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Effectiveness of AOC removal by advanced water treatment systems: a case study

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Abstract

Recently, the appearance of assimilable organic carbon (AOC) in the water treatment system and effluent of the treatment plant has brought more attention to the environmental engineers. In this study, AOC removal efficiency at the Cheng-Ching Lake water treatment plant (CCLWTP) was evaluated. The main objectives of this study were to: (1) evaluate the treatability of AOC by the advanced treatment system at the CCLWTP, (2) assess the relativity of AOC and the variations of other water quality indicators, (3) evaluate the effects of sodium thiosulfate on AOC analysis, and (4) evaluate the efficiency of biofiltration process using granular activated carbon (GAC) and anthracite as the fillers. Results show that the averaged influent and final effluent AOC concentrations at the CCLWTP were approximately 124 and 30 μg acetate-C/L, respectively. Thus, the treatment plant had an AOC removal efficiency of about 76%, and the AOC concentrations in the final effluent met the criteria established by the CCLWTP (50 μg acetate-C/L). Results indicate that the biofiltration process might contribute to the removal of the trace AOC in the GAC filtration process. Moreover, the removal of AOC had a correlation with the decrease in concentrations of other drinking water indicators. Results from a column test show that GAC was a more appropriate material than anthracite for the AOC removal. Results from this study provide us insight into the mechanisms of AOC removal by advanced water treatment processes. These findings would be helpful in designing a modified water treatment system for AOC removal and water quality improvement.

Keywords: Assimilable organic carbon (AOC); Advanced water treatment system; Ozonation; Chlorination

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1. Introduction

The Kaoping River located in southern Taiwan flows through the Kaoping metropolitan area, and empties into the South Taiwan Strait. The Kaoping River basin is the largest river basin in the Taiwan. The river is 171-km long, drains a catchment of about 3257 km^2. It is severely polluted due to the upstream discharge of farming, industrial, and domestic wastes. Cheng-Ching Lake water treatment plant (CCLWTP) (the largest water treatment plant in southern Taiwan), located in southern Taiwan, is the main supplier of domestic water for the Greater Kaohsiung area, the second largest metropolis in Taiwan, with a population of over 2 million and the location of major heavy industries. Since the raw water of WTP is drawn from nearby CCL, a man-made off-line reservoir storing surface water pumping from the Kaoping River, the CCL water treatment plant has encountered a challenge with regard to both technical and managerial requirements. Advanced water treatment system has been applied to the CCL water treatment plant since 2004 to provide high quality drinking water to the residents lived in, the Kaoping metropolitan area and to meet the stringent drinking water standards. The current water treatment system of the CCL contains the following processes: pumping station, preozonation process, sedimentation basin, pellet softening, rapid filter basin, ozonation process, and biological activated carbon (BAC) filtration followed by chlorination (Fig. 1). During the distribution of drinking water, bacterial regrowth may lead to a deterioration of bacterial water quality, amplification of corrosion, generation of bad tastes and odors, and proliferation of macroinvertebrates [1]. Such phenomenon of bacterial regrowth results from the proliferation and detachment of heterotrophic bacteria surviving on pipe surfaces of distribution systems. The bacterial regrowth potential in drinking water distribution system is a function of many parameters [2]. Microbial growth in drinking water requires nutrients and carbon sources such as organic carbon, nitrogen, and phosphorus. Organic carbon, especially assimilable organic carbon (AOC) has been considered as the main control factor of the microbial growth in drinking water distribution systems [3,4]. Recently, the appearance of AOC in the water treatment system and effluent of the treatment plant has brought more attention to the environmental engineers. AOC, which has been defined as a biological pollution, often causes the deterioration of the water quality due to the multiplication of heterotrophic bacteria inside the distribution and treatment systems. The methods for AOC analysis include the measurement of biomass growth, plate count, and the measurement of adenosine triphosphate (ATP) [5]. The most reported method to date is the total plate counts with the inocula of the standard bacteria *Pseudomonas fluorescens* P17 and Spirillum NOX [6].

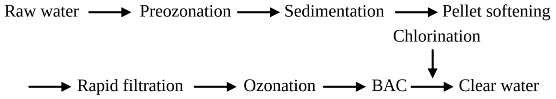

Fig. 1. The water treatment processes of the CCLWTP.

In this study, water samples from each treatment process of the CCLWTP were collected and analyzed periodically to assess the AOC removal. In addition, column test was conducted to simulate the operation of the filtration process. The main objectives of this study were to: (1) evaluate the treatability of AOC by the advanced treatment system at the CCLWTP, (2) assess the relativity of AOC and the variations of other water quality indicators, (3) evaluate the application of sodium thiosulfate on AOC analysis, and (4) evaluate the efficiency of biofiltration process using granular activated carbon (GAC) and anthracite as the fillers.

