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Startup pattern and performance enhancement of pilot-scale biofilm process for raw water pretreatment

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HIGHLIGHTS

- Two pilot-scale biofilm reactors were established with different startup strategies.
- Precoated biofilm carriers favor biomass enrichment and reduce nitrite accumulation.
- The optimum DO level for adequate nitrification was 1.0–2.6 mg L^{-1}.
- The suitable temperature range for adequate nitrification was 21–22 °C.
- The presentence of algae increased the risk of disinfection by-products production.

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ABSTRACT

The quality of raw water is getting worse in developing countries because of the inadequate treatment of municipal sewage, industrial wastewater and agricultural runoff. Aiming at the biofilm enrichment and pollutant removal, two pilot-scale biofilm reactors were built with different biological carriers. Results showed that compared with the blank carrier, the biofilm was easily enriched on the biofilm precoated carrier and less nitrite accumulation occurred. The removal efficiencies of NH_4^+-N, DOC and UV_{254} increased under the aeration condition, and a optimum DO level for the adequate nitrification was 1.0–2.6 mg L^{-1} with the suitable temperature range of 21–22 °C. Study on the trihalomethane prediction model indicated that the presentence of algae increased the risk of disinfection by-products production, which could be effectively controlled via manual algae removing and light shading. In this study, the performance of biofilm pretreatment process could be enhanced under the optimized condition of DO level and biofilm carrier.

1. Introduction

In developing countries, abundant nutrients are discharged from the municipal sewage, industrial wastewater and agricultural runoff because of their inadequate treatment and disposal, which cause the serious pollution problems of natural waters. Thereinto, the pollution of drinking water source directly threatens the drinking water safety (Chu et al., 2010; Zhang et al., 2013). For example, the major pollutants such as ammonia and organics existing in water could complicate the chlorination process and form disinfection by-products (Chowdhury et al., 2009; Benner et al., 2013; Han et al., 2013), which would cause health problems to people. However, traditional raw water treatment processes including coagulation, sedimentation, sand-filtration and disinfection, could not remove nitrogen and dissolved organic carbon (DOC) effectively.

The biofilm process is a promising alternative for the pretreatment of raw water because of its potential economic advantages, lower secondary pollution, and less disinfection by-products (DBPs) production (Bruce and Douglas, 2002; Yu et al., 2007; Chu et al., 2011; Qian et al., 2011; Yu et al., 2012; Feng et al., 2013; Han et al., 2013; Zhang et al., 2013). But it is difficult to start up because of the limited growth and enrichment of functional microorganism in the oligotrophic niche (Egli, 2010). In addition, the performance of biofilm process is affected by the influent quality, dissolved oxygen (DO) level, temperature and presence of algae (Mallick, 2002; Feng et al., 2013; Han et al., 2013; Zhang et al., 2013). However, few literatures reported the effect of startup pattern on the performance and potential risk of biofilm process for the raw water pretreatment.

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In this study, two pilot-scale biofilm reactors with different biological carriers are established for raw water pretreatment. The purposes are to investigate the effect of startup pattern on the performance of pilot-scale biofilm process, and also to reveal its potential risk and control strategy in the presentence of algae.

2. Methods

2.1. Characteristics of polluted raw water

The polluted raw water was collected from a river located in Hangzhou, China. The major quality are summarized in Table 1. This kind of water is similar to polluted raw water in Eastern China according to the on-the-spot investigation and related literature (Chu et al., 2010; Feng et al., 2013; Zhang et al., 2013).

2.2. Biofilm pretreatment process

2.2.1. Reactor setup

Two continuous flow reactors (R_1 and R_2) with an effective volume of 63.9 L (147 cm × 14.5 cm × 30 cm) were used in this study (shown in Fig. 1). The reactors filled with the same volumetric carriers (TA-II elastic filler, purchased from Tianyu Environmental Protection Engineering Co., Ltd.; 1.52% of filling ratio), which had a diameter and surface area of 200 mm and 18 $m^2\ m^{-3}$, respectively. In the whole operation period, the environmental temperature was 10–41 °C, corresponding to an influent temperature of 11–35 °C. The carriers in R_1 with precoated biofilm were elastic filler obtained from a continuous reactor feeding synthetic polluted raw water, and the biomass on the carrier is approximately 0.95 ± 0.07 mg TOC g^{-1} carrier. In reactor R_2, blank carriers were added as the control.

2.2.2. Reactor operation

The reactors are operated for more than 6 months, and the whole operation period is divided into four stages (P_1, P_2, P_3 and P_4). The objectives and operating parameters are shown in Table 2. At stage P_1, the reactors were fed with the polluted raw water, and natural biofilm formation method was used. At stage P_2, the effects and the growing characteristics of algae were studied under high temperature. For reducing harmful algae in raw water, the algae were controlled and the operation performance evolution after algae removal was estimated in P_3. In P_4, the performance was investigated under different DO levels.

