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Achieving one-stage sludge reduction by adding Chironomid larvae in wastewater treatment systems

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ABSTRACT

Although worm predation is effective for excess sludge reduction, it usually needs large land facility and high operational cost. In this study, Chironomid larvae (CL), a novel microfauna for sludge treatment was applied to a one-stage sludge reduction system (sequencing batch reactor, SBR). The results showed that adding CL induced the sludge reduction, and the sludge production rate was 31% lower than that in the control. Low volatile suspended solids/suspended solids (VSS/SS) ratio (0.77) and sludge volume index (70 mL/g) were achieved. Moreover, adding CL did not deteriorate the contaminant removal (organic carbon and nitrogen), and the competition between CL and nitrifying bacteria for oxygen was beneficial for nitritation.

1. Introduction

Activated sludge is a commonly used process for domestic and industrial wastewater treatment. Despite its high efficiency in removing pollutants, it produces large amounts of excess sludge, which is costly to treat and accounts for up to 60 % of operating cost in wastewater treatment plants (WWTPs) (Tejada et al., 2013). Many effective techniques have been developed to lower sludge production (Wei et al., 2003; Khursheed and Kazmi, 2011).

Microfauna predation sludge reduction technique attracts attention due to its cost-efficient and environment-friendly characteristics (Das et al., 2015; Zhang et al., 2013; Suthar, 2012). By introducing higher level organisms that feed on bacteria, microfauna predation extends the food chain in wastewater treatment process, increases total energy loss, and thus inducing sludge reduction (Buy et al., 2008). Several worm species including *Lumbriculus variegates* (Hendrickx et al., 2009), *Limnodrilus hoffmeisteri* (Tian et al., 2012), *Aulophorus furcatus* (Tamis et al., 2011), and *Tubifex* (Huang et al., 2007) naturally existing in WWTPs have been applied to minimize sludge production. Because these worm species cannot maintain at a high density in WWTPs for a long time (Wei et al., 2003), a two-stage reactor system has been used, with the first reactor for contaminants removal, and the second reactor for excess sludge treatment while the residual sludge being returned to the first reactor (Lee and Welander, 1996).

Chironomid is a species-rich family of Diptera with aquatic larvae (Van kleef et al., 2015). Compared with worms applied to sludge reduction, Chironomid larvae (CL), a main benthic fauna group widely distributed in natural environments (Sun et al., 2007), can tolerate stresses (e.g. low oxygen) (Habib et al., 1997) and contaminants (e.g. heavy metal and organic compounds) in freshwater (Di Veroli et al., 2012; Watts and Pascoe, 1996). CL could maintain a high activity in WWTPs, and synchronously reduce the sludge by feeding on bacterial biomass. CL can be used as for sludge reduction in the one-stage system, in which the contaminants removal and the sludge predation can be simultaneously achieved.

The objective of this study was to determine the feasibility of adding CL to WWTPs for sludge reduction. There were two tasks in this study. First, the sludge reduction capacity of CL was examined in sequencing batch reactors (SBRs) fed with real domestic wastewater. Second, the effects of CL on nitrogen removal and chemical oxygen demand (COD) removal were determined by measuring the effluent qualities and the populations of nitrifying bacteria.

2. Materials and methods

2.1. Wastewater, activated sludge, and CL

Domestic sewage from a residential area of Beijing University of Technology (Beijing, China) was used as the influent. Average

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chemical oxygen demand (COD) and ammonium nitrogen (NH_4^+–N) of the sewage were 143.6 and 69.3, respectively. The salt concentration of the sewage was 0.7 g/L. The carbon/nitrogen (C/N) ratio was increased to 4–5 by adding sodium acetate in order to ensure nitrogen removal. Activated sludge taken from a pilot-scale sequencing batch reactor (SBR) (volume: 7000 L) with a good nitrification performance was used as the inoculum. The CL naturally growing in the aerobic zones of a continuous plug-flow step feeding wastewater treatment system (volume: 66 L) was collected and then cleaned using distilled water.

2.2. Experimental setup and operational conditions

Two SBRs (each with a working volume of 5 L) were studied as the one-stage sludge reduction system, with one as the CL-SBR being introduced with CL and the other one as the control SBR without CL. The SBRs were operated with a cycle time of 360 min, including 7 min feeding, 30 min anoxic reaction, 285 min aerobic reaction (with the aeration strength of 60–80 L/h), 30 min settling, 3 min decanting, and 5 min idle period. In each cycle, 2.5 L of domestic wastewater was pumped into the SBRs.

The two SBRs were operated for 596 cycles including three phases listed below: In the Phase I (Cycle 1–72), two SBRs were operated without CL addition to achieve a steady status in terms of biomass characteristics and effluent quality. The solids retention times (SRTs) in two SBRs were maintained at 18 days by wasting 248 mL of activated sludge daily. In the Phase II (Cycle 73–260), CL was introduced to the CL-SBR with a density of 0.5 g-CL/g-MLSS based on preliminary experiment, and excess sludge was no longer discharged to achieve one-stage sludge reduction with zero wastage through CL predation. The SRT was prolonged to 46 days. In the Phase III (Cycle 261–596), the mixed liquor suspended solids (MLSS) concentration in the CL-SBR was adjusted to the same level as the control SBR. The SRT of CL-SBR was optimized to maintain a stable sludge concentration, with 120 mL excess sludge being discharged from the CL-SBR daily. The SRT was shortened slightly to 37 days.

