Characterization and Treatment of Natural Organic Matter from Raw Water Supply Reservoir in Thailand

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Abstract

The purpose of this paper is to review the characteristic of natural organic matter (NOM) in raw water supply reservoir in Thailand. The dissolved organic carbon (DOC), ultraviolet absorption at wavelength 254 nm (UV-254), specific ultraviolet absorption (SUVA), trihalomethane formation potential (THMFP), hydrophobic organic fraction (HPO), hydrophilic organic fraction (HPI) and fluorescent excitation emission matrix (FEEM) were utilized to represent the nature of NOM from six reservoir including Mae-Hia Reservoir, Aung-Keaw Reservoir, Mae-Kuang Reservoir in Chiang Mai province, the Bhumibol Dam reservoir in Tak province, the Northern-Region Industrial Estate Reservoir in Lamphun province, and Sri-Trang Reservoir in Songkhla province. In addition, the removal of NOM in raw water supply from six reservoirs by coagulation was also summarized. The collected data show that the major group of organic matter found in reservoir water is humic acid and fulvic acid like substances, DOC values were less than 5 mg/L and UV-254 in all samples were less than 0.3. The alum coagulation that was used in conventional water treatment plant seems to be used effectively in objective of NOM removal also. This method is convenient and has low operation cost and showed the appreciatory value of organic removal in term of UV-254 compared with DOC in comparable to coagulation with $FeCl_3$. The contact flocculation filtration using alum as coagulant could reduce NOM less than that operated with jar test.

Keywords: DOC, FEEM, HPO, HPI, Reservoir Water, THMFP, UV-254

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Introduction

Thailand located in the tropical zone, and then the high intensity of precipitation was observed in this area. Many reservoirs were constructed to purpose of collecting runoff for many activities such as irrigation, power plant, industrial and water supply. Therefore water reservoir is one of the main sources of raw water supply in Thailand. But these water reservoirs could be contaminated by the NOM, especially dissolved organic matter (DOM). DOM in the terrestrial ecosystem originates from the decomposition of plant by various microorganisms (Khan et al.,2005). DOM in natural source including lake, river and reservoir, compose a heterogeneous mixture of aromatic and aliphatic organic compounds that contain mainly humic substances (50%-90%) and other substances (e.g. carbohydrates and proteinaceous matter) (Wen Chen et al.,2003;Ogawa et al.,2001) and (Lytle and Perdue, 1981). In aquatic environment, DOM is an important energy source of microbes as well as a source of carbon (Leenheer and Croue, 2003). Fulvic acid is known to be a dominant component among humic substances in aquatic ecosystems (Khan et al., 2005) due to their solubility compared to humic acids. DOM could react with chlorine used in the disinfection process to form potentially carcinogenic disinfection by-products (DBPs) such as haloacetic acids (HAAs) and trihalomethane (THMs) (Rook, 1974). However, DOM was decreased during the water treatment process by chemical precipitation, coagulation-flocculation (Mumean et al., 2008; Mark Benjamin,2002) and (James, 1985). The DOC, UV-254, SUVA, THMFP, HPO, HPI and FEEM are parameters that normally used to present the quantity and nature of DOM in water (Khan et al.,2005; Wen Chen et al.,2003; Musikavong et al.,2007; Musikavong et al., 2007; Andy Baker et al.,2007) and (Kathleen et al., 2008).

The aim of this work thus was to review the previous works on the characterization of NOM in reservoir water and the optimal condition of coagulation for the removal of NOM in Thailand. This summarized data may be useful for further study, water treatment plant operation design or water source management and DOC control planning with the appropriate technology and cost-effectiveness.

Material and methods

Characteristic of raw water supply and coagulation condition of six reservoir including Mae-Hia Reservoir, Aung-Keaw Reservoir, Mae-Kuang Reservoir in Chiang Mai province, the Bhumibol Dam reservoir in Tak province, the Northern-Region Industrial Estate Reservoir in Lamphun province, and Sri-Trang Reservoir in Songkhla province, Thailand (Mumean et al.,2008; Homklin, 2005; Musikavong et al., 2007; Janhom, 2004; Phumpaisanchai, 2005) and (Labaiji et al., 2008) were summarized and discussed in this study. Their production rates and capacities were presented in Table 1

Table 1. Production rates of water treatment plant and reservoir capacities of water supply plants studied.

