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Research paper

Effects of wastewater treatment processes on the sludge reduction system with 2,4-dichlorophenol: Sequencing batch reactor and anaerobic-anoxic-oxic process

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ABSTRACT

The effects of two wastewater treatment processes (sequencing batch reactor, SBR; and anaerobic-anoxic-oxic, A2O) on sludge reduction with metabolic uncoupler 2,4-dichlorophenol (DCP) were studied in laboratory. The experimental results showed that the reduction of cumulative excess sludge in SBR and A2O was 43.7% and 44.2%, respectively, during the stable stage of the test. The two processes had similar average sludge yield and sludge yield reduction, i.e., 0.306 and 0.305 mg of SS/mg chemical oxygen demand (COD), and 16.9% and 17.8%, respectively. The effect of DCP on the wastewater treatment efficiencies (namely, removal of COD, total nitrogen, NH_4^+-N, and total phosphorus) of the two processes were also similar. SBR was more likely to slightly retard the increase of activated sludge SVI with lesser increase in extracellular polymeric substances and protein/polysaccharide ratio. Although DCP did not dramatically affect the microbial communities of sludge, SBR was more favorable for increasing the activated sludge SOUR and maintaining the primary microorganisms of sludge than A2O.

1. Introduction

Excess sludge, a significant and undesirable byproduct of biological wastewater treatment, is mass-produced. In activated sludge process, a typical biological wastewater treatment process, the sludge yield is 0.3–0.5 g/g chemical oxygen demand (COD; Grady et al., 2011). For example, in China, over 3.5×10^7 tons of dewatered sludge (with 80% water content) was produced in 2013 (China State EPA, 2014). With more wastewater treatment facilities and increasingly stringent environmental and legislative constraints, the production of excess sludge will continue to increase. Currently, the treatment and disposal of excess sludge have become serious issues for many wastewater treatment plants (WWTPs) because its cost can account for 40–60% of the total operational costs of WWTPs (Guo et al., 2013). Therefore, effective in-situ treatment technologies for reducing excess sludge production from the source (namely, in-situ sludge reduction technologies) should be developed.

To date, the studied in-situ sludge reduction technologies are based on four mechanisms: lysis-cryptic growth, maintenance metabolism, predation on bacteria, and uncoupling metabolism (Guo et al., 2013). Among these, the metabolic uncoupler addition method is promising because of its high efficiency and low effect on wastewater treatment. Moreover, this method does not require the modification needed for conventional wastewater treatment processes or the installation of expensive facilities. Typical metabolic uncouplers studied in previous researches include 2,4-dichlorophenol (DCP; Chen et al., 2006; Li et al., 2016; Song et al., 2010; Xie et al., 2010), 3,3′,4′,5-tetrachlorosalicylanilide (TCS; Feng et al., 2014; Li et al., 2016; Velho et al., 2016), *para*-nitrophenol (Zuriaga-Agustí et al., 2016), 2,4,6-trichlorophenol (TCP; Feng et al., 2013; Zheng et al., 2008), and tetrakis (hydroxymethyl) phosphonium sulfate (THPS; Guo et al., 2014b; Xiao et al., 2016; Li et al., 2016).

Three biological wastewater treatment processes were used in previous continuous studies on sludge reduction with metabolic uncouplers, as follows: conventional activated sludge (CAS; Romero-Pareja et al., 2017; Xiao et al., 2016; Ye and Li, 2005), sequencing batch reactor (SBR; Feng et al., 2014; Zuriaga-Agustí et al., 2016), and anaerobic-anoxic-oxic (A2O) processes (Guo et al., 2014b; Li et al.,

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2016; Xiao et al., 2016; Yan et al., 2016). Among these three processes, SBR and A2O, being biological nutrient removal technologies, are popular wastewater treatment techniques. Organic components (COD), nutrients (N and P), and other contaminants can be simultaneously removed from wastewater by these two processes (Liu et al., 2014; Lu et al., 2016; Yan et al., 2016). SBR and A2O are widely applied in wastewater treatment plants. For example, among the WWTPS of China, A2O process is the most popular, with a ratio of 31%, while SBR accounts for 10% (Zhang et al., 2016). Thus, studies using SBR or A2O processes are more useful for research purposes than those using CAS in wastewater treatment. However, previous studies only focused on the effects of metabolic uncoupler with almost no research available on the simultaneous performance comparison between SBR or A2O processes as sludge reduction processes with metabolic uncoupler. To promote the application of the metabolic uncoupler addition method, it is necessary to evaluate the sludge reduction with metabolic uncoupler addition in the two wastewater treatment processes.

Therefore, the present research aims to study the effects of the two wastewater treatment processes (SBR and A2O) on sludge reduction with metabolic uncoupler, using DCP as an example.

2. Materials and methods

2.1. Wastewater and metabolic uncoupler

The wastewater used in the test was obtained from a residential area in Beijing, China. The characteristics of the wastewater are summarized in Table 1. The metabolic uncoupler, DCP, used in the test, was bought from Tokyo Chemical Industry Co., Ltd.

