BIOMEDICAL AND ENVIRONMENTAL SCIENCES **18**, 137-140 (2005)

Factors Affecting Bacterial Growth in Drinking Water Distribution System[1]

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Objective To define the influence of some parameters, including assimilable organic carbon (AOC), chloramine residual, etc. on the bacterial growth in drinking water distribution systems. **Methods** Three typical water treatment plants in a northern city (City T) of China and their corresponding distribution systems were investigated. Some parameters of the water samples, such as heterotrophic plate content (HPC), AOC, COD_{Mn}, TOC, and phosphate were measured. **Results** The AOC in most water samples were more than 100 µg/L, or even more than 200 µg/L in some cases. The HPC in distribution systems increased significantly with the decrease of residual chlorine. When the residual chlorine was less than 0.1 mg/L, the magnitude order of HPC was 10^4 CFU/mL; when it was 0.5-0.7 mg/L, the HPC was about 500 CFU/mL. **Conclusion** For controlling the biostability of drinking water, the controlling of AOC and residual chlorine should be considered simultaneously. The influence of phosphors on the AOC tests of water is not significant. Phosphors may not be the limiting nutrient in the water distribution systems.

Key words: Drinking water; AOC; HPC; Phosphors; Residual chlorine; Biostability

INTRODUCTION

Recently, the biostability of drinking water has been researched and many important conclusions have been made. LeChevallier *et al*.[1] (1990) showed that the growth of *E. coli* isolate is inhibited by AOC levels <54 µg/L. Van der Kooij *et al*.[2] showed that HPC bacterial growth in distribution water does not occur at AOC levels <10-15 µg/L. But some aspects of the factors affecting bacterial growth are still uncertain and tenuous, such as the relationships between bacterial growth potential and the index of organic matter, the influence of inorganic nutrient on the growth of bacteria.

The traditional water treatment process in China could not improve water quality any longer and meet the public demands, and the distribution systems could not maintain water quality[3]. It is urgent to investigate the water quality situations and to find some new controlling methods. The objectives of this study were to investigate the water quality situations, including AOC, pH, turbidity, temperature, COD_{Mn}, TOC, HPC, TP, etc. in the water treatment process and the associated water distribution system, and to analyze the factors affecting bacterial growth and the relationships between the indexes.

MATERIALS AND METHODS

Sampling Site Selection

Three typical water treatment plants in a northern city (City T) of China and their corresponding distribution networks were selected. Samples were taken from January to November in 2003 (From April to June, the study was stopped due to the outbreak of SARS).

Water Treatment Process in the Water Treatment Plants

Traditional treatment processes include coagulation, sedimentation and sand filtration, in the three water treatment plants, which use surface water as raw water. The hydraulic retention time in the clear water wells of the water treatment plants is about 2 h. Chlorine is introduced at the inlet of coagulation process. Generally, residual chlorine is about 1.0 mg/L in the outlet of the clear water well.

Source Water Quality

The three plants use the same source water. The quality of the source water is summarized in Table 1.

[1]This work was supported by the National Natural Science Foundation of China, No. 50238020, National High-tech Research Development Program (the 863 Program), No. 2002AA601140.
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0895-3988/2005
CN 11-2816/Q

TABLE 1

Source Water Quality of the Water Treatment Plants

Parameter	Range
Temperature (℃)	1-28
pH	8.0-8.5
TOC (mg/L)	2.71-10.08
CODMn (mg/L)	4.3-7.8
Turbidity (NTU)	1.8-13.0

HPC Measurement

Heterotrophic bacteria in water samples were determined by plate counting (R2A agar; Difco). Agar plates were incubated for 1 week at 20±1℃ before the colonies were counted[4].