Reservoir	Production rate (m^3/day)	Reservoir capacity (m^3)
Mae-Hia	-	-
Aung-Keaw	500-800	-
Mae-Kuang	52,800	-
Bhumibol Dam	-	$13,462x10^6$
Northern-Region Industrial Estate	14,400	600,000
Sri-Trang	1,500-3,000	500,000

The characteristic of raw water supply in each reservoir was compared and described in term of DOC (include DOC of hydrophobic organic fraction; HPO and hydrophilic organic fraction; HPI), UV-254, and SUVA. The reduction of DOM was evaluated in term of the reduction in DOC, UV-254, SUVA and Fluorescent peak (Fluorescent excitation-emission matrix, FEEM). The efficiencies of coagulation by Alum and/or $FeCl_3$, normally using for water treatment plant in Thailand, at the optimum condition were presented and discussed. The trihalomethane formation potential (THMFP) of coagulated water was also summarized in this paper.

For better understanding the effect of coagulant on DOC removal, the experiment of $FeCl_3$ coagulation was investigated and discussed in this study. The sampling site is pumping station of Sri-tring reservoir located in Songkhla, Southern Thailand. Sri-tring reservoir is only a raw water source for waterworks of Prince of Songhla University. The raw water samples were collected 3 times in rainy season (during December 2007-January2008). Then the raw water samples were analyzed to determine pH (pH meter HACH Sessions 1 in according to standard method 4500-H^+ B; (APHA and WEF,1998), turbidity (turbidity Meter HACH model 2100N according to Standard method 2130 B; (APHA and WEF,1998), alkalinity (titration method in according to Standard method 2320B; (APHA and WEF,1998). A portion of raw water samples was filtered through a pre-combusted (550°C for 2 hr.) Whatman GF/F filter (0.7 m), and filtrated raw water were measured UV-254 and DOC. The other portions of raw water samples were used in the $FeCl_3$ coagulation experiments with pH uncontrolled and fixed at pH 5, 6, and 7 using a Jar-Test apparatus. The $FeCl_3$ dosages used were 10 to 80 mg/L. The reduction of DOM was studied in term of UV-254 and DOC. Then water samples were taken from the optimum condition of $FeCl_3$ coagulation for DOC and UV-254 measurement. DOC was analyzed in accordance with standard method 5310D (APHA and WEF,1998) using a TOC analyzer (O.I. analytical, College Station, Texas, USA). UV-254 was analyzed in accordance with standard method 5910B (APHA and WEF,1998) using a UV/VIS spectrophotometer, Genesys 10 UV, with matched quartz cells, that provided a path length of 10 mm.

Results and Discussions

The pH of water samples collected form six water reservoir was in the range of 6.5-7.8, turbididy measured was lower than 10 NTU except the Sri-Trang reservoir samples that has slightly higher turbidity (10-15 NTU) in some period. These values showed that raw water in all six reservoirs had low tubidity. The summary of DOC, UV-254, SUVA, THMFP, HPO and HPI in raw water supply from reservoirs was presented in Table 2. It can be noted that the ranges of DOC, UV-254, SUVA, and THMFP were between 1.7 and 6.4 mg/L

(10-30 mg/L in ground water to surface water; (Khan et al.,2005) and (James, 1985) and (Kavanaugh, 1978), 0.050 and 0.280 cm-1, 1.7 and 12.2 L.mg-1.m-1, and 236 and 488 μg/L respectively. HPO was the dominant NOM fraction in reservoir water which referred the dominant of humic and fulvic like substances as presented in Table 3. In comparative to their putative origins region developed by Chen et al. (2003) and Musigavong et al. (2007) (Figure 1), It could seem that humic and fulvic like substances were observed position in region III and IV. Whereas proteins substances in water samples from Sri-Trang reservoir existed in region V that could be Tryptophane like substances. This group of organic was a protein matter that was also detected in treated water from household (Wen Chen et al.,2003 and Musikavong et al.,2007). It might say that there was impure matter by the domestic source elsewhere to the Sri-tring reservoir basin. These could have probability consequence problem during coagulation because the hydrophilic property itself (James, 1985; Homklin, 2005; Musikavong et al., 2007 ; Janhom, 2004 and Phumpaisanchai, 2005). In the case of Northern Region Industrial Estate, protein existence should be observed continuously because it is situated in the utility areas of water and wastewater treatment. Therefore the protein contamination in Mae-Kuang river, nearby water source should be monitored also even though it still did not be detected now in this river. The contamination of protein which contains nitrogen components in still water source like a water reservoir may let algae bloom occur easier than flowing water source. In still water reservoir, sunlight could penetrate through deeply that support the growth of algae. Such as the Sri-Trang reservoir that ever measured DO in day time of dry season more than 10 mg/L that indicated algae bloom occurrence (Mumean et al.,2008).

