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Biostability in distribution systems in one city in southern China: Characteristics, modeling and control strategy

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ABSTRACT

This study investigated the bacterial regrowth in drinking water distribution systems receiving finished water from an advanced drinking water treatment plant in one city in southern China. Thirteen nodes in two water supply zones with different aged pipelines were selected to monitor water temperature, dissolved oxygen (DO), chloramine residual, assimilable organic carbon (AOC), and heterotrophic plate counts (HPC). Regression and principal component analyses indicated that HPC had a strong correlation with chloramine residual. Based on Chick-Watson's Law and the Monod equation, biostability curves under different conditions were developed to achieve the goal of HPC $\leqslant$ 100 CFU/mL. The biostability curves could interpret the scenario under various AOC concentrations and predict the required chloramine residual concentration under the condition of high AOC level. The simulation was also carried out to predict the scenario with a stricter HPC goal ($\leqslant$ 50 CFU/mL) and determine the required chloramine residual. The biological regrowth control strategy was assessed using biostability curve analysis. The results indicated that maintaining high chloramine residual concentration was the most practical way to achieve the goal of HPC $\leqslant$ 100 CFU/mL. Biostability curves could be a very useful tool for biostability control in distribution systems. This work could provide some new insights towards biostability control in real distribution systems.

Introduction

The qualified finished water from water treatment plants can experience complex chemical, physical and biological changes during transportation in the distribution systems before it reaches the taps. The problems of water deterioration in the networks include chemical instability effects, such as elevated turbidity, color, taste, odor and iron concentration (Rigal and Danjou, 1999; Lehtola et al., 2004; Niu et al., 2006; Husband and Boxall, 2011), as well as biological instability effects, such as bacterial regrowth, nitrification and propagation of protozoa (Sibilie et al., 1998; Lipponen et al., 2002; Chowdhury, 2012; Lu et al., 2013).

The regrowth of microorganisms, especially pathogens, can have large impacts on public health. Non-pathogens can also lead to bio-corrosion and off-flavor. High priority has been given to the control of bacterial regrowth in the USA. and Europe (Ashbolt, 2004; McGuire, 2006). Heterotrophic plate count (HPC) is widely used as an index to evaluate the bacterial regrowth in drinking water distribution systems. Different criteria of HPC have been set, ranging from 100 to 500 CFU/mL (Pavlov et al., 2004).

Generally, there are two approaches available to con-

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trol the bacterial regrowth in distribution systems. First, maintain an adequate disinfectant concentration for better inactivation efficiency. Second, lower the substrate concentration to cut down the food supply of microbes. However, the measures to control bacterial regrowth are quite site-specific. It is hard to design a universal control strategy for all distribution systems. Van der kooij (1992) found a significant correlation between assimilable organic carbon (AOC) and the geometric mean of heterotrophic bacteria in one distribution system in the Netherlands where the chlorine residual in waters was less than 0.1 mg/L. The requirement of HPC < 100 CFU/mL could be satisfied with AOC < 10 μg/L. Lu (2005) revealed that HPC had a good relationship with chloramine residual (r = –0.59, P < 0.001) and AOC (r = 0.39, P = 0.002) in one distribution system in China when chloramine residual was 0.05–1.0 mg/L. Zhang et al. (2002) pointed out that AOC was not the limiting factor for bacterial regrowth in distribution systems. High residual chloramine (> 2 mg/L) could effectively repress microbial activity in waters even at high AOC levels. HPC had a significant correlation with chlorine (r = –0.74, P = 0.0001) but a relatively poor correlation with AOC (r = –0.21, P = 0.028) (Zhang and DiGiano, 2002). Therefore, the HPC may be influenced by AOC and disinfectant residual simultaneously. The increase of HPC may be due to high AOC feeding, mainly in distribution systems with low disinfectant concentration, while the HPC density can be limited by a high disinfectant residual concentration even at a relatively high AOC concentration.

Biostability analysis in real distribution systems has mainly been carried out with regression models. Some mechanistic models, such as SANCHO, PICCOBIO and BAM, were developed with the pipe loop reactor or biological annular reactor. There are few reports about the assessment of these models in real distribution systems (DiGiano and Zhang, 2004; Zhang et al., 2004). The biostability in real distribution systems in large cities remains poorly understood. Moreover, there is no information available on control strategy based on systemic analysis of whole water supply networks (from water treatment plant to distribution systems). The aim of this study was to systemically investigate the factors that influenced HPC levels in real drinking water distribution systems in one large city in Southern China and find a cost-effective strategy to control bacterial regrowth. Mathematical tools were applied to identify the most important parameters and evaluate their impacts on HPC concentration. Different water treatment processes and disinfection technologies were also evaluated to establish a feasible strategy for control of bacterial regrowth.

1 Materials and methods

1.1 Profile of water treatment plant, distribution system and sampling points

Raw water and the effluents of a horizontal sedimentation tank, sand filter, O_3 contact tank, biological activated carbon (BAC) filter, and pumping station were selected as the sampling points (**Fig. 1**). Water quality monitoring was performed in sub-district D and sub-district Z, both of which were served by the N water treatment plant (**Table 1**). Field surveys were conducted in summer (August 2007; water temperature at approximately 30°C) and winter (November 2007, January 2008 and March 2008; water temperature at approximately 20°C), respectively. Water temperature, dissolved oxygen (DO), HPC, AOC, and chloramine residual were determined.

1.2 Water quality analysis

Water temperature, DO and chloramine residual were measured using a mercury thermometer, YSI 550A Handheld Dissolved Oxygen Instrument (YSI, USA) and Pocket Colorimeter™II (Hach, USA), respectively. HPC was detected according to the Pour Plating Method with R2A media (22°C, 7 days) (APHA, 1995). AOC was measured according to the literature (Liu et al., 2002).

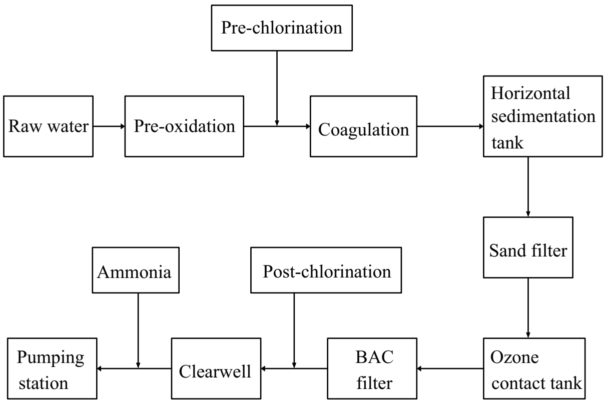

Fig. 1 Flowchart of the studied water treatment plant. BAC: biological activated carbon.

Table 1 Distribution systems and sampling points

Water plant	Distribution systems	Pipe material	Service year of pipe before investigation	Number of sampling points	Number of samples
N water treatment plant	Sub-district D	Cast iron	4	8	35
	Sub-district Z	Cast iron	8	5	18