Organic Carbon Measurement (AOC, TOC, COD_{Mn})

Total organic carbon (TOC) content in the water samples was analyzed using a high-temperature combustion technique with a Shimadzu 5000 TOC analyzer (Kyoto, Japan). The content of AOC was measured by the standard method. The maximum growth of *Pseudomonas fluorescens P17* (ATCC 49642) and *Spirillum sp.* strain NOX (ATCC 49643) in water samples was used to correspond to the amount of AOC[5]. COD_{Mn} was measured by the "standard methods for the examination of water and waste water".

Phosphate

The analysis of phosphate concentrations was analyzed by a colorimetric ascorbic acid method based on the "standard methods for the examination of water and waste water"[6].

RESULTS

Influence of AOC on the Bacterial Growth

Fig. 1 shows the relationship between AOC and HPC in the water samples. The AOC in most product water of the studied water treatment plants and the water from the associated distribution systems was more than 100 μg/L, or even more than 200 μg/L in some cases. Although the AOC content was lower (<100 μg/L), HPC could still obtain the magnitude order of 10^4 CFU/mL in some sampling points. Conversely, when the AOC content was higher (>200 μg/L), HPC could be relatively lower (10^2 CFU/mL).

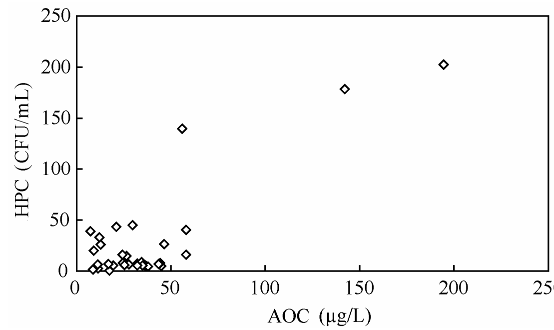

FIG. 1. Relationship between AOC and HPC in City T.

Fig. 2 shows the relationship between AOC and HPC in drinking water samples from Macao. In Macao distribution networks, the AOC content was less than 50 μg/L and HPC level was below 10^2 CFU/mL, suggesting that AOC might be an important factor affecting bacterial growth in drinking water.

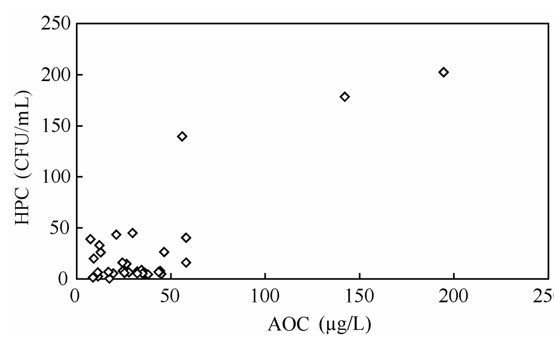

FIG. 2. Relationship between AOC and HPC in Macao.

Influence of Residual Chlorine on the Bacterial Growth

Fig. 3 shows the influence of residual chlorine on HPC. With the decrease of residual chlorine, the bacterial increased. When the residual chlorine was below 0.1 mg/L, the bacterial were of 10^4 CFU/mL. However, when it was 0.5~0.7 mg/L, the HPC was about 500 CFU/mL, and the microbial risk was still high. The main factor affecting water biostability in City T was the biodegradable carbon content (Figs. 1 and 3).

Figs. 4 and 5 show the residual chlorine, HPC and AOC situations in the distribution systems of Macao. The lower levels of bacteria in the distribution systems were resulted from the higher residual chlorine and lower AOC content. The comparison of water quality indexes between the two city distribution systems is shown in Table 2.

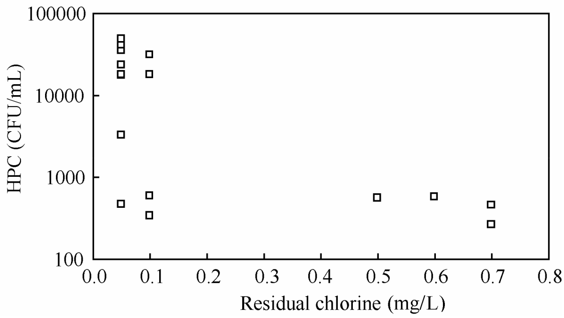

FIG. 3. Influence of residual chlorine on bacterial growth in City T.