Table 2. Summary of DOC, UV-254, SUVA, THMFP, HPO and HPI in raw water supply from reservoir water in Thailand.

Water Sources	DOC (mg/L)	UV-254 (cm^{-1})	SUVA L mg^{-1} m^{-1}	THMFP (μg/L)	DOCofH PO[1] (mg/L)	DOC of HPI[2] (mg/L)	References
Aung-Keaw Reservoir	2.4	0.109	4.5	403	1.05	0.92	(Musikavong et al., 2007; Homklin, 2005)
Aung-Keaw Reservoir[3]	1.7	0.050	2.9	NA	NA	NA	(Chaimongkol et al., 2008)
Mae-Kuang Reservoir	2.4	0.050	2.1	236	1.31	0.86	(Musikavong et al., 2007; Homklin, 2005)
Mae-Hia Reservoir	6.4	0.110	1.7	583	2.57	2.72	(Musikavong et al., 2007)
Bhumibol Dam Reservoir	2.5	0.077	3.1	318	1.07	1.11	(Musikavong et al., 2007)
Northern Region Industrial Estate Reservoir	5.4	0.139	2.6	488	3.36	2.53	(Janhom, 2004)
Sri-Trang Reservoir[3]	2.6	0.131	12.2	N.A.	N.A.	N.A.	(Sudajun et al., 2007)
Sri-Trang Reservoir[3]	2.3	0.280	12.2	N.A.	N.A.	N.A.	(Mumean et al., 2008)

Remark: [1]HPO = Hydrophobic organic fractions, [2]HPI = Hydrophilic organic fraction, 3 = average values, N.A. not available

Table 3. Summary of fluorescent peak positions in raw water supply from reservoir water in Thailand.

Water Sources	Fluorescent peak positions (nm_{Ex}/nm_{Em})				References
	Tyrosine-like substance	Tryptophan-like substance	Humic and fulvic acids like substances (Region I)[1]	Humic and fulvic acids like substances (Region II)[1]	
Aung-Keaw Reservoir	N.D.	N.D.	260/460	330/440	(Musikavong et al., 2007;Homklin, 2005)
Aung-Keaw Reservoir[2]	N.D.	N.D.	270/465-480	330/410-420	(Chaimongkol et al., 2008)
Mae-Kuang Reservoir	N.D.	N.D.	260/460	310/410	(Musikavong et al., 2007;Homklin, 2005)
Mae-Hia Reservoir	N.D.	N.D.	260/420	330/400	(Musikavong et al., 2007)
Bhumibol Dam Reservoir	N.D.	N.D.	260/420	330/440	(Musikavong et al., 2007)
Northern Region Industrial Estate Reservoir	N.D.	N.D.	260/420	330/410	(Janhom, 2004)
Sri-Trang Reservoir[2]	N.D.	295/370-380	270/440	335/410	(Mumean et al.,2008)

Remark: [1]Regrading the fluorescent peak region that established by Musikavong et al. (2007), N.D. not detectable

