

THE FATE OF DISSOLVED ORGANICS IN WATER PURIFICATION PROCESSES TREATING POLLUTED RAW WATER

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ABSTRACT

The main purpose of this study is to look into the fate of dissolved organics through conventional water treatment processes preceded by prechlorination with high dosage to treat polluted raw water. In addition to organic surrogate parameters analyses, organics were fractionated into humic acid, fulvic acid, hydrophilic-acid and -neutral-four fractions. The results showed that the removal of hydrophilic fraction organics were limited, and prechlorination probably transformed some organics from other fractions into hydrophilic-neutral fractions. Therefore although prechlorination with high dosage could facilitate the plant operation when treating polluted raw water, it probably had some adverse effect on dissolved organics removal.

KEYWORDS

Aqueous organics, prechlorination, coagulation, sedimentation, filtration, organic fractionation, humic substances, THMFP.

INTRODUCTION

The Feng-San Reservoir, located in southern Taiwan, is an off-line reservoir storing water pumped from the Tung-Kang River, which is the major source of public water supply for Greater Kaohsiung area, the second largest metropolis in Taiwan with a population over two million and the location of major heavy industries. Owing to upstream discharge of farming, industrial, and domestic wastes, the reservoir has become eutrophicated. The Feng-San Water Treatment Plant (abbreviated by FSWTP afterward), located on the side of Feng-San Reservoir, draws its raw water directly from the reservoir, and treats it by prechlorination, coagulation (with alum), sedimentation, filtration (single medium), and disinfection processes with daily flow about 350,000 cubic metres currently.

Owing to eutrophication in the reservoir, ammonia-nitrogen and NPDOC (nonpurgeable dissolved organic carbon) concentrations of raw water could be higher than 3 and 3.5 mg/L, respectively, during low water season. As these pollutants could interfere with water purification processes, the strategy adopted by the FSWTP is to add a sufficient amount of chlorine (daily average dosage may be higher than 40 mg/l as Cl₂) during low water season, at the beginning of the treatment train. That is to oxidize ammonia-nitrogen and organics by chlorine in order to reduce the load on subsequent treatment processes. However, chlorine could also react with organics to form

chlorinated organics, and it is the big concern of the general public in Kaohsiung area.

The main purpose of this study is to look into the fate of organics through conventional water treatment processes with high dosage of prechlorination. In addition to organic surrogate parameter analyses, organics contained in samples taken from raw water and effluents from various treatment units of FSWTP were concentrated and fractionated into various groups, based on their adsorption upon nonionic and ion-exchange resin adsorbents. Laboratory batch coagulation experiments with and without prechlorination, were also conducted with raw water from FSWTP to investigate the effect of prechlorination on the fate of organics.

EXPERIMENTAL

Sampling and Water Quality Analyses

Raw water, prechlorinated water, coagulation-sedimentation effluent, sand-filter effluent and finished water were collected from FSWTP. Three types of samples were taken. Type I samples were collected in one-litre amber glass bottles and intended for conventional water quality analyses, such as: turbidity, alkalinity, total dissolved solids (TDS), ammonia-nitrogen, organic-nitrogen, free and combined chlorine residuals. The analytical methods followed those in Standard Methods (APHA *et al.*, 1989). Type II samples were collected headspace free in 40 ml glass bottles with Teflon-lined caps and intended for trihalomethane (THM) and THM formation potential (THMFP) measurements which were done by the purge and trap packed-column gas chromatograph method described in Standard Methods using a gas chromatograph (Model 3400, Varian, Walnut Creek, Calif.) equipped with a purge and trap module (Model LCS-2000, Tekmar, Cincinnati, Ohio) and an electrolytic conductivity detector (Model 1000, Tracor, Elk Grove, IL.). For THMFP measurements, adequate amounts of sodium hypochlorite solution were injected to ensure that 2 to 5 mg/L free chlorine residual existed at the end of 7 days (25°C) incubation period. Type III samples were collected in 20-litre high density polyethylene distilled water cartons (NIKKO, Osaka, Japan) for organic parameter analyses and organic fractionation experiments.

