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Study on the release of HPC and particles in ozonation and biological activated carbon processes

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HIGHLIGHTS

- Pre-ozonation would improve BAC filtration effluent water quality.
- Changes in the particle counts of BAC filtration influent had no effect on the particle counts of the effluent.
- A sudden increase in the filtration velocity led to a significant release of HPC and particles.
- A large number of leakage particles and HPC appeared at an initial BAC filtration period.
- The release of HPC and particles was most severe at the top layer of the BAC filtration.

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ABSTRACT

The release of heterotrophic plate count (HPC) and particles in ozonation and biological activated carbon (O_3-BAC) processes and related influential factors were studied using a laboratory-scale apparatus in this paper. The results showed that pre-ozonation of BAC influent had a positive effect on the decrease of the particle counts and HPC of BAC effluent. We also found BAC filtration influent particle counts had no effect on the effluent. While the particle counts of the BAC filtration influent varied between 42–58, 170–184 and 248–269 Count/mL (CNT/mL), the particle counts of effluents remained stable in the range 19–23 CNT/mL. In addition, the BAC filtration velocity had little influence on the release of HPC and on the particle counts from BAC, but a sudden increase in the BAC filtration velocity lead to a significant release of HPC and increased particle counts. These hydraulic shocks also made particles with sizes of 5–10 μm more likely to leak from the BAC filtration. We also found that the maximum particle count and HPC in water initially filtered with BAC were as high as 311 CNT/mL and 4.7 log. These levels took approximately 30 min to decrease to a stable and a normal level, which were approximately 20 CNT/mL and 3.2 log. Finally, the leakage of HPC and the number of particles decreased with increasing depth, with the highest amount of leakage occurring at the top layer of the BAC filter.

1. Introduction

Because of the deterioration of source water quality and because of the public demand for safe drinking water, ozonation and biological activated carbon (O_3-BAC) processes have been widely used as an advanced drinking water treatment technology. Utilizing adsorption and biodegradation, O_3-BAC has been shown to be efficient in removing tastes and odors, biodegradable dissolved organic carbon, microcystin-LR, and disinfection by-product precursors [1,2].

However, microorganisms and particulate matter can penetrate the BAC bed and flow into the effluent because of the accumulation of biotical and abiotic substances on the BAC, which poses a serious microbial problem. A previous study of Liu [3] proposed that bacteria on the biofilm of a BAC medium was approximately 10^5–10^7 HPC/cm^2 and noted that the accumulated extracellular metabolites were easily washed out during operation.

Many researchers have reported that excessive numbers of heterotrophic plate count (HPC) bacteria emerge in the effluent of O_3-BAC [3,4]. Some researchers have noted that a few members HPC bacteria produce virulence factors and can act as opportunistic pathogens, which can cause diseases mainly in vulnerable individuals, i.e., the very young, the elderly, immune-suppressed populations, and pregnant women [5]. Furthermore, some HPC bacteria

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found in biological processes were resistant to chlorine disinfectant. Pernitsky found that a chlorine-resistant subgroup within the HPC bacteria population in biological process effluent might exist; therefore, the Hom model was found to better describe the inactivation kinetics of plate count bacteria in biological process effluent compared to the Chick–Watson model [6]. In addition, because the attachment and growth of bacteria can lead to biofilm formation on particles, particle-associated HPC bacteria can cause a further concern for their substantially increased resistance to disinfection [7]. Particle-associated HPC bacteria have been shown to be more resistant to disinfection by chlorine, ozone and ultraviolet (UV) radiation compared to planktonic bacteria. In a study by Pernitsky, disinfection with free chlorine (CT = 30–75 mg min/L) resulted in 0.7–2 log reduction in attached HPC bacteria compared to a 2–4 log reduction in unattached bacteria [8]. Due to this high resistance, more chlorine disinfectant has to be added into BAC effluent to maintain the efficiency of disinfection of HPC bacteria. However, high doses of chlorine disinfectant in drinking water will trigger chemical security problems because of the corresponding occurrence of disinfection by-products [9].