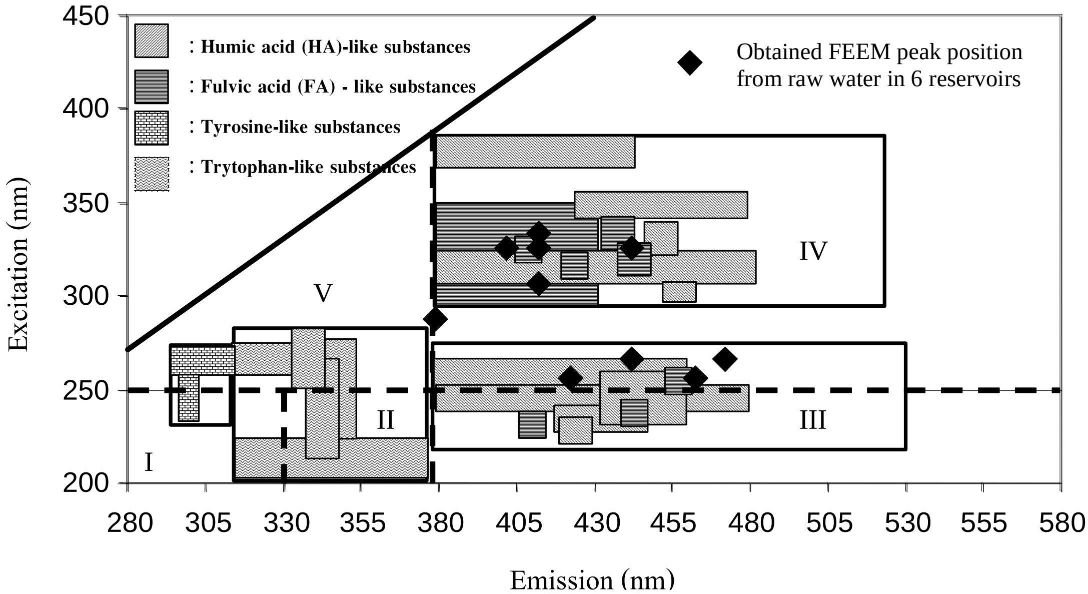

Figure 1. Fluorescent peak position observed from raw water supply in 6 reservoirs when compare with Putative origins region, develop by Chen et al. (2003) and Musikavong et al. (2007)

Some type of these algae may cause the problem of odor in water supply as found in Hat Yai water treatment plant and the cause of algae blom was the high NH_3^+-N concentration in raw water supply in dry season.

According to minimize the THMFP, the important thing is maximum DOM removal from raw water supply during coagulation. Not only the suspended solids or turbidity that could be removed in the coagulation process but it could remove DOC also (Mumean et al., 2008; Mark Benjamin, 2002; James, 1985; Musikavong et al., 2007). The coagulation processes used for water treatment plant that use raw water supply from six reservoirs were summarized in Table 4 and Figure 2. In according to optimum condition of each experiment, it could be seem that the reduction of UV-254 average value was higher than 52% and DOC removal efficiency is similar to THMFP but they were less than UV-254 removal (Figure 2(a)). The reason of this phenomenon is UV-254 could detect DOM in form of most aromatic organic substances, which could be reduced effectively by coagulation while DOC could be used to detect total DOM, which include aromatic and non aromatic organic substance. But when non aromatic organic substance was difficulty treated by coagulation, therefore the total efficiency of DOM reduction in term of DOC was lower than UV-254 reduction. Therefore THMFP reduction was the proportional with the DOC reduction. When we consider with the DOC reduction in term of DOC of HPO and DOC of HPI (Figure 2(b)), It found that the DOC of HPO was more easily to remove than DOC of HPI, approximately removal ratio 2:1;HPO:HPI. The reason is hydrophobic molecule surface have the excess ion on the interface solid-liquid, more easy to remove, compare with hydro philic molecule which have a electric charge from dissociation of inorganic acid group, for example, a carboxyl group located on the particulate surface or the interface, quite stable due to the presence of adsorbed water molecules, therefore it was more difficult to remove by coagulation. Moreover, it can be noted that ferric chloride coagulation was more effectively than alum coagulation for DOM removal.

From figure 2, It could be said that the overall DOM reduction efficiently for raw water supply reservoir can reach over 50% by alum coagulation at pH 5.5 with more than 40 mg/L alum added. When we consider with the other treatment process, from the result of physical condition study of raw water supply in these reservoirs, it was found that their raw water have low turbidity (lower than 10 NTU). It was due to the sediment precipitation that naturally occurred in water reservoir. This turbidity leave is too low for the conventional coagulation process. Mumean et al. (2008) and Labaiji et al. (2008) had investigating the application of contact-flocculation filtration for water treatment from Sri-Trang reservoir. This filtration method was normally appropriate for low turbidity water source (lower than 30 NUT). They found that the optimum filtration rate for Sri-Trang water treatment was 10 $m^3/m^2 \cdot hr$. The reduction of turbidity is in comparable to the reduction of DOC but the DOC reduction efficiency obtained from the filtration process (26%) was lower than the jar test method (49%) in the same condition. For UV-254 reduction, it was different between the filtration and jar test results. However the filtrated water turbidity was lower than standard value set up (PWA) (Drinking water standard). Therefore, the contact-flocculation filtration is interesting for study in further work in order to develop to the DOM removal.