Organic Parameter Analyses and Organic Fractionation

Water samples were first filtered through 0.45 µm membrane filter. UV absorbance was measured at 254 nm (A₂₅₄) by a spectrophotometer (Model U-1000, Hitachi, Tokyo, Japan), and fluorescence measured by a spectrofluorophotometer (Model RF-540, Shimadzu, Tokyo, Japan). NPOC was measured by the combustion-infrared method described in Standard Methods using a total organic carbon analyzer (Model 915B, Beckman, Fullerton, Calif.). If necessary, proper preconcentration by vacuum-rotary evaporation (at 38°C) was conducted before sample injection into TOC analyzer.

In the organics fractionation part of the experiment, the methods of Leenheer (1981) and Thurman (1985) of using XAD macroreticular resin and ion-exchange resins to extract and concentrate organics from water and quantitatively classify into various fractions were followed. In this study, only four organic fractions were recovered, namely: humic acid, fulvic acid, hydrophilic acid, and hydrophilic neutral. The flow chart of the organic fractionation scheme is shown in Fig. 1. The macroreticular resin used was Amberlite XAD-8 (Rohm and Haas, Philadelphia, PA.), the cation-exchange resin was Bio-Rad AG-MP-50 (Bio-Rad, Richmond, Calif.) and the anion-exchange resin was Amberlite IRA-93 (Rohm and Haas, Philadelphia, PA.). The resins cleanup and columns (Pyrex glass columns, 2 cm ID X 25 cm) preparation procedures can be found elsewhere (Leenheer, 1981).

First, the pH value of filtered sample was lowered to 2.0 with concentrated HCl and 30 litres were pumped through the three resin columns (XAD-8, cation-exchange, and anion-exchange) sequentially at the flow rate of 10 mL/min (Fig. 1). Next, the XAD-8 resin was discharged into a beaker and the adsorbed humic substances were desorbed with 250 mL of 0.1N NaOH. The solution collected was adjusted to pH=1 with 2N HCl, let settle for 2 hrs, and filtered through 0.45 µm membrane filter. The organic fraction contained in the filtrate was called fulvic acid. Then 250 mL 0.1N NaOH