2.2. Wastewater treatment processes and their operations

Two laboratory-scale SBRs and two laboratory-scale A2Os were operated in parallel during the test. One SBR and one A2O were operated with 10 mg of DCP/L influent (SBR-DCP and A2O-DCP), while the other two were operated as controls without DCP addition (SBR-Con and A2O-Con). DCP was continuously added in the filling phase of SBR and the oxic tank of A2O. The four processes were operated for 85 d at room temperature (20–28 °C).

The working volumes for each part of the A2O were as follows: anaerobic tanks, 4 L; anoxic tanks, 4 L; oxic tanks, 16 L; and settlement tanks, 4 L. The anaerobic and anoxic tanks were mixed via mechanical stirring, while the oxic tanks were aerated to maintain the dissolved oxygen (DO) levels. The hydraulic retention times (HRTs) and DO of the first three tanks were maintained at 2 h and < 0.1 mg/L (anaerobic tanks), 2 h and 0.2–0.5 mg/L (anoxic tanks), and 8 h and 1.5–3 mg/L (oxic tanks). The HRT in the settling tank was 2 h. The internal (mixing liquor) and external (sludge) recycling ratios were 100% and 200%, respectively.

The working volume of SBR was 5 L. It was operated for 6 h per cycle. To stimulate the A2O, each cycle included 15 min for the filling phase, 45 min for the stirring phase, 4 h for aerating and stirring, 45 min for the settling phase, and 15 min for the decanting phase. The DO in the filling and stirring phases was maintained at less than 0.1 mg/L, which could be regarded as the anaerobic stage. The DO in the aerating and stirring phases was maintained at 2–4 mg/L, regarded as the oxic stage. Meanwhile, the DO in the settling and decanting phases was maintained at 0.2–0.5 mg/L, regarded as the anoxic stage. Therefore, the HRTs of the three stages were 1 h (anaerobic stage), 4 h (oxic stage), and 1 h (anoxic stage).

Table 1
Influent used in the two processes during the test.

Parameter	Range	Mean
pH	7.56–8.43	7.87
COD (mg/L)	64–452	172
SS (mg/L)	16–551	195
NH_4^+-N (mg/L)	24.41–59.54	46.11
TN (mg/L)	37.6–92.4	56.93
TP (mg/L)	3.03–9.45	5.86

In order to maintain similar sludge concentrations in the oxic tank of A2O and the aeration and stir phase of SBR, activated sludge was regularly discharged as excess sludge from the oxic tank of A2O and the last stage of the aerating and stirring phase of SBR. The sludge concentrations in the oxic tank of A2O and the aeration and stir phases of SBR were maintained at 2–4 g/L. The sludge retention times (SRT) in the two control systems were about 9.6–10.5 d, while those in the two metabolic uncoupler-added processes were 12.6–13.4 d.

2.3. Analysis and calculation

The influent, effluent, and mixed sludge in the aerating and stirring phases of SBR and the oxic tanks of A2O were regularly sampled during the test. Water quality parameters, including chemical oxygen demand (COD), NH_4^+–N, total nitrogen (TN), total phosphorous (TP), pH, and suspended solid (SS) of both the influent and effluent were analyzed. Mixed sludge characteristics, including sludge concentration (suspended solids [SS] and volatile suspended solids [VSS]), sludge volume index (SVI), extracellular polymeric substances (EPS), and special oxygen uptake rate (SOUR), were analyzed. COD was determined using a COD meter (DR2800, HACH, USA), while the pH was measured using a pH meter (PB-10, Sartorius, Germany). DO was measured using an online DO meter (3310, WTW, Germany). The EPS of the activated sludge samples was extracted by using a cation exchange resin (Dowex Marathon C) technique described by Guo et al. (2014a). The polysaccharide (PS) content of the extracted EPS was determined using the phenol-sulfuric acid method, with glucose as a standard (Dubois et al., 1956), while the protein (PN) content was determined using the Lowry method (Lowry et al., 1951), with bovine serum albumin as a standard. SOUR was measured using the method described by Mancuso et al. (2017). Other parameters were analyzed using standard methods (Rice et al., 2012).

The excess sludge production, the sludge yield (y_{obs}) in the four processes and their reduction in the two DCP-added processes were calculated in accordance with the method of Guo et al. (2014b). The energy uncoupling coefficients for the DCP-added system, E_u, can be defined by Eq. (1) (Chen et al., 2008).

$$E_u = \frac{(y_{obs})_{Con} - (y_{obs})_{DCP}}{(y_{obs})_{Con}}, \quad (1)$$

where $(Y_{obs})_{Con}$ is the sludge yield of the control system; $(Y_{obs})_{DCP}$ is the sludge yield of the DCP-added system.

The removal rates for each water quality parameter, R, were defined by Eq. (2) as:

$$R\ (\%) = \frac{c_{inf.} - c_{eff.}}{c_{inf.}} \times 100, \quad (2)$$

where $C_{inf.}$ is the concentration of the water quality parameter in the influent, $C_{eff.}$ is the concentration of the water quality parameter in the effluent.

The relative specific removal rates of each water quality parameter, RSRR, were defined as shown in Eq. (3).

$$RSRR = \frac{R_{DCP}}{R_{Con}}, \quad (3)$$

where R_{DCP} is the removal in the DCP-added system, R_{Con} is the removal in the control system.

The inhibition coefficients of removal for each water quality parameter, IC, were defined as shown in Eq. (4) (Chen et al., 2006).