2. Material and methods

2.1. Sample collection and transportation

Drinking water samples were collected from pumping station (raw water), preozonation process, ozonation process, BAC filtration, and chlorination process once a week during a 1-year investigation period. The sampling processes followed the guidelines described in the standard methods [1]. The collected samples were transported to the laboratory on ice and then stored at 4°C for the analysis.

2.2. AOC measurement

Water samples taken from the effluence of each process were analyzed for AOC using van der Kooij techniques [6]. The water samples were heated at 70°C for 0.5 h within 6 h after sampling to destroy vegetable cells. After cooling, *Pseudomonas fluorescens* strain P17 was inoculated into the water samples. The water samples were incubated at 25°C for 8 days and then the cell formation units were counted at days 3, 6, and 8. Subsequently, the same water sample was heated at 70°C for 0.5 h to kill the strain P17 and then NOX strain was inoculated. The inoculated water samples were incubated at 25°C for 3 days and the cell formation units were counted. AOC concentration was calculated by comparing the cell formation unit number and yield coefficient. In this study, the yield coefficient of P17 and NOX were 4.1×10^7 μg acetate-C/L and 1.2×10^7 μg acetate- C/L, respectively.

2.3. Column test

Column test for the comparison of AOC removing efficiency between GAC and anthracite was conducted at the CCLWTP. The feasibility of anthracite for the filtration process was also assessed in the column study. Two columns with different filling materials were used in the column test. One column was constructed with anthracite, sand, and stone, and the other column contained GAC. Fig. 2 presents the components of the glass column filled with anthracite, sand, and stone. The GAC column was filled with 110 cm of the GAC, with an empty bed contact time (EBCT) of 6.6 min. The biological anthracite filtration (BAF) column was filled with 80 cm of anthracite, 20 cm of sand, and 10 cm of stone, with an EBCT of 6.6 min. The influent water used in the column test was from the ozonation unit and the filtration rate was 7.3 m/h.

2.4. The effect of sodium thiosulfate on AOC measurement

Residual chlorinated and halogenated compounds in water samples might inhibit the growth of the strains P17 and NOX. Thus, 18 mg/L of the reducing agent sodium thiosulfate ($Na_2S_2O_3$) was added to the water samples to eliminate the adverse effects on AOC measurement. Moreover, an extra water sample with no $Na_2S_2O_3$ addition was collected from the preozonation

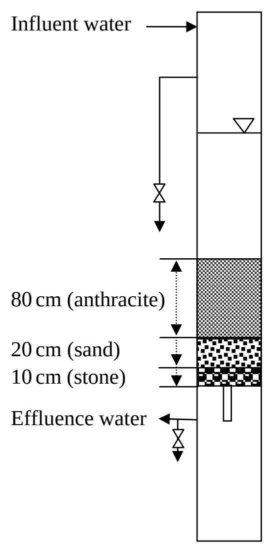

Fig. 2. The diagram showing the components of the glass column.

and clear water (chlorination) units to assess the effect of the addition of $Na_2S_2O_3$ on AOC measurement.

3. Results and discussions

3.1. The AOC concentrations in the effluent of various treatment processes

Water samples from each treatment process of the advanced water treatment system were collected and analyzed weekly to evaluate the treatability of AOC during 24 weeks (Fig. 3). Table 1 summarized the performance in terms of AOC removal by various treatment processes of WTPCCL. Results show that the WTP had the AOC removal efficiencies of about 76, 81 and 75% in terms of AOC-T, AOC-P17 and AOCNOX, respectively. The average AOC concentrations in raw water, preozonation, ozonation, BAC, and chlorination processes were 124, 162, 62, 26, and 30 μg acetate-C/L, respectively. Results reveal that the increase in AOC concentration was observed after the treatment of preozonation. This might result from the oxidation of organic matters to more biodegradable and assimilable compounds such as oxalic acid [7,8]. While a sharp increase in AOC level after preozonation was noted, this study revealed that the increase was due primarily to AOC–NOX concentration instead of AOC-P17. This observation was consistent with the findings reported by Huck et al. [9]. But different from observations reported by Van der Kooij et al. [8], in which the increase in AOC following ozonation was associated primarily with AOC-P17. Thus, the total counts of the inoculated strains were increased and resulted in the increase of the AOC concentrations. Results also show that the AOC concentrations dropped to 26 μg acetate-C/L after the treatment of BAC. This indicates that BAC had a significant efficiency in the trace AOC removal.

