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Research article

Influence of high temperature on the performance of aerobic granular sludge in biological treatment of wastewater

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ABSTRACT

The effect of temperature on the efficiency of organics and nutrients removal during the cultivation of aerobic granular sludge (AGS) in biological treatment of synthetic wastewater was studied. With this aim, three 3 L sequencing batch reactors (SBRs) with influent loading rate of 1.6 COD g $(L\ d)^{-1}$ were operated at different high temperatures (30, 40 and 50 °C) for simultaneous COD, phosphate and ammonia removal at a complete cycle time of 3 h. The systems were successfully started up and progressed to steady state at different cultivation periods. The statistical comparison of COD, phosphate and ammonia for effluent from the three SBRs revealed that there was a significant difference between groups of all the working temperatures of the bioreactors. The AGS cultivated at different high temperatures also positively correlated with the accumulation of elements including carbon, oxygen, phosphorus, silicon, iron, aluminium, calcium and magnesium that played important roles in the granulation process.

1. Introduction

The increase of human population demands new water resources and also results in increased amount of wastewater to be treated before being discharged into the natural ecosystems (Escapa et al., 2015). Due to the limited water resources especially in dry climatic regions, wastewater treatment and subsequent recycling is a practical option that can help solve limited water resources problem (Almuktar et al., 2015). Domestic biological wastewater treatment is one of the most competent defences against the transmission of infectious waterborne disease and poor water quality. The main pollutants responsible for poor wastewater quality include nitrogen (N), particularly ammonia-N (NH_3–N) and chemical oxygen demand (COD). Existing wastewater treatment plants (WWTPs) are capable of removing waste organic matter (as COD), faecal bacterial levels and nitrogen through aerobic microbiological processes with active aeration (e.g. activated sludge process) (Shao et al., 2014; Christgen et al., 2015).

Another well-established technology for the aerobic treatment of wastewater is the sequencing batch reactor (SBR) system. Dependent upon the design, SBR has some positive attributes: for instance short hydraulic retention time (HRT) that allows high organic loading rate (OLR) and lower sludge production (Dutta et al., 2014). Compared to the activated sludge system, SBR system can have smaller footprints due to the absence of primary or secondary settling (Christgen et al., 2015; Emadian et al., 2015). SBR system involves recurrence of cycles comprising five continuous phases: feed, react, settle, discharge and idle. The reactor is aerated during reaction phase and during settling phase, the aeration is stopped to allow sedimentation of biomass so that excessive loss of biomass with the effluent during discharge phase can be avoided. Hence, retention of biomass in the reactor will depend on sedimentation phase, which in turn depends on the sludge form and properties (Dutta et al., 2014).

SBRs containing aerobic granular sludge (AGS) have been widely studied as they bring two predominant interests: (i) the fast

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settling properties of AGS, which facilitate the biomass retention in the reactor (Adav et al., 2008); and (ii) the presence of substrate profiles across the granule radius, which allows concurrent aerobic, anoxic and anaerobic processes into the same granule (Yilmaz et al., 2007). Both features help to scale down the required reactor capacity leading to more compact designs, or in treating high strength wastewater (e.g. industrial sewage) (Isanta et al., 2012).

Currently, a significant number of studies focusing on the morphology, activity and operation of AGS at lab-scale and full-scale (Brazil, the Netherlands) have been reported (Niermans et al., 2014; Zhang et al., 2016). High shear stress and short settling periods are the main criteria in selecting fast-settling biomass and to encourage granulation (Beun et al., 2002; Tay et al., 2004). In addition, a feast-famine regime in the reactor also helps the granules stability, whereas granules become more filamentous when feast durations prevail over famine durations in the SBR (de Kreuk and van Loosdrecht, 2004; McSwain et al., 2004). Previous work by de Kreuk et al. (2005a) reported that simultaneous removal of N and phosphorus (P) can be achieved by initiating an anaerobic feeding step to select polyphosphate-accumulating organisms (PAOs) from heterotrophic bacteria. Moreover, stability is improved for granules rich in PAO because their maximum growth rate is lower compared to conventional heterotrophic biomass (Picioreanu et al., 2000; de Kreuk and van Loosdrecht, 2004).

Even though it is true that the results obtained with AGS using SBR system (AGS-SBR) at lab-scale are promising, important challenges still remain and more information about the stability of granules and their performance at high temperatures is needed. This needed information is essential in order to establish if AGS could be a feasible treatment to remove organics and nutrients from wastewater at hot climate areas. Most of previous studies were carried out at ambient temperature, e.g., 20–25 °C (de Kreuk and van Loosdrecht, 2004; Whang and Park, 2006) or lower (de Kreuk et al., 2005b). Despite some studies on AGS have been performed at elevated temperature, e.g., 25–30 °C (Zitomer et al., 2007; Song et al., 2009; Ebrahimi et al., 2010), there is still a lack of information regarding the influence of high temperatures on aerobic granulation. The objective of this paper is thus, to investigate the removal of organics and nutrients from wastewater by aerobic granulation at high temperature, namely 30 °C, 40 °C and 50 °C. This study also presents the results of elemental composition for different granules developed at different high temperatures. The knowledge and understanding from this study might be useful to describe phenomenon of AGS at high temperatures for its practical application at hot climate areas especially countries with tropical and desert like climates.