2.3. Calculation of observed sludge yield

The observed sludge yield (Y_{obs}, mg MLSS/mg COD), defined as the ratio of produced sludge (ΔMLSS) to the removed COD (ΔCOD) was used to evaluate the sludge reduction capacity of CL in the CL-SBR. The ΔMLSS consisted of the increase biomass quantity in the SBRs and the cumulative sludge from excess sludge discharge and effluent.

2.4. Analytical methods

COD was measured with a quick-analysis apparatus (Lian-hua Tech. Co., Ltd, 5B-1, China). NH_4^+–N, nitrate nitrogen (NO_3^-–N), and nitrite nitrogen (NO_2^-–N) were analyzed using a Flow-injection apparatus (Quick Chem8500, Lachat instrument, USA). Total nitrogen (TN) was measured using a Vario TOC Cube (Elementar, Germany). MLSS and mixed liquor volatile suspended solids (MLVSS) were analyzed using the standard methods (APHA, 1998). Dissolved oxygen (DO) was continuously monitored using a WTW Multi 340i meter (WTW Company, Germany).

The activities of autrotrophic nitrifier (ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB)) were evaluated using specific oxygen uptake rate (SOUR) with an activated sludge respirometer (Strathtox, strathkelvin,UK). Allylthiourea and sodium chlorate were used to inhibit AOB and NOB in the SOUR tests. Fluorescence in situ hybridization (FISH) was performed to characterize the nitrifying bacterial community in SBRs (Manz et al., 1992). EUB_{mix} (mixture of equal amounts of EUB338, EUB338II and EUB338III) was used for most *Eubacteria*, Nso190 was used for AOB, Ntspa662 was used for *Nitrospira*, and NIT3 was used for *Nitrobacteria* (Gu et al., 2012).

3. Results and discussion

3.1. The effect of CL on sludge reduction

The feasibility of adding CL to achieve sludge reduction was studied by comparing two SBRs (one adding CL, the other as control without adding CL) (Table 1). After a steady state of biomass characteristics was achieved (phase I), CL was added to the CL-SBR to start up the one-stage sludge reduction system (phase II). Excess sludge was no longer discharged to evaluate whether sludge-reduction could be achieved solely by CL predation. Compared with the control SBR (937 mg/d and 0.3 mg MLSS/mg COD), the sludge production and Y_{obs} in the CL-SBR obviously decreased (646 mg/d and 0.21 mg MLSS/mg COD), indicating that CL predation induced sludge reduction (about 31%). Because the sludge reduced by CL predation was less than the sludge produced, the MLSS concentration in the CL-SBR gradually increased from 2839 mg/L to 3671 mg/L at a SRT of 46 days. To stabilize MLSS concentration, the SRT was shortened (37 d) in the phase III by wasting excess sludge (120 mL) from the CL-SBR. The MLSS concentration remained stable (2815 ± 15 mg/L) and kept the same level as that in the control SBR (2835 ± 14 mg/L). High sludge reduction rate (31%) and low Y_{obs} (0.24 mg MLSS/mg COD) were maintained in the CL-SBR, indicating that the stable sludge reduction could be achieved in the one-stage sludge reduction system by adding CL. Compare with the excess sludge discharge (248 mL) in the control SBR, the CL-SBR reduced more than 50%.

Although the sludge reduction efficiency (31%) in this study was lower than previous studies (about 60%) that used a separate worm predation reactor or carriers (Tian et al., 2012; Rensink and Rulkens, 1997), the operating parameters (e.g. dissolved oxygen, CL density) were not optimized in this study. A better sludge reduction performance is expected once these parameters are optimized. Furthermore, a stable CL density is a key factor in achieving sludge reduction. In this study, CL was supplemented monthly to compensate the CL amount loss caused by the larvae transition to adults. But this method was difficult to deploy in large-scale operation due to the operational cost and potential environmental impact. To solve this problem, CL could be

Table 1
Sludge reduction over the three phases in two SBRs

Parameters	Phase I (n = 7)		Phase II (n = 14)		Phase III (n = 14)	
	Control SBR	CL-SBR	Control SBR	CL-SBR	Control SBR	CL-SBR
MLSS (mg/L)	2830 ± 31	2839 ± 42	2829 ± 45	3671 ± 477	2815 ± 15	2835 ± 14
Effluent SS (mg/L)	33 ± 3	33 ± 3	34 ± 5	37 ± 5	35 ± 4	39 ± 4
Sludge production (mg/d)	903 ± 113	954 ± 90	937 ± 105	646 ± 94	1000 ± 26	686 ± 15
Sludge reduction (%)			(937 − 646)/937 = 31 %		(1000 − 686)/1000 = 31 %	
Y_{obs} (mg MLSS/mg COD)	0.32 ± 0.04	0.33 ± 0.04	0.30 ± 0.04	0.21 ± 0.03	0.34 ± 0.01	0.24 ± 0.01