Evaluation of the Innovated Disinfection Process with High Dissolved CO₂

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Abstract

A novel high-dissolved CO₂ device was developed for the disinfection of treated sewage wastewater. Several experiments were conducted regarding the waterborne pathogen inactivation rate, the treatment time and the disinfection target (several treated sewage wastewaters, canal and river water). The results indicated that different disinfection targets can lead to 2.8-3.0 log-inactivation of waterborne pathogens within 20 minutes of treatment under 0.3 MPa of pressure in the device. Results also showed that the suspended solid (SS) in raw water affected the disinfection efficiency.

Keywords: disinfection, high dissolved CO₂, liquid film

INTRODUCTION

Disinfection has become a challenging aspect of water treatment because of the rapid elevation of health standards and the growing concern for pollution free water resources. Coagulation-membrane filtration (Fiksdal and Leiknes, 2006), UV radiation (Hijnen *et al.*, 2006), and ozone associated processes (Rennecker *et al.*, 1999; Jyoti *et al.*, 2004; Rashmi *et al.*, 2007) have been developed as new disinfection technologies to replace chlorination disinfection due to its toxic and carcinogenic by-products (Steve, 2009) and the invalidation of some chlorine-resistant protozoan, such as *Cryptosporidium* (Kristen *et al.*, 2000) and *Giardia* (Lawryshyn and Cairng, 2003). However, the high construction costs and operation expenses have become problems that prevent their use in practical applications. Therefore, an innovative disinfection process using high-dissolved CO₂ was developed to minimize the operating cost and provide a free by-product effect. This process is a new concept differing from high pressure CO₂ disinfection (Laura *et al.*, 2005) and supercritical CO₂ disinfection (Ishikawa *et al.*, 1997; Kobayashi *et al.*, 2007; Liao *et al.*, 2007).

In this paper, treated sewage wastewater (both in Japan and Thailand), canal water (Thailand) and river (Thailand) water were used as targets for the disinfection to confirm the disinfection effects in practical applications. The relation between inactivation rates of the *fecal coliforms* (FC) and *total coliforms* (TC) (the indicator waterborne pathogen) as well as the treatment time were examined. Additionally, other factors affecting the FC and TC inactivation rates were also discussed.

MATERIALS AND METHODS

Disinfection mechanism

The high-dissolved CO₂ device is shown in Fig. 1. To improve the contact efficiency between CO₂ and water, the nozzle with a small radius was set to provide influent at a high rate. When the influent stroked the bottom of the device, many liquid films (bubbles) were produced, and as a result, the CO₂ dissolution rate increased because of the larger gas-liquid contact area.

Inside the device, the microorganism uptake the CO₂ dissolved in the water because of the existence of the CO₂ concentration difference between the inside (low) and outside (high) of the cell. When the water was discharged outside the device, the pressure suddenly decreased, while the CO₂ inside the cell appeared and caused a large amount of bubbles quickly, resulting in a rupture of the microorganism. Additionally, the CO₂ penetrating into the microorganism was able to alter the properties of the cells (Dixon and Kell, 1989). Therefore, disinfection in this study can be defined as microorganism inactivation.

Fig. 1 - Mechanism of the high-dissolved CO₂ device

Disinfection experiment

The effluent from the final settling tank of a wastewater treatment plant (WWTP) as well as canal water and river water were used as targets for disinfection in this study. During this study, one set of operational conditions was applied for the device, as shown in Fig. 2. CO₂ was filled the device before the experiment; the water cycled in 20 min after it was pumped into the device; and the samples were taken at different times.

Analytical procedures

Enumeration of bacteria was done by plate count method as recommended by Japan Sewage Works Association (JSWA, 1997). This method of analysis has been used for the estimation of the overall reduction in the colony forming units (CFU). For this purpose, desoxycholate agar was used as the growth medium. The samples before and after treatment suitably diluted was introduced into each Petri dish first and then 10 mL of media was added and mixed, after they turned into solid, another 10mL of media was added. For *FC* count, these Petri dishes were inverted and incubated at 44.5°C for 18-20

h; For *TC* count, these Petri dishes were inverted and incubated at 37°C for 18-20 h. The colonies developed were counted and expressed as CFU/mL. The data presented are the means with standard errors of the results of experiments performed in several sessions. The log survival ratio ($\log_{10} (N/N_0)$) was calculated to determine the final inactivation effect, where N_0 was the number of initial microorganisms in the untreated sample, and N was the corresponding viable number of microorganisms after treatment. Suspended solid (SS) and volatile suspended solid (VSS) were analyzed by Standard methods for water and wastewater analysis (APHA, 1989), TOC was analyzed by TOC-5000 (SHIMADZU, Japan).

