CFU/ml 5 x 10^0 CFU/ml Avg. =8 CFU/ml *E.coli* = 1 x 10^0 CFU/ml 0 x 10^0 CFU/ml Avg. = 0.5 CFU/ml
-	**MF** *Total coliform* = - *E.coli* = -
-	**3.0 mg/l Al + MF** *Total coliform* = - *E.coli* = -
-	**UF** *Total coliform* = - *E.coli* = -
-	**3.0 mg/l Al + UF** *Total coliform* = - *E.coli* = -

4.6.2 Bacteriophage indicator

To evaluate the virus removal performance of the In-line coagulation combined with ceramic membrane filtration, bacteriophages (viruses that infect bacteria) have been used as possible indicators for enteric viruses as their morphology and survival characteristics closely resemble to some of the important human virus groups.

In order to compare the efficiency of each membrane pore size for viral indicator reduction, *E. coli* K12 A/λ (F+), *E.coli* WG5 *and Salmonella typhimurium* WG 49 were use as host for bacteriophages detection from the filtrated Ping River waters of In-line coagulation with 2.5 mg/l Al combined with 1.0μm, MF, and UF. Similarly, bacteriophages were detected from the filtrated Ang Keaw Reservoir waters through In-line coagulation with 3.0 mg/l Al combined with 1.0μm, MF, and UF.

F-specific RNA bacteriophages were analyzed in double agar layer method by using *Salmonella typhimurium* WG 49 as host strains. The procedures followed the standardized protocol (ISO, 1997). For somatic coliphage counts, *Escherichia coli* strain WG5 (*E.coli* WG5), which is resistant to nalidixic acid, was used as host to enumerate somatic coliphage in the double agar layer plaque assay on phage agar described in the corresponding standardized protocol (ISO, 1998). As described previously, natural host strains of somatic coliphages include besides *Escherichia coli* or other closely related bacterial species. F-specific RNA bacteriophages are infectious for bacteria which possess the F- or sex plasmid originally detected in *Escherichia coli* K-12. Therefore, *E. coli* K12 A/λ (F+) might be used as host strain for enumeration of F-specific RNA bacteriophages and somatic coliphages

Figure4.14 was illustrated the example of bacteriophage plaque forming in this study. Table 4.7 was shown the bacteriophage count results from filtrated Ping River water and filtrated Ang Keaw Reservoir water by In-line coagulation combined with 1.0μm, MF, and UF. From the obtained results, F-specific RNA bacteriophages that using WG 49 as host, was not found in almost dilution line in both of two water sample sources. Even in the raw water from Ang Keaw reservoir, the result was also absent while $1x10^2$ PFU/ml was presented the raw water from Ping River.

As can be seen from table 4.7, somatic coliphage that using *E.coli* WG5 as host, was presented $2x10^1$ PFU/ml in Ping River water and reduced to 1.5 PFU/ml by 1.0μm filtration. Filtrated Ping River water through MF, UF, In-line coagulation combined with 1.0μm, MF, and UF were shown all absent results. For Ang Keaw reservoir water, the results was presented $1x10^2$ PFU/ml in raw water and reduced to $1 x10^1$ PFU/ml by 1.0μm filtration. Filtrated Ang Keaw reservoir water through MF, UF, In-line coagulation combined with 1.0μm, MF, and UF were shown all absent results.

In case of using *E. coli* K12 A/λ (F+) as host for enumeration of F-specific RNA bacteriophages and somatic coliphages, it was suspected that the presented results shown in the dilution line were not related each other; for instance, the plaques counted from raw water of Ping River were $6.5x10^2$ and $0x10^1$ PFU/ml and the plaques counted from filtrated Ping River water (through 1.0μm) were $1x10^2$ and $0x10^1$ PFU/ml, and the plaques counted from raw water of Ang Keaw Reservoir were $1.5x10^3$ and $3x10^2$ PFU/ml. These results could not use as quantitative data as its unreliable results obtained. This may be explained that plaque assay in this study was enumerated by adding 1 ml of water samples each plate counts; therefore, the possible detection limit was not less than 0.5 PFU/ml. The limitation of the plaque count assays exhibited in this study might be implied that the concentration of bacteriophages (F-specific RNA bacteriophages and somatic coliphages) in water samples rather much more lowly under the detection limit.

This may be suggested to further studies that, it is necessary to apply more water sample volume adding for plaque assay and/or apply virus concentration method in order to increase bacteriophages concentration in water samples prior plaque assay. Moreover, the virus spike, which normally used for evaluate the water treatment applicability in previous studies (Haramoto *et. al*, 2004; Shirasaki *et. al*, 2008), may be introduced to be the optional method to increase the virus concentration in water samples.