2.3. Analysis methods

2.3.1. Chemical index analysis

The water samples were routinely collected and analyzed using Standard Methods issued by Chinese SEPA (2002). Unfiltered water samples were used for analysis of turbidity, total nitrogen (TN) and total phosphorus (TP). The water samples were pre-filtered using a 0.45 μm (pore size) glass fiber filter before ammonium, nitrite, nitrate, DOC and UV_{254}-detectable compounds (UV_{254}) were analyzed. The pH was determined using pH meter with a selective electrode (METTLER TOLEDO 320, Switzerland). DO meter (YSI Model52, USA) was employed to measure the DO level. DOC was analyzed using a catalyzed combustion

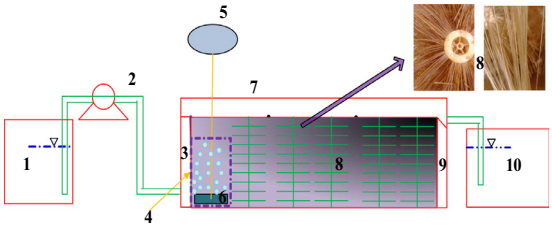

Fig. 1. Schematic diagram of biofilm pretreatment process: (1) influent tank; (2) peristaltic pump; (3) influent area; (4) water diffuser; (5) aerator; (6) air diffuser; (7) reactor; (8) elastic carrier; (9) effluent area; (10) effluent tank.

total organic carbon (TOC) analyzer (TOC-V CPH, Shimadzu). UV_{254} was read from a spectrophotometer (UV-2401PC, Shimadzu) at 254 nm wavelength.

Chlorophyll a, b and c were used as indicators to quantify the algae in the water, and the ratio change of chlorophyll a, b and c could be used to illustrate the algae species changing. Spectrophotometry was employed to describe the absorbance of chlorophyll extracting solution at the wavelength of 630, 645, 663 and 750 nm (Chinese SEPA, 2002). The levels of *chlorophyll* a, b and c could be calculated according to equations (1–3) presented below.

$$Chl_a = \frac{(11.64(D_{663} - D_{750}) - 2.16(D_{645} - D_{750}) + 0.10(D_{630} - D_{750})) \times V_1}{V_2 \times L} \quad (1)$$

$$Chl_b = \frac{(11.64(D_{663} - D_{750}) - 2.16(D_{645} - D_{750}) + 0.10(D_{630} - D_{750})) \times V_1}{V_2 \times L} \quad (2)$$

$$Chl_c = \frac{(11.64(D_{663} - D_{750}) - 2.16(D_{645} - D_{750}) + 0.10(D_{630} - D_{750})) \times V_1}{V_2 \times L} \quad (3)$$

2.3.2. Biomass and biofilm analysis

The elastic carrier was sampled from reactors and then exposed to ultra-sound wave (300 W) for 4 h to remove the biofilm attached on the carrier. Total solids (TS), total carbon (TC), inorganic carbon (IC), TOC and DOC were used for biomass change (expressed as weight of biomass/weight of carrier, mg g^{-1}). TS was detected according to the Chinese State Environ-mental Protection Agency (SEPA) Standard Methods (ChineseSEPA, 2002). TOC analyzer (TOC-V CPH, Shimadzu) was used for analysis of TOC, IC and DOC.

2.3.3. DNA extraction and PCR-DGGE

Total DNA of different biofilm samples were extracted using a soil DNA kit (OMEGA) (Feng et al., 2013). Polymerase chain reaction (PCR) was employed to amplify the V3 region of 16S rRNA, and the universal bacterial primers P357GC and P518 were used for DGGE analysis. The PCR was conducted out using a thermal cycler under the conditions same as the description of Han et al. (2013). 5 μL PCR products were detected by electrophoresis on a 0.8% agarose gel stained with goldview. DGGE was performed using an AD-code mutation detection system (Bio-Rad, Hercules, CA, USA) as reported by Feng et al. (2012). Samples containing

Table 1
The major quality of polluted raw water.

Parameters	T (°C)	Turbidity (NTU)	TOC (mg L^{-1})	UV_{254}	NH_4^+-N (mg L^{-1})	NO_2^--N (mg L^{-1})	NO_3^--N (mg L^{-1})	TP (mg L^{-1})
Range	11–35	0–61.4	0.5–13.9	0.0721–0.1810	0.21–3.90	0.00–0.80	0.36–2.33	0.04–0.50
Average (±SD)	26 ± 11	12.4 ± 12.2	4.4 ± 2.9	0.0992 ± 0.0183	1.43 ± 0.90	0.15 ± 0.13	1.09 ± 0.39	0.15 ± 0.09