2. Materials and methods

2.1. Experimental procedure and bioreactor set-up description

Three similar double-walled cylindrical glass column bioreactors of 100 cm total high and of 6.5 cm diameter, with a working volume of 3 L were used in this study. The height (H) to diameter (D) ratio was H/D = 15.4. Conventional operation of SBR was employed with 3 h for each cycle and with a hydraulic retention time (HRT) of 6 h. Each cycle was divided in four stages: static influent feeding (60 min), aeration (110 min), settling (5 min) and effluent discharge (5 min) (Table 1). The feeding phase was considered static because no aeration or stirring was involved during influent filling. In previous studies, the combination of static feeding with aeration period afterwards has shown good results of reducing both P and N using AGS at lab-scale (de Kreuk et al., 2005a; Isanta et al., 2012). During aeration phase, compressed air was supplied with an air pump at a constant flow rate of 0.24 $m^3\ h^{-1}$ (2.0 cm s^{-1} superficial air flow velocity). A porous diffuser located at the bottom of the reactor helped in the aeration process by creating small air bubbles. The working temperatures for the bioreactors were controlled at 30 ± 1, 40 ± 1 and 50 ± 1 °C using water bath sleeves and a thermostat without controlling the dissolved oxygen (DO) and pH level. The bioreactors were referred to as SBR_{30}, SBR_{40} and SBR_{50}. Feeding pump, discharge pump and aeration pump with the setting time for each phase in the bioreactors were controlled by digital timers programmed according to appropriate period. 1.5 L of activated sludge from Madinah city municipal sewage treatment plant was added into each bioreactor during the start-up phase as inoculums. Synthetic wastewater was used in all experiments. The synthetic wastewater was fed and discharged by a set of two peristaltic pumps. The effluent discharge point was positioned at the middle height in the glass column, resulting in volumetric exchange ratio (VER) of 50% per cycle. The bioreactors were operated without excess sludge discharge, thus the effluent was the only passage for biomass wasting. The sludge retention time (SRT) was determined by the discharge of total suspended solids (TSS) with the effluent.

Table 1
Operation parameters for the lab-scale SBRs at different temperatures.

Parameter	Value
Temperature	30, 40 and 50 ± 1 °C
Cycle	3 h
Influent	60 min
Aeration	110 min
Settling	5 min
Effluent	5 min
Exchange rate	50%
COD_{total} load	1.6 COD g $(L\ d)^{-1}$
Influent COD	400 ± 8.6 mg L^{-1}
Influent $PO_4^{3-}P$	20 ± 0.7 mg L^{-1}
Influent NH_3-N	55 ± 0.8 mg L^{-1}

2.2. Synthetic wastewater preparation and inoculation sludge sample collection

The SBR influent was a synthetic domestic wastewater containing the same composition as reported in previous studies (de Kreuk et al., 2005a) (see Table 2). The synthetic wastewater was fed from the bottom of the bioreactor. The two stock solutions were prepared and added to the bioreactor with tap water for each cycle. The influent wastewater loading rate was 1.6 COD g $(L\ d)^{-1}$ and the COD/N ratio was 8. The seed activated sludge used as inoculums was collected from the aeration tank of the Madinah city Sewage Treatment Plant in Saudi Arabia, which is a local municipal wastewater treatment plant (WWTP). The amount of inoculum was about 1.5 L.

Table 2
Composition of synthetic domestic wastewater.

Component	Concentration (mM)	Component	Concentration (mM)
Solution X:		Solution Y:	
CH_3COONa	65.1	NH_4Cl	35.2
$MgSO_4 \cdot 7H20$	3.7	K_2HPO_4	4.4
KCl	4.8	KH_2PO_4	2.2
		Trace element[a]	10 mL L^{-1}

[a] Trace element solution contained (mmol L^{-1}): EDTA 342.2, $ZnSO_4 \cdot 7H_2O$ 15.3, $CaCl_2 \cdot 2H_2O$ 111.3, $MnCl_2 \cdot 4H_2O$ 51.1, $FeSO_4 \cdot 7H_2O$ 35.9, $Na_2Mo_7O_{24} \cdot 2H_2O$ 2.7, $CuSO_4 \cdot 5H_2O$ 12.0, and $CoCl_2 \cdot 6H_2O$ 13.5.