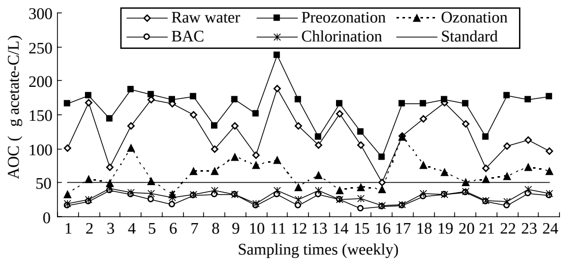

Fig. 3. AOC concentrations in the effluent of various treatment processes.

Table 1
AOC concentrations in the effluent of various treatment processes

Sampling location	Raw water	Preozonation	Ozonation	BAC	Removal efficiency of BAC (%)	Chlorination
AOC–NOX (μg acetate-C/L)	104	170	52	23	56	27
AOC-P17 (μg acetate-C/L)	18	5	10	2	80	3
AOC-Total (μg acetate-C/L)	122	175	62	25	60	30
Range (μg acetate-C/L)	50–189	117–491	33–116	13–38	*	17–42
Sample size (*n*)	25	25	25	25	25	25

*Not avaliable.

The filtration and biodegradation processes might contribute to the removal of the trace AOC. AOC levels could be expected to be low following BAC treatment [8,9] because ozonation would lead to easier adsorption or degradation of the by-products by the subsequent unit processes. Filtration through BAC resulted in removal efficiencies of 70, 56 and 58% in terms of AOC-P17, AOC–NOX and AOC-T, respectively. The higher removal efficiency of AOC-P17 suggested that this component was more easily adsorbed than the AOC–NOX. These results showed that GAC adsorption and biodegradation were effective at AOC control. Similar observations had been reported by other researchers [10,11]. Slight increase of the AOC concentration was also observed after the chlorination process. This might be also due to the oxidation potential of chloride, which caused the increase in biodegradable organics (e.g., carboxylic acids) [11,12]. Results of the 1-year investigation indicate that the AOC concentrations in the final effluence met the criteria established by the WTP (50 μg acetate-C/L). Thus, the advanced treatment processes could reduce AOC effectively and were helpful to the improvement of drinking water quality in the Kaoping metropolitan area (Fig. 3).

3.2. Correlations between AOC and other drinking water quality indicators

In this study, coliform, total bacterial count (TPC), total dissolved solids (TDS), and particle counts were also analyzed. This is to evaluate the relationship between AOC and other water quality indicators. In general, coliform was applied as an index of water pollution. As shown in Table 2, the amount of coliform in raw water was about 3636 CFU/100 mL, and then reduced to less than 1 CFU/100 mL after the treatment. TPC in the raw water was about 10,184 CFU/mL, and dropped to less than 5 CFU/mL after the treatment. Moreover, TDS and particle counts also decreased to 313 mg/L and 192 counts/mL, respectively, in the treated water. Results indicate that the decrease in AOC, coliform, TPC, TDS, and particle counts were observed. This suggests that the removal of AOC had a correlation with the decrease in concentrations of other drinking water indicators [13].

Table 2
Results of AOC and other drinking water quality indicators in the effluent of each treatment process

Sampling location	Raw water	Preozonation	Ozonation	BAC	Removal efficiency of BAC (%)	Chlorination
AOC–NOX (μg acetate-C/L)	104	170	52	23	56	27
AOC-P17 (μg acetate-C/L)	18	5	10	2	80	3
AOC-Total (μg acetate-C/L)	122	175	62	25	60	30
Range (μg acetate-C/L)	50–189	117–491	33–116	13–38	*	17–42
Sample size (*n*)	25	25	25	25	25	25

*Not available.

3.3. The effect of sodium thiosulfate on AOC measurement

In order to determine the effects of the addition of sodium thiosulfate on AOC measurement in effluent of preozonation and chlorination, samples with or without sodium thiosulfate were evaluated. Results show that AOC in the water sample with the addition of sodium thiosulfate was higher than the unamended sample (Fig. 4). The AOC concentrations in effluents of preozonation were 174 and 97 μg acetate-C/L in the amended and unamended samples, respectively. The AOC concentrations in effluents of chlorination were 34 and 16 μg acetate-C/L in the amended and unamended samples, respectively. Results of this experiment indicate that the removal of residual chlorine and halogenate compounds was beneficial for the growth of P17 and NOX and was helpful to the measurement of AOC.