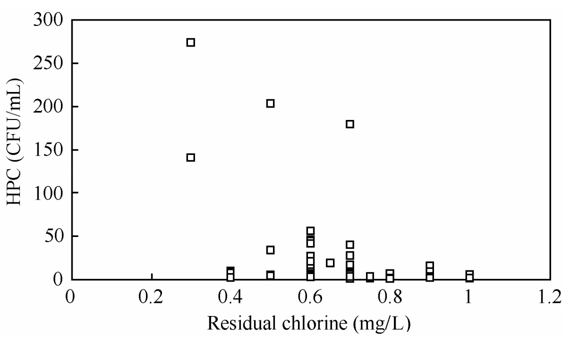

FIG. 4. Influence of residual chlorine on bacterial growth in Macao.

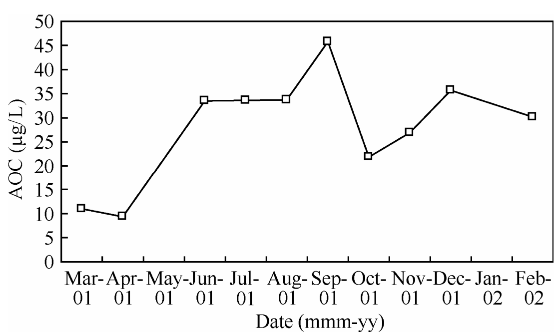

FIG. 5. Mean values of AOC contents in the Macao water distribution system in different months.

TABLE 2

Comparison of Water Quality Indexes Between the Two Cities

	Mean of Residual Chlorine (mg/L)	Mean of AOC (μg /L)	HPC (CFU/mL)
City T	0.22	93-453	10^2~10^4
Macao	0.64	5-50	<300

Influence of Phosphate on the Bacterial Growth

In March and July, the total phosphate (TP) contents in source water, product water and distribution water were measured (Fig. 6). From March to July, the TP content in source water increased from 33 μg/L to 65 μg/L, and was 24.4-30.1 μg/L in product water. However, it did not fluctuate obviously in distribution water and the mean value was 26.4 μg/L.

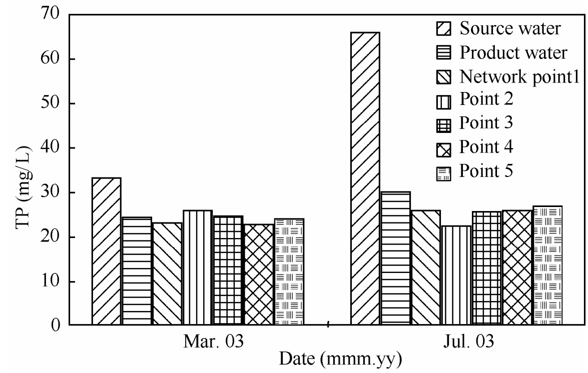

FIG. 6. TP contents in water samples from City T.

Fig. 7 shows the influence of the addition of phosphors to the source water and distribution water on the test results of AOC in City T. After the addition of phosphors, the AOC did not increase significantly, suggesting that phosphors might not be the limiting nutrient and removal of biodegradable organic matter was the key for improving the biostability.

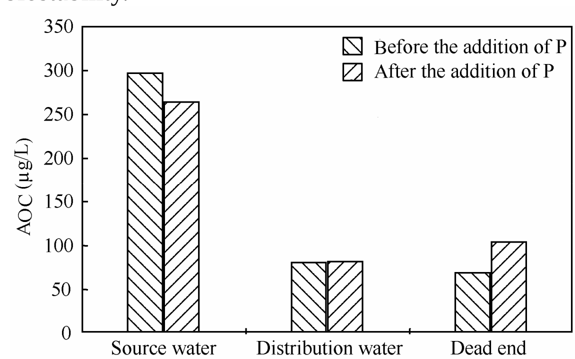

FIG. 7. Influence of phosphor addition on AOC.