In addition the application of others coagulants such as polyaluminum chloride (PAC) or organic polymer should be established in order to study of the DOM reduction and THMFP. The use of HPO and HPI fraction analysis should be done continuously also to find the appropriate treatment method that could reach people health protection and low cost objectives.

Conclusion

In this study, the turbidity value in raw water supply reservoir was low (4-15 NTU). HPO was the dominant NOM fraction in reservoir water. Humic and fulvic acid like substances was the major fluorescent organic matter in reservoir water. UV-254 could be easily reduced by alum coagulation in comparing with DOC and THMFP. DOC of HPO was easier to remove in comparing with DOC of HPI. It could noted that the overall DOM reduction can reach over than 50% by alum coagulation with alum dose > 40 mg/L at pH 5.5. In addition, it seems that the efficiency of $FeCl_3$ coagulation in DOC reduction is higher than alum coagulation. The purpose of water treatment in Thailand should consider not only turbidity or suspended particulates reduction by coagulation process but also the organic matter removal in further to reduce health risk from THMs that could be produced in water treatment processing which finishing by chlorination.

Table 4. Percent reduction of NOM by alum and ferric chloride ($FeCl_3$) coagulation at optimum condition

Water Sources	Percent reduction (%)					Optimal Conditions
	DOC	UV-254	THMFP	DOC of HPO	DOC of HPI	
Aung-Keaw Reservoir (Musikavong et al., 2007;Homklin, 2005)	60	82	64	80	33	Alum 60 mg/L, control pH at 5.5
Aung-Keaw Reservoir (Chaimongkol et al., 2008)	46	69	N	N.A.	N.A.	Existing condition of Aung-Keaw water treatment
Mae-Kuang Reservoir (Musikavong et al., 2007;Homklin, 2005)	46	56	40	50	28	Alum 40 mg/L, control pH at 6
Mae-Hia Reservoir (Musikavong et al., 2007)	46	52	43	60	27	Alum 40 mg/L, control pH at 6
Bhumibol Dam Reservoir (Musikavong et al., 2007)	44	61	50	51	44	Alum 60 mg/L, control pH at 5.5
Northern Region Industrial Estate Reservoir (Janhom, 2004)	50	N.A.	50	N.A.	N.A.	Alum 40 mg/L, control pH at 5.5
Sri-Trang Reservoir (Sudajun et a.,2007)	32	64	N.A	N.A.	N.A.	Alum 20 mg/L, control pH at 5
Sri-Trang Reservoir [This study]	50	69	N.A.	N.A.	N.A.	$FeCl_3$ 10 mg/L, control pH at 6

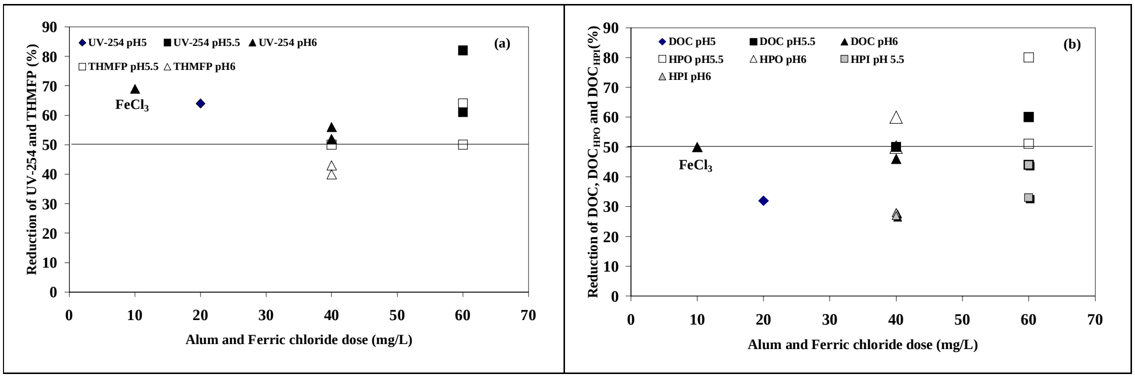

Figure 2. Reduction of UV-254 and THMFP, DOC, DOC_{HPO} and DOC_{HPI}, in function of Alum/Ferric chloride dosage and pH value from the optimum condition of 6 Reservoir.

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