In addition to the excessive release of HPC bacteria and their high resistance to disinfection, the leakage of particles, including microorganisms, organic materials, and inorganics, was found to be present in BAC effluent [4,10]. Using an SEM analysis, Stewart reported that 85% of released granular activated carbon (GAC) particles were colonized with less than 50 bacterial colonies, but among them, 8% had hundreds to several thousands of bacterial cells [11]. Therefore, the release of only a few particles could introduce significant numbers of organisms into the water. The existence of particles will not only increase the possibility of occurrence of chemical-disinfection-resistant protozoa Giardia cysts and Cryptosporidium oocysts, but it will also decrease the efficiency of disinfection of BAC effluent. Marda found a rapid loss of monochloramine in O_3-BAC process effluent, whereby one of the reasons for this was the leakage of debris and fines of activated carbon media generated from the BAC filter [12]. The influence of particle concentration on disinfection efficiency was investigated by Stringfellow, where their results showed that only a 1 log reduction could be achieved at the highest concentration of particles (1.8 mg/L) after 5 min when treated with 2 mg/L free chlorine, and an approximately 1.5 log reduction was achieved when the particle concentration was lowered to 0.18 mg/L. At a particle concentration of 0.018 mg/L, no culturable bacteria were found after 2 min [4]. Another concern was that if these leaked particles flowed into drinking water distribution systems, it could cause particle accumulations [13] that would enhance biological growth by offering nutrients and a surface area for bacteria to grow on and protect bacteria from disinfectant residuals, leading to the discoloration of tap water and to biological risks.

In view of the above, the objective of this paper is to evaluate the release of HPC and particles in ozonation and biological activated carbon (O_3-BAC) processes and influential factors to make recommendations on drinking water O_3-BAC treatment plant operations.

2. Materials and methods

2.1. Raw water quality

Raw water was taken from Sanhaowu Lake at Tongji University. The main water parameters are listed in Table 1.

Table 1
Raw water quality.

Parameter	Raw water
Temperature (°C)	19.5(±3.6)
Turbidity (NTU)	1.65(±0.55)
pH	6.66(±0.06)
UV_{254} (cm^{-1})	0.059(±0.004)
DOC (mg/L)	3.30(±0.67)

2.2. Laboratory-scale O_3-BAC apparatus

The schematic diagram for the laboratory-scale O_3-BAC apparatus is shown in Fig. 1. Raw water was poured into the reservoir ($0.18\ m^3$) with the addition of aluminum polychloride at a dose of 10 mg/L. Then, water in the reservoir was pumped into a sand filtration column (with an internal diameter of 6.3 cm and a height of 80 cm). The sand filtration velocity was 2.5 m/h, which provided approximately 19 min of empty bed contact time (EBCT). Sand column was backwashed every 24 h at a rate of 20 L/(m^2 s) for 10 min. During our tests, the adjustable flow meter installed in the sand filtration discharging tube was used to change the EBCT (empty bed contact time) of sand filtration. By this way, we can achieve different sand filtration effluent particle counts and BAC filtration influent particle counts simultaneously.

The ozone contactor column had an internal diameter of 4 cm and a water depth of 0.85 m. When the flow rate was 95 mL/min, which was used most frequently during these experiments, the hydraulic retention time in the ozone contactor column was approximately 12 min. The ozone production rate could be changed from 0 to 0.2 g/min using an Ozone generator (COM-AD-01, ANSEROS, Germany). In these experiments, the ozone dose was maintained at 3 mg/L. The dissolved ozone concentration of the BAC column influent water ranged from 0.5 to 1.2 mg/L, which was measured with a dissolved ozone tester (DOZ30, CLEAN, USA).

The BAC column had an internal diameter of 4 cm and was 1.2 m tall, and the GAC bed height was 0.7 m. When the flow rate was 95 mL/min, which was used most frequently during these experiments, the EBCT was approximately 10 min and corresponding to a filtration velocity of 4.6 m/h. Sample ports are set in intervals of 10 cm in a long the height of the column. BAC column was backwashed at a rate of 16 L/(m^2 s) every 4 days for 8 min. The adjustable flow meter installed in the discharging tube was used for changing the filtration velocity.

Table 2 shows the GAC characteristics. The GAC filtration were initiated by applying unozonated influent to the biofilm formation for six months [14]. During that time, the virgin GAC was exposed to the microbial community present in the water, which led to a rapid initial colonization.

2.3. Analytical methods

The particle counts were measured by a portable particle measuring sensor (WPCS, IBR, China), whereby particles larger than 2 μm could be detected, and the particles could be divided into eight channels: 2–3, 3–5, 5–7, 7–10, 10–15, 15–25, and >25 μm.

An HPC analysis was performed using an R2A medium with incubation for seven days at 25 °C before enumeration.

The dissolved organic carbon (DOC) was measured with a TOC analyzer (TOC-L, SHIMADZU, Japan). The UV absorbance at a wavelength of 254 nm (UV_{254}) was determined with a spectrophotometer (HACH, DR5000, USA). All water samples were filtered through a 0.45 mm membrane (Millipore) to remove insoluble particles in water before the DOC and UV_{254} test. The turbidity was measured using a HACH 2100Q turbidity meter.

3. Results and discussion

3.1. Effect of ozonation on BAC effluent particle counts and HPC

Fig. 2 shows the results of the HPC and particle counts at different treatment stages when ozone was online and out of service.