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Controlling mechanism of chlorination on emitter bio-clogging for drip irrigation using reclaimed water

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ABSTRACT

Drip irrigation using reclaimed water or polluted surface water involves a higher risk of bio-clogging, which is the most typical and the most complex type of clogging, and the clogging of drip irrigation emitters limits the use and spread of drip irrigation technology. Due to its strong oxidizing effect, chlorination has been considered as the most effective method of controlling emitter bio-clogging. However, the detailed controlling mechanism has remained unclear until now. Meanwhile, there have been no unified standards established for chlorination to refer to. Therefore, field experiments were carried out in a sewage treatment plant, where the reclaimed water after secondary treatment was treated with the Cyclic Activated Sludge System (CASS) process that had been incorporated to the drip irrigation system to study the controlling mechanism and impacts on non-pressure-compensating emitter bio-clogging. There were three chlorination treatments studied, which included 2.5 mg/L × 2 h (low concentration, long duration), 5.0 mg/L × 1 h (moderate concentration and duration), and 10 mg/L × 0.5 h (high concentration, short duration). The results showed that the chemical chlorination could control the microbial growth in the bio-clogging substances effectively, with the microbial phospholipid fatty acids (PLFAs) decreased by 8.3%–36.1%, the number of microbial species decreased by 2–3, the microbial activity decreased by 2.6%–23.2%, and the secretion of extracellular polymeric substances (EPS) decreased by 19.8%–43.4%. Thus, the bio-clogging substances were well controlled, and the contents of solid particles (SD) content decreased by 4.8%–48.2% compared to the non- chlorinated treatment, while the discharge ratio variation (Dra) and Christiansen uniformity coefficient (CU) increased by 14.7%–22.8% and 6.77%–19.9%, respectively. However, the effects of different chlorination modes varied significantly. Chlorination with a low concentration and a long contacting duration decreased microbial activity, and better controlled emitter bio-clogging. Thus, the chlorination treatment of 2.5 mg/L × 2 h was recommended in the drip irrigation system using reclaimed water treated with CASS technology.

1. Introduction

Emitter clogging has become one of the main obstacles for the development and application of drip irrigation. Therefore, the life and effectiveness of the drip irrigation systems are greatly influenced by emitter clogging. As water shortage and water pollution are becoming increasingly serious all over the world, reclaimed water and polluted surface water are also reused for irrigation to solve the imbalance between water supply and demand. Due to the different water quality of the irrigation water, physical, chemical and bio-clogging are likely to occur (Bucks et al., 1979; Adin and Sacks, 1991; Ravina et al., 1992; Capra and Scicolone, 1998; Wu et al., 2008), and these three factors are more likely to induce emitter clogging. In particular, the reclaimed water, which contains sufficient suspended solids, salinity, algae, microorganisms and other pollutants, and leads to the typical bio-clogging in emitters (Li et al., 2009). A large number of studies have indicated that bio-clogging substances appear similar to have a biofilm structure (Capra and Scicolone, 2004; Duran-Ros et al., 2008; Liu and Huang, 2009; Li et al., 2012). In biofilms, microorganisms played a very important role in inducing the emitter bio-clogging effect, adhering to the emitter path and, relying on their own secretions to increase the viscosity, they continue to absorb the suspended particles, leading to the emitter clogging (Li et al., 2013a,b). Therefore, controlling

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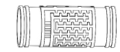
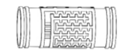
Table 1
Parameters of the drip irrigation emitters.

No.	Emitter flow q (L/h)	Geometry parameters of water flow path length × wide × depth (mm)	Manufacturing deviation	Emitter structure	Manufacturer
E1	1.05	20.23 × 0.57 × 0.67	2.6%		Netafim
E2	1.20	152.23 × 2.40 × 0.75	3.8%		Longda Hebei
E3	2.60	152.23 × 2.40 × 1.01	4.2%		Longda Hebei

the growth of microorganisms can effectively relieve the emitter bio-clogging.