Fig. 2 - Device operating conditions

RESULT AND DISCUSSION

Optimization of operating conditions

The effluent from the final settling tank of a WWTP (Ube City, Japan) used as the target for disinfection was treated under different pressures. The experiment was repeated for two months. The average results are shown in Fig. 3 and show that *TC* only achieved a 1.2 log-inactivation under 0.2 MPa of pressure for 20 min. However, a 2.0 log-inactivation of *TC* occurred quickly under 0.5 MPa and 0.4 MPa of pressure in 10 min. Additionally, under 0.3 MPa of pressure, *TC* log-inactivation reached 2.7-3.0. Therefore, the operational condition of 0.3 MPa for 20 min was selected because the lowest pressure achieved the highest *TC* log-inactivation. Also, compared to the supercritical CO₂ method, which requires pressures as high as 8-20 MPa (Ishikawa *et al.*, 1995), this method saved lots of energy. In addition, when compared to the high pressure process for disinfection, which requires a long duration of pressure leading to the deformation of the cell (Laura *et al.*, 2005), the method used in this study saved operation time.

Fig. 3 - Inactivation of *TC* under different inside pressures in the device. (Each data point is an average of independent experiment and error bars represent the data range.)

Disinfection effect of different initial *FC*

Experiments were conducted at least twice, with several effluents from the final settling tank of the WWTP (Table 1), at the operational condition of 0.3 MPa of pressure. WWTP1 had a *FC* log-inactivation as high as 1.5 in 10 min. However, it took time for the other two samples to increase the *FC* log-inactivation in 10 min, but after 10 min, the *FC* log-inactivation quickly increased. The reason for these results is that these two samples had more initial *FC* numbers, and 10 min was not long enough for all of the bacteria to uptake enough CO₂, which lead to the explosion of all cells when discharged outside of the device. Based on these results, we speculated that lower initial microbial numbers could quickly achieve high disinfection effects.

Table 1 - Water quality of different WWTP final settling tank effluents in Thailand

Place	SS (mg/L)	VSS (mg/L)	TOC (mg/L)	<i>FC</i> (CFU/mL)	Sample
Din Deang WWTP	3.41	2.38	5.52	940±20	WWTP1
Si phraya WWTP	5.36	4.64	5.11	1300±45	WWTP2
Chong Nonsi WWTP	5.73	3.08	6.86	2400±120	WWTP3

Fig. 4 - Inactivation of *FC* from different WWTP final settling tank effluents. (Each data point is an average of independent experiment and error bars represent the data range.)

Disinfection effect of different suspended solids concentrations in raw water

As shown in Fig. 5, canal water 1 and the river water (Table 2) shared lower initial *FC* numbers compared to the WWTP samples, but the *FC* log-inactivation was lower than 0.4 in the first 10 min, then quickly increased after 10 min. One reason for this result could be that the higher SS in the canal and river waters inhibited the uptake of CO₂ by the bacteria, leading to the slower *FC* inactivation. The results also revealed that it was possible to reach a high *FC* log-inactivation of 2.8 for the canal and river waters in 20 min. Canal water 2 contained a very high initial *FC* number, and the *FC* log-inactivation was relatively flat due to the high initial *FC* number that inhibited the effects of the SS.

Table 2 - Water quality of different canal and river water in Thailand

Place	SS (mg/L)	VSS (mg/L)	TOC (mg/L)	<i>FC</i> (CFU/mL)	Sample
Pathuntani Klong 5	11.6	2.26	9.55	72±8	Canal water 1
Khlong Phadung Krung Kaseme	33.6	13.4	13.0	35000±550	Canal water 2
Chao Phraya River (Largest river in Bangkok)	17.7	2.08	7.73	690±30	River water

Fig. 5 - Inactivation of *FC* for different canal and river waters. (Each data point is an average of independent experiment and error bars represent the data range. ↓: No colony was detected, the log inactivation was suggested more than this point.)

To be sure of the effect of SS in raw water, another experiment was conducted with the supernatant from the final settling tank of the WWTP (Ube City, Japan) with the same initial *TC* numbers, but with different SS concentrations. The average results shown in Fig. 6 indicate that high SS samples resulted in lower *TC* log-inactivation in the first 10 min. Especially, the highest SS sample (SS = 20.9 mg/L) showed no *TC* inactivation between 5 and 10 min. It was speculated that bacteria buried in the SS inhibited the speed of CO₂ uptake into their cells. However, after 10 min, the *TC* log-inactivation quickly increased, and it was thought the continuous bubbling released the bacteria buried in the SS, allowing the bacteria to take up CO₂ again. From these results, after 20 min, the *TC* log-inactivation of the two samples could not reach 2.67 (result of SS = 1.67 mg/L). The results also demonstrated that low SS in the target water produced greater disinfection efficiency.

Fig. 6 - The relationships between *TC* inactivation and the treatment time with different SS. (Each data point is an average of independent experiment and error bars represent the data range.)

CONCLUSION

- (1) The optimum operational condition of the device is a pressure of 0.3 MPa. When a high-dissolved CO₂ device is used for the disinfection of the effluent from the final settling tank in a WWTP, the *TC* log-inactivation was as high as 3.0 in 20 min.
- (2) *FC* log-inactivation could be as high as 2.8 for canal and river water disinfection. In addition, the disinfection efficiency would increase if it is possible to remove the SS from the raw water.

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