Relationships Between the Indexes

The correlations between AOC and COD_{Mn}, TOC are shown in Figs. 8 and 9. The correlation coefficient of AOC and CODMn was 0.3, and that of AOC and TOC was 0.12.

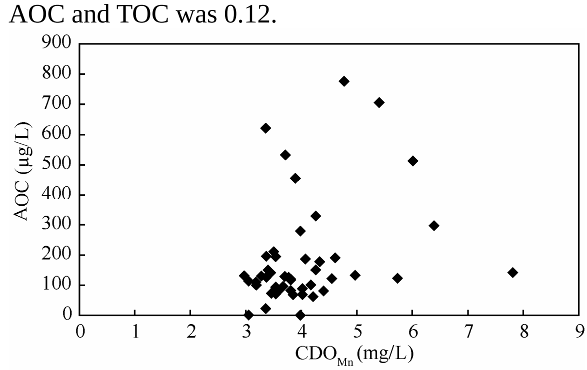

FIG. 8. Correlation between AOC and COD_{Mn}.

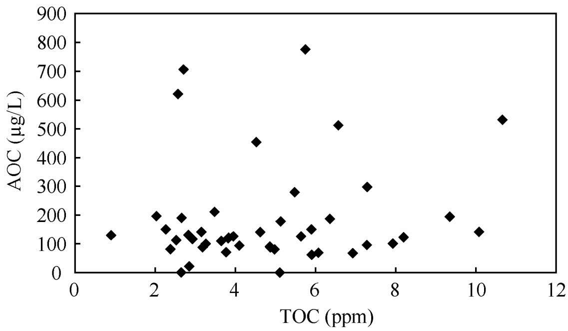

FIG. 9. Correlation between AOC and TOC.

DISCUSSION

The AOC content in most product water of the studied water treatment plants and the water from the associated distribution systems is more than 100 µg/L, or even more than 200 µg/L. As a widely used biological indicator, AOC represents the organic matter directly assimilated by bacteria in drinking water. The index established indicates the potential of heterotrophic bacteria growth, a certain relationship should therefore exist between AOC and HPC. However, according to the research, the relationship still seems uncertain.

With the reduction of residual chlorine, HPC in the distribution systems increased significantly. When the residual chlorine was less than 0.1 mg/L, the magnitude order of HPC was 10^4 CFU/mL. Therefore, residual chlorine seems to be the most important factor controlling bacterial growth. However, when residual chlorine was 0.5-0.7 mg/L, the HPC level was about 500 CFU/mL, and the microbial risk was still high. Theoretically, if chlorine concentration is high enough, bacteria growth can be effectively controlled. Nagy *et al.*[7] reported that 1-2 mg/L residual chlorine can reduce bacteria in biofilms by 2 logs, and maintenance of 3-5 mg/L residual chlorine is necessary to reduce it by 3 logs. However, excessive addition of chlorine may induce DBPs. Consequently, for controlling the biostability of drinking water, the controlling of AOC and maintenance of residual chlorine should be considered simultaneously.

Recently, it was reported that in some source water conditions, phosphors become the limiting nutrient for bacterial growth[8-9]. As an evaluating indicator of biological stability, AOC in the water samples from City T, rather than phosphorus, is the limiting nutrient. In this situation, AOC is the principal controlling parameter.

The correlation coefficient of AOC and COD_{Mn} is 0.3, and that AOC and TOC is 0.12, suggesting that COD_{Mn} or TOC can not be substituted for AOC in assessing biostability of drinking water.

ACKNOWLEDGEMENTS

The authors thank Mr. Wen-Jie HE, and Hong-Da HAN and Mrs. Jian-Kun HU from Tianjin Drinking Water Ltd. Co. for their excellent technical assistance and the supply of research base.

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(*Received July* 8, 2004 *Accepted November* 24, 2004)