3.4. AOC removal efficiency in column test

In the column test, GAC and anthracite were applied to evaluate the AOC removing efficiency of these two materials, respectively. If anthracite could apply instead of GAC, the cost of water treatment would be reduced. The influent water used in the column test was from the ozonation unit and the concentration of AOC in the water was about 62 μg acetate-C/L. Results of column test show that the AOC removal efficiencies were 60% in the GAC column and

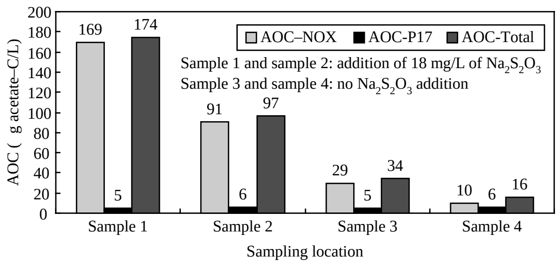

Fig. 4. Effect of sodium thiosulfate addition on AOC measurement (samples 1 and 3: effluences of preozonation, samples 2 and 4: effluences from chlorination).

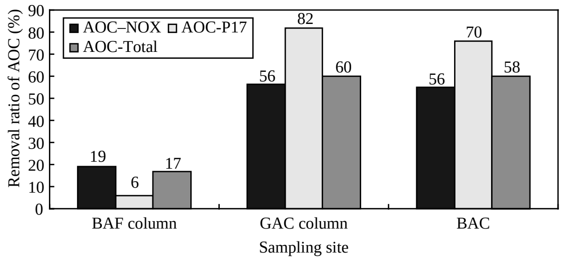

Fig. 5. AOC removal efficiency of the column test.

17% in the anthracite column, respectively. Moreover, approximately 58% of AOC removal was observed in BAC unit in the WTP (Fig. 5). Thus, GAC had a more effective efficiency on AOC removal than anthracite. For this reason, it might not be appropriate to replace activated carbon with anthracite as the filling materials in the biofiltration system based on the practicability point of view. Results show that BAC column and BAC in the WTP of ozonated water decrease an average of 82 and 70% of AOC-P17 and 56 and 56% of AOC–NOX, respectively (Fig. 5). The total AOC concentration decreased in all of the samples. Results indicate that biofiltration alone removed the AOC-P17 formed in ozonation. However, little is known about the characteristics of AOC at different process stages. The amount of removal in the biofilter was plotted against the influent AOC, in the calculation of correlation coefficient, the AOC data of run was excluded, since the values of P17 were systematically higher. Evidently, the results also show that a higher removal of AOC-P17 is obtained when treating higher inflect concentrations. On the other hand, increased influent concentration results in increased effluent concentrations. For this reason, if the target is to minimize effluent AOC concentration, the AOC of influent has to be minimized by turning off the ozonation. However in many cases intermediate ozonation is needed, for example to prevent significant colonization of filter media by organism of public health concern [14–16].

4. Conclusions

The following conclusions can be drawn from the present investigation. In this study, AOC removal efficiency of the advanced water treatment processes of the CCL was assessed. Moreover, effects of two different filling materials on the efficiency of biofiltration process were evaluated in the column study. Results of the laboratory and field investigation show that a significant AOC removal efficiency was observed by the applied BAC system in the WTP. Conclusions of this study include the following:

(1) Significant AOC removal efficiency was achieved in the WTPCCL, and the AOC concentrations in the effluent could meet the established standard.
(2) The increased AOC concentrations after the treatment of preozonation and chlorination might be caused by the oxidation of organic matters to more biodegradable and assimilable of organic compounds.
(3) The removal of AOC had a correlation with the decrease in concentrations of other drinking water indicators (e.g., coliform, TPC, TDS, and particle counts).
(4) The addition of sodium thiosulfate in water samples could enhance the performance of the AOC analysis.
(5) GAC is a more appropriate filling material than anthracite in the biofiltration system for the removal of AOC.
(6) BAC filtration played an important role in the removal of the trace AOC. Thus, the application of BAC for AOC removal is feasible and should be included as a required treatment unit in the advanced WTP. From this reason, anthracite could not apply instead of GAC.
(7) GAC filtration proved to be most effective at removing AOC with a high removal efficiency of more than 80%.
(8) Treatment processes (like ozonation) which increased the amount of organics in carbonyl group would likely lead to a product water with poor biological stability. Ozonation therefore, should be combined with the GAC or biological processes to minimize the AOC formation potential.

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