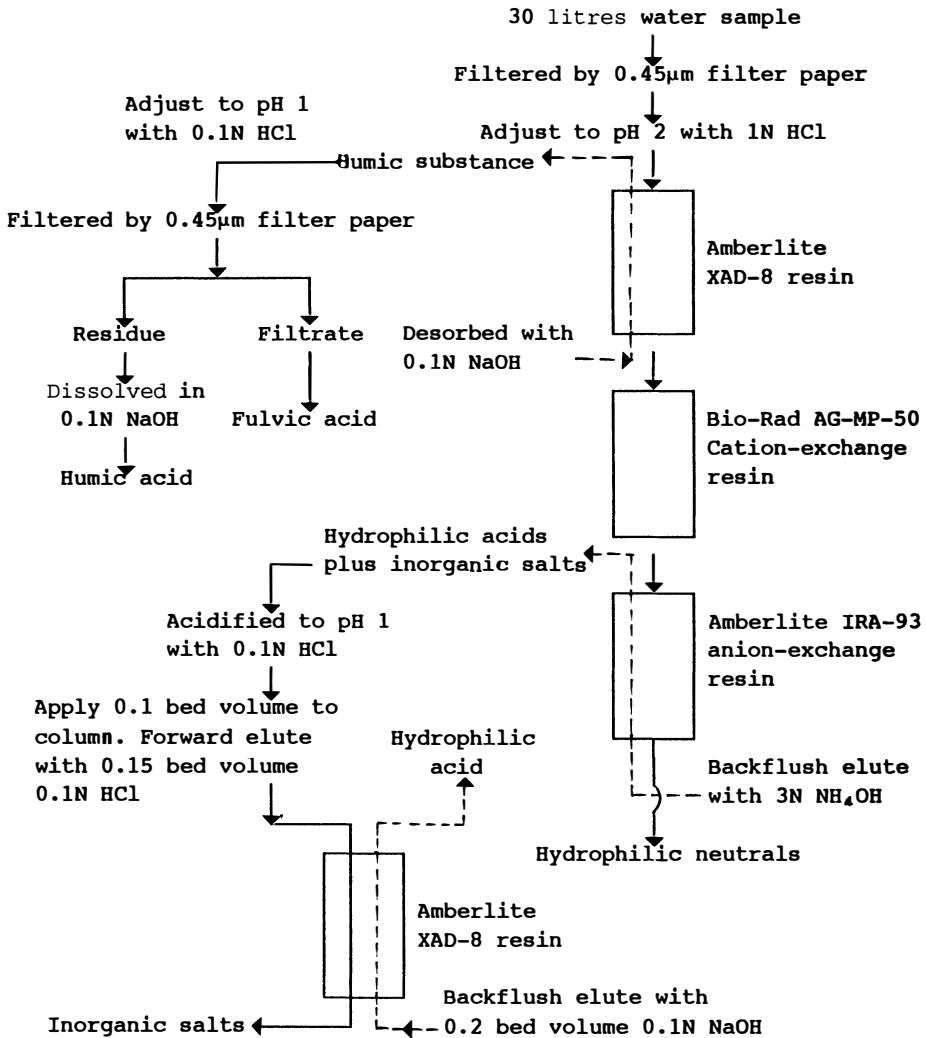


Fig. 1. Analytical procedure for dissolved organic carbon fractionation (Modified from Leenheer (1981))

was used to wash out the solids retained on the filter, and this organic fraction was called humic acid. The second column contained cation-exchange resin, and all inorganic cations were exchanged onto the resin and hydrogen was released.

Hydrophilic acid and inorganic anions were adsorbed onto the third column of anion-exchange resin. Then desorbed by backflush-elution with 250 mL of 3N NH₄OH. At this point, the hydrophilic acid fraction contained all the inorganic salts. Desalting can be accomplished by using XAD-8 column (2.5 cm ID X 25 cm) and diluted HCl (0.1N) as the mobile phase. First, the eluate of the anion-exchange resin column was acidified to pH 1 with HCl, and 0.1 bed volume of the acidified solution was applied to the top of XAD-8 column. Then 0.15 bed volume of 0.1N HCl as pumped through the column at the flow rate of 1 to 2 mL/min, followed by distilled water as the eluents. Forward elution was continued until the salt has eluted from the column. Hydrophilic organic acid then can be backflush-eluted with 0.1N NaOH

followed by distilled water (Fig. 1). Only the neutral, water-soluble organic species would pass through three columns without being retained, therefore the organics contained in the third column's effluent would be counted as hydrophilic neutral fraction.

Batch Coagulation Tests with and without Prechlorination

Ten liters of raw water from FSWTP were transferred to a glass cylinder (30 cm ID X 20 cm), which was under the rotating paddles of a jar test apparatus (Model 7790-500, Phipps & Birds, Richmond, VA), first 40 mg/L of Cl_2 (5% NaOCl solution, Ishizu, Osaka, Japan) were added, then 40 mg/l of alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$, Merck, Germany), after that followed by 1 min rapid mixing at 100 rpm, 20 min slow mixing at 30 rpm, and 30 min quiescent settling. Then supernatant was withdrawn. The above procedure was repeated three times, the supernatants collected were combined, and NPDOC analysis and organic fractionation performed. Then the above procedures were repeated but without chlorine addition.

RESULTS AND DISCUSSION

Effect of Treatment Processes on Conventional Water Quality Parameters

The variation of conventional water quality parameters through the prechlorination, coagulation, sedimentation, filtration treatment processes of FSWTP are shown in Table 1. It can be noticed that the raw water contained high concentrations of ammonia-nitrogen and organic-nitrogen. While the treatment processes employed were effective for turbidity removal, the variation of pH value, alkalinity, and total dissolved solids was minor. As the current operational strategy adopted by the FSWTP is to add enough amount of chlorine into raw water at the very beginning of the treatment train (27 mg/L for the sampling date of Table 1), to let free chlorine residual last through the whole process, with the check point that the free chlorine residual in finished water must be within 0.2-1.5 mg/L, as required by local regulations, the removal of ammonia and organic nitrogen was apparent. However, as there were plenty chances of contact between chlorine and organics, the possibility of chlorinated organics formation existed. This is also the motivation of this research, to look into the transfer of organics through water treatment processes.