Many methods of relieving emitter clogging were studied, including precipitation, filtration, chlorination, acid, ultraviolet disinfection and lateral flushing. Among these, the strong oxidation of chlorine can kill or inhibit the reproduction and growth of microorganisms (bacteria) and prevent the formation of biofilms, thus effectively reducing emitter clogging (Li et al., 2010). Therefore, chlorination has been widely used to prevent the bio-clogging (Hills and Brenes, 2001; Puig-Bargues et al., 2005; Dehghanisanij et al., 2005; Cararo et al., 2006), but different ways of chlorination were also proposed: emitter clogging could be effectively slowed down by a period of chlorination of 10–30 min, with residual chlorine concentration at 10–20 mg/L (Feigin et al., 1991). Controlling residual chlorine concentrations at 3–5 mg/L every day would have a good effect on relieving the mucus clogged emitters using wastewater (Ravina et al., 1997). Tajrishy et al. (1994) continuously added the chlorine to reclaimed water and maintained a chlorination concentration of 0.4 mg/L. Tajrishy et al. (1994) also maintained the residual chlorine concentration at 2–6 mg/L in the final hour of irrigation as well, and the emitter clogging was well controlled. Dehghanisanij et al. (2005) presented that the intermittent chlorine with a concentration of 1–20 mg/L could alleviate emitter clogging caused by the sedimentation of organic matter and algae. Nakayama and Bucks (1981) showed that the emitter flow recovered to 95% of the initial level when the chlorine concentration was 100 mg/L. Coelho and Resende (2001) proved that a residual chlorine concentration of 150–600 mg/L had an effect on the partially clogged emitters, but failed for completely clogged emitters. Li et al. (2010) recommended that the drip irrigation emitters with low flows using reclaimed water should have chlorination applied weekly at a concentration of 2.5 mg/L. Overall, the results from related studies showed the effective chlorine concentrations ranging from 1–20 mg/L to 100–600 mg/L, and the three durations of chlorine exposure in the systems varied from tens of minutes to hours. Although chlorination was generally helpful in reducing the emitter clogging in the drip irrigation systems, no norm was acquired, and the effect of chlorination on the emitter bio-clogging was evaluated from the perspective of the emitter outflow. The key reason for this result was that the mechanism of chlorination to control the growth of microorganisms in the clogging substances, as well as bio-clogging process, was still unknown.

Therefore, to determine a better and more appropriate mode of chemical chlorination for controlling bio-clogging, three types of commonly used driplines were examined in a drip irrigation experiment using reclaimed water treated with the Cyclic Activated Sludge System (CASS) process after secondary treatment, and the dynamic changes of microorganisms within the emitter clogging substances were studied. After studying the effect of different chlorination modes on microbial contents, species, activities and the secretion of viscous extracellular polymeric substances (EPS), and the formation of bio-clogging substances in emitters and the effective methods were suggested, aiming to provide a support for establishing a suitable mode of chemical chlorination for controlling bio-clogging.

2. Materials and methods

2.1. Experimental designs and system layout

The chlorine concentration was chosen according to the results obtained by Li et al. (2010) obtained: 99.9% of the total bacteria in the sewage effluent could be eliminated by a residual chlorine concentration of 2.5–10 mg/L and the drip irrigation system could also maintain good performance. Thus, three chlorination modes were considered to control the emitter bio-clogging in the experiment using the reclaimed water. Three treatments of residual chlorine concentration and chlorine contacting time (the duration of sodium hypochlorite being added to the system) combinations were set up on the basis of the same amount of total chlorine: 2.5 mg/L × 2 h (low concentration, long duration, marked as C2.5T2), 5.0 mg/L × 1 h (moderate concentration and duration, marked as C5T1), 10 mg/L × 0.5 h (high concentration, short duration, marked as C10T0.5). Meanwhile, a control treatment without chlorination (C0T0) was set up for comparison. Three types of non-pressure compensating driplines (E_1, E_2 and E_3) with 16 mm lateral internal diameter were used (Table 1), and each treatment contained two replications, which consisted of 40 emitters and had a lateral length of 12 m. The structure parameters of the emitter are shown in Table 1. In addition, the manufacturing variations of new emitters were tested before the experiment (ISO, 2004), and the emitter quality was "excellent" according to the classification of emitter quality criteria (ASAE, 2003).

The layout of the drip irrigation system is shown in Fig. 1. During the experiment, the filtration consisted of a 120-mesh screen filter and a 120-mesh disk filter, and the head pressure of the lateral was 10 m H_2O. The system was operated for 5 h a day (6:00–8:30 am, 4:30–7:00 pm) from Monday to Friday using an automatically time governor to control the operation. The chlorination was applied when the degree of emitter clogging exceeded 25%, according to the international standard (ISO, 2004). In this experiment, the mean values of the discharge ratio variation (Dra) for the three types of emitter were 72.48%, 72.62%, and 76.92%, respectively, when the system ran for 400 h and the chlorination was conducted once every two weeks. According to the chlorine concentration and duration time, the outflow was tested both before and after the chlorination. The first stage of the experiment was from May 7, 2012 to November 20, 2012, the system operated for 600 h in total. To prevent freezing as the temperature dropped, driplines were placed in-house. The second stage was from April 8 to May 5, 2013, the system operated for only 100 h in total. This low operation time was mainly because the emitter was considered to be completely clogged Therefore, the experiment comprised 700 h of operation time in total. To enhance the bactericidal effect of chlorination, an appropriate amount of hydrochloric acid (HCl) was added to the reclaimed water before the chlorination, with the pH