Table 4.7 Bacteriophage count results from filtrated Ping River water and filtrated Ang Keaw Reservoir water by In-line coagulation combined with 1.0μm, MF, and UF

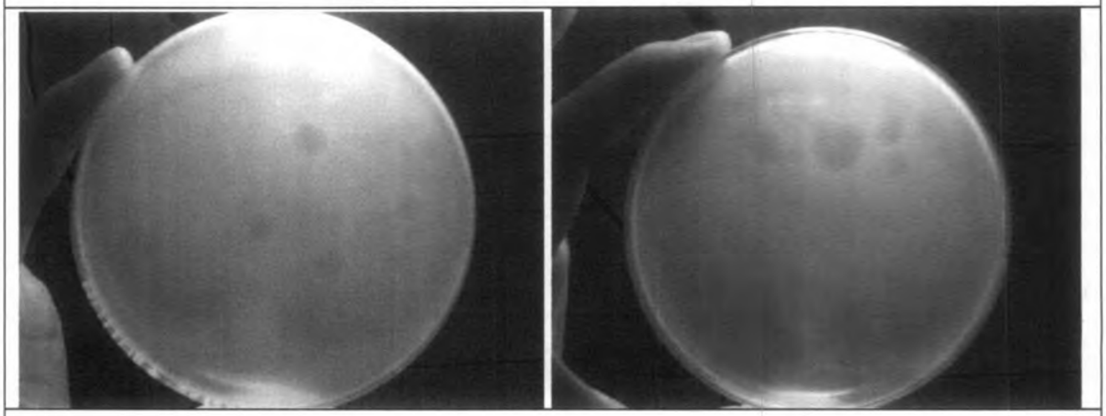
Water samples	Plaque Forming Unit (PFU/ml) in dilution line														
	Using K12 as host					Using WG5 as host					Using WG49 as host				
	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
Ping River water															
Raw water	-	ND	6.5	ND	ND	-	2	ND	ND	ND	-	ND	1	ND	ND
1.0 μm	-	ND	1	ND	-	-	1.5	ND	ND	-	-	ND	ND	ND	-
2.5mg/lAl+ 1.0 μm	-	2	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-
MF	2	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
2.5mg/l Al + MF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
UF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
2.5mg/l Al + UF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
Ang Keaw Reservoir water															
Raw water	-	-	3	1.5	ND	-	-	1	ND	ND	-	-	ND	ND	ND
1.0 μm	-	7	ND	ND	-	-	1	ND	ND	-	-	ND	ND	ND	-
3.0mg/lAl+ 1.0 μm	-	3	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-
MF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
3.0mg/l Al + MF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
UF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-
3.0mg/l Al + UF	ND	ND	ND	-	-	ND	ND	ND	-	-	ND	ND	ND	-	-

Note: - = Not analyzed

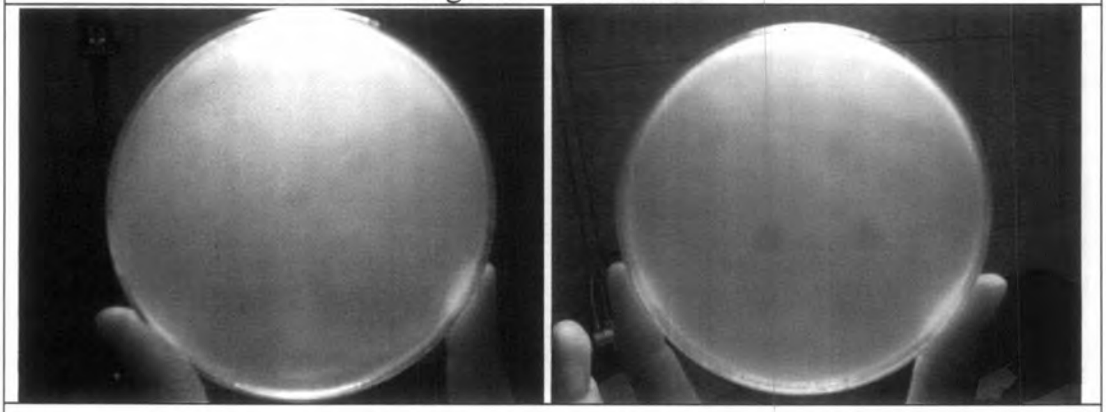
ND = Not detected

* Data were shown in average value (two-plaque-present plate counts were chosen for average in each dilution)

Using *E. coli* K12 A/λ (F+) as host



Using *E.coli* WG5 as host



Using *Salmonella typhimurium* WG 49 as host

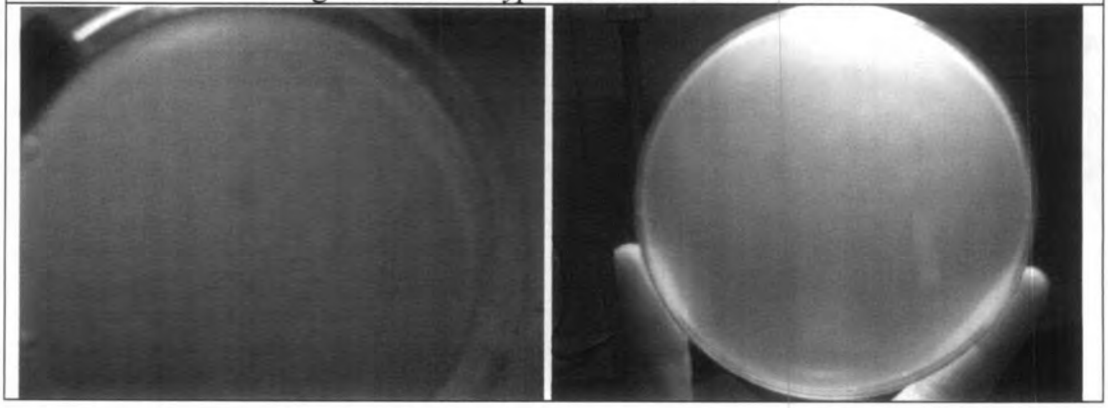


Figure 4.14 Example of bacteriophage plaques detected from this study by using a.) *E. coli* K12 A/λ (F+) , b.) *E.coli* WG5,and c.) *Salmonella typhimurium* WG 49 as host