The Variation of Organic Surrogate Parameters through Water Treatment Processes

The results of NPDOC analyses for water from FSWTP at two sampling dates are shown in Table 2. The NPDOC of the December sample was higher than that of September, this is expected as winter is usually the dry season of southern Taiwan, therefore the dilution factor for wastewater from upstream would be smaller. However, both sets of data indicated continuous increasing in cumulative NPDOC removal, with total removal ranged from about 37 to 46%. Semmens and Field (1980) studied organics removal by coagulation from the Mississippi River water, and found that TOC reductions of greater than 50 percent may be achieved at high alum dosed at pH 5.0. The total organic removal is to be affected by water quality, such as pH value, coagulant type, dosage, and related processes.

The results of A254 and fluorescence are shown in Table 3. The values of both parameters had a big drop after prechlorination, and thereafter the variations with treatment processes were minor. The explanation for the A254 part is: as organic compounds that are aromatic or that have conjugated double bonds absorb light in the ultraviolet (UV) wavelength range (Edzwald *et al.*, 1985), and oxidation and substitution are important mechanisms in the interaction between chlorine and organics in water (Johnson and Jensen, 1986), that sharp reduction was probably caused by break down or open up of the aromatic ring and conjugated double bonds structure. Furthermore, the big increase in NPDOC/A254 ratio after prechlorination can be explained by the big drop in A254 and low decrease in NPDOC caused by chlorine oxidation. The subsequent decrease in the ratio when chlorinated water was further treated by coagulation and sedimentation indicated that the removal of NPDOC was higher than that of UV-absorbance substances. This seems to be contradictory to that reported in the literature (Semmens and Field, 1980). The real reasons for this discrepancy are not clear at this time.

TABLE 1 Basic Water Quality Parameters for FSWTP*

Parameters	Raw water	Prechlorinated water	Coagulation-sedimentation effluent	Sand-filter effluent	Finished water
Temperature-°C	22.3	22.3	22.1	21.8	21.9
pH	7.3	7.2	6.9	6.9	7.0
Turbidity-NTU	14.3	12.6	1.0	0.43	0.38
Alkalinity-mg/L as CaCO ₃	109	94	97	103	101
Total dissolved solids-mg/L	478	432	379	401	421
Ammonia nitrogen-mg/L	3.15	0.26	0.26	0.11	0.19
Organic nitrogen-mg/L	1.30	0.59	0.12	0.07	0.08
Free chlorine residuals-mg/L as Cl ₂	ND**	1.80	1.41	2.52	0.40
Combined chlorine residuals-mg/L as Cl ₂	ND	5.68	0.50	0.33	0.20

* Chemical dosage: chlorine 27 mg/L as Cl₂, coagulant dosage 35 mg/L as alum

** ND: not detected

TABLE 2 NPDOC Values for FSWTP

Sampling date	Parameters	Raw water	Prechlorinated water	Coagulation-sedimentation effluent	Sand-filter effluent	Finished water
Sept. 4, 1990*	NPDOC(mg/L)	2.79	2.42	2.06	1.66	1.74
	Cumulative removal(%)	-	13.3	26.2	40.5	37.6
Dec. 28, 1990**	NPDOC(mg/L)	3.45	3.07	2.24	2.02	1.86
	Cumulative removal(%)	-	11.0	35.1	41.4	46.1

* Chemical dosage: chlorine 12 mg/L as Cl₂, coagulant 40 mg/L as alum

** Chemical dosage: chlorine 27 mg/L as Cl₂, coagulant 35 mg/L as alum

The variation of the fluorescence value with the treatment train is similar to that of A254, i.e. a big drop in prechlorination, and after that the change is minor. It is speculated that the drop in fluorescence by chlorination was probably caused by substitution of chlorine into the organic matrix, rather than by removal of fluorescent substances, as Table 2 indicates only 11% reduction of NPDOC by chlorination, while chlorine substitution into aromatic ring could cause a big drop in fluorescence intensity (Skoog, 1985).

TABLE 3 A254 and Fluorescence Values for FSWTP

Parameters	Raw water	Prechlorinated water	Coagulation-sedimentation effluent	Sand-filter effluent	Finished water
A254	0.072	0.023	0.024	0.022	0.020
NPDOC/A254	47.9	133.5	93.3	91.8	93.0
Fluorescence	8.1	0.2	0.5	0.4	0.2
Fluorescence/NPDOC	2.35	0.07	0.22	0.20	0.11

Dissolved Organic Fractionation and Their Variation through the Treatment Processes

The results of NPDOC fractionation of raw water and effluents from various treatment units of FSWTP into humic acid, fulvic acid, hydrophilic acid, and hydrophilic neutral fractions are shown in Table 4. The groups of compounds which could be included in each organic fraction and their properties can be found in the literature (Thurman, 1985). It can be noticed from Table 4 that the hydrophilic neutral fraction, which consisted of identifiable, low molecular weight organics, had the largest share of raw water's NPDOC (over 50%); while the other three

TABLE 4 NPDOC Fractionation of Water Samples from FSWTP

Samples	Fraction	NPDOC(mg/L)	Percentage(%)
Raw water NPDOC=3.45 mg/L	Humic acid	0.08	2.3
	Fulvic acid	0.21	6.1
	Hydrophilic acid	0.11	3.2
	Hydrophilic neutral	1.90	55.0
	Totals	2.16	66.6
Prechlorinated water NPDOC=3.07 mg/L	Humic acid	0.05	1.6
	Fulvic acid	0.20	6.5
	Hydrophilic acid	0.12	3.9
	Hydrophilic neutral	1.92	62.5
	Totals	2.29	74.5
Coagulation sedimentation effluent NPDOC=2.24 mg/L	Humic acid	0.02	0.9
	Fulvic acid	0.11	4.9
	Hydrophilic acid	0.12	5.4
	Hydrophilic neutral	1.53	68.3
	Totals	1.78	79.5
Sand filter effluent NPDOC=2.20 mg/L	Humic acid	0.02	1.0
	Fulvic acid	0.09	4.5
	Hydrophilic acid	0.14	6.9
	Hydrophilic neutral	1.59	78.7
	Totals	1.84	91.1
Finished water NPDOC=1.86 mg/L	Humic acid	0.02	1.1
	Fulvic acid	0.10	5.4
	Hydrophilic acid	0.08	4.3
	Hydrophilic neutral	1.62	87.1
	Totals	1.82	97.8

fractions, namely: humic acid, fulvic acid, and hydrophilic acid, which were mainly high molecular weight organics, each had a share of lower than 10% of total NPDOC. Compare to the values reported by Thurman (1985), based on data compiled from the literature, which indicated that about 50% of the DOC in average river water was aquatic fulvic and humic acids, 30% was hydrophilic acids, and the remaining 20% was identifiable simple compounds; and to the values obtained by the authors through analyzing raw water from a nearby water treatment plant which drew from an unpolluted reservoir by the same organic fractionation procedures as in this study, which showed about 33% of the NPDOC was fulvic and humic acids, 14% was hydrophilic acids, and 36% was hydrophilic neutral (Yeh, 1991), the percentage occupied by the hydrophilic neutral fraction of FSWTP's raw water seems to be high. Those low molecular weight organics were suspected of coming from anthropogenic sources, especially the swine and poultry farming wastes, as over 0.7 million hogs and 4 million poultry were raised throughout the watershed of Tung-Kang River, which is the water source of Feng-San Reservoir, and most of the wastewater produced was not adequately treated, and eventually some pollutants reached the reservoir.

Next, when the variation of four fractions of organics through the water treatment processes of FSWTP was monitored, it can be found from Table 5 that after prechlorination with 27 mg/L of Cl_2 , humic acid and fulvic acid fractions were reduced by 44.6, and 6.7%, respectively, while the two hydrophilic fractions were increased by about 10%. This probably indicated the transformation of some humic substances into halogenated organics or other small molecular weight organic compounds (J.M. Montgomery Consulting Engineers, 1985). For example: Christman (1983) demonstrated that a variety of nonvolatilitic aliphatic halogenated products resulted from the chlorination of aquatic humic and fulvic acids, especially the C_2 chlorinated acid. Krasner *et al.* (1989) selected thirty-five water treatment facilities in the U.S. to gather data on the presence of disinfection by-products (DBPs) in drinking water, and reported that trihalomethanes were the largest class of DBPs detected, with haloacetic acids being the next most significant DBP fraction. As these C_2 chlorinated acids are identifiable, simple compounds, and probably belong to the hydrophilic fractions, this supports the speculated transformation. Furthermore, as the formation of chlorinated by-products strongly depends on the type of precursor, and the chlorine to carbon molar ratios, the possible existence of complex polyelectrolytic acids, which belong to hydrophilic acid fractions, in the chlorinated water can not be completely excluded.

TABLE 5 Cumulative NPDOC Removal(%) of Each Organic Fraction

Organic fraction	Prechlorinated water	Coagulation-sedimentation effluent	Sand-filter effluent	Finished water
Humic acid	44.6	75.2	79.2	75.5
Fulvic acid	6.7	45.8	55.7	54.5
Hydrophilic acid	-10.2	-7.8	-32.8	16.4
Hydrophilic neutral	-11.0	19.5	16.3	14.7

The cumulative NPDOC removals in humic and fulvic acid fractions of the coagulation-sedimentation effluent were about 75 and 46%, respectively (Table 5). This means that the removals of humic and fulvic acid fractions in the coagulation-sedimentation processes were about 30 and 40%, respectively, Randtke (1988) reported that removals of dissolved natural organic matter by coagulation generally ranged between 10 and 90% with an average of around 30%. A report of the AWWA Research Committee (1979) compiled observed removals of humic acid, fulvic acid and other organics in natural waters by various researchers, the range was also between 20 and 90%. However, organics removal by coagulation strongly depends on pH and coagulants dosage, with best removal usually occurring at around pH 5. As pH value of the water of FSWTP was around 7, no wonder its humic substances removal by alum was only medium. After sedimentation, the further removal of humic acid was minor, while fulvic acid had about 10% increase in removal by sand filtration, probably due to the higher contact opportunities inside the media to promote destabilization. The

data concerned with the removal of hydrophilic acid fraction with various processes seemed to fluctuate a lot, probably because the separation of hydrophilic acid fraction from water matrix was more complicated than other fractions. Finally, the removal of hydrophilic neutral fraction by coagulation-sedimentation was found to be about 20% compared to that in raw water. The selective removal of hydrophilic compounds was probably achieved by the interactions between their polar functional groups and hydrolyzed aluminum (Sinsabaugh *et al.*, 1986). However, after sedimentation the little decrease in cumulative NPDOC removal of hydrophilic neutral fraction with the treatment train can not be explained at this time.

Next, when isolation recoveries of the organic fractionation procedures employed in this study are concerned (the definition of isolation recovery here is the ratio of the sum of NPDOC concentrations of the isolated four organic fractions to the NPDOC concentration of original water sample), it can be noticed from Table 4 that recovery increased consistently with the treatment train, from 66.6% for raw water to 97.8% for finished water. There are two explanations for this phenomenon. First, the total organics in water can be classified into hydrophobic-acid, -base, and -neutral fractions, and hydrophilic-acid, -base, and -neutral fractions; while in this study only hydrophobic acid, hydrophilic acid, and hydrophilic neutral fractions were eluted. Therefore the other three fractions were retained in the resin columns. However, with the addition of chlorine, organic transformation between fractions could happen via oxidation and/or substitution mechanisms in the interaction between chlorine and organics in water. Glaze *et al.* (1980) studied the characteristics of nonvolatile halogenated compounds formed during water chlorination, and found that natural organics did not adsorb on XAD resins efficiently after chlorination. Second, the removal of hydrophilic organics during water treatment processes was usually poorer than that of hydrophobic (AWWARF and KIWA, 1988).

The THMFP of original water samples and each organic fraction are shown in Table 6. It demonstrates that the THMFP of humic acid and fulvic acid fractions generally decreased with the treatment train, those contained in hydrophilic acid fraction were lower than the detection limit, and the THMFP of hydrophilic neutral increased drastically with the treatment train. From the THMFP values obtained from the unfractionated original samples, it can be noticed that the removal of most THM precursors occurred in the coagulation-sedimentation processes. When the sum of THMFP of four organic fractions was compared with that obtained from the unfractionated original samples, the recoveries were found to increase with the progress of treatment train. It is speculated that some organics, contained in raw water and effluents from earlier stage of the treatment train and not eluted from resin columns, were THM precursors. For example: Hoehn *et al.* (1984) studying the significance of algae in contributing organic matter to the THM-precursor pool in lake water, suggested that THM precursors were predominantly hydrophobic neutral

TABLE 6 THMFP($\mu\text{g/L}$) of Original Water Sample and Each Organic Fraction of FSWTP

Parameters	Raw water	Prechlorinated water	Coagulation-sedimentation effluent	Sand-filter effluent	Finished water
Humic acid	36.6	22.6	17.7	20.9	17.9
Fulvic acid	44.0	61.4	40.6	37.5	36.8
Hydrophilic acid	ND*	ND*	ND*	ND*	ND*
Hydrophilic neutral	38.7	50.8	79.0	101.1	120.1
Totals	119.3	134.8	137.3	159.5	174.8
Values for original samples	270.5	258.5	166.6	166.3	168.1
Recoveries (%)	44	52	82	96	104

* ND: not detected

compounds. However, that organic fraction was not eluted from resin column in this study, and hydrophobic organics were probably selectively removed during water treatment processes. Furthermore, there were probably organic transformations between various fractions during water treatment processes, as discussed before concerning the increase of NPDOC recoveries with treatment train in organic fractionation study.

The Effect of Prechlorination on Organic Coagulation Removal

The isolation recoveries and the percentage of NPDOC occupied by each organics fraction of the FSWTP's raw water and those treated waters from laboratory batch coagulation experiments with and without prechlorination are shown in Table 7. It revealed that with prechlorination the removal of humic acid and fulvic acid were higher than that without; however, concentration of hydrophilic neutral fraction also increased when prechlorination was practiced. This probably indicated the breakdown of larger organic molecules to smaller ones by oxidation power of chlorine, and these low molecular weight organics were more difficult to remove, resulting in higher NPDOC concentration in the treated water. The isolation recoveries of treated waters, especially that with prechlorination, were higher than that of raw water. This is consistent with those observed in the full-scale treatment plant.

TABLE 7 NPDOC Fractionation of Water Samples from Batch Coagulation Study

Samples	Fraction	NPDOC(mg/L)	Percentage(%)
Raw water NPDOC=2.94 mg/L	Humic acid	0.09	3.1
	Fulvic acid	0.26	8.8
	Hydrophilic acid	0.21	7.1
	Hydrophilic neutral	1.63	55.4
	Totals	2.19	74.5
Coagulated- settled supernatant NPDOC=2.22 mg/L	Humic acid	0.05	2.3
	Fulvic acid	0.20	9.0
	Hydrophilic acid	0.24	10.8
	Hydrophilic neutral	1.43	64.4
	Totals	1.93	86.0
Prechlorinated- coagulated- settled supernatant NPDOC=2.37 mg/L	Humic acid	0.03	1.3
	Fulvic acid	0.13	5.5
	Hydrophilic acid	0.22	9.3
	Hydrophilic neutral	1.95	82.3
	Totals	2.33	98.3

CONCLUSIONS

When dissolved organics contained in the polluted raw water of FSWTP were fractionated into humic acid, fulvic acid, hydrophilic acid, and hydrophilic neutral fractions, it was found that the percentage occupied by the low molecular weight hydrophilic neutral fraction was much higher than other fractions. It is postulated to be due to the contribution from anthropogenic organic pollutants. Furthermore, the percentage occupied by the hydrophilic neutral was increased with the progress of the treatment train, as humic and fulvic acids were more effectively removed by conventional treatment processes than that of hydrophilic fractions, and high dosage of prechlorination probably transformed some organics from other fractions into hydrophilic neutral fraction. Therefore it is concluded that: although the current treatment processes, employed by the FSWTP to treat polluted raw water, were effective for the removal of ammonia-nitrogen and turbidity, the removal of low molecular weight dissolved organics as limited. And although prechlorination with high dosage could facilitate the plant operation, it probably had some adverse effect on dissolved organic removal.

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