Bioresource Technology 185 (2015) 445–449

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Short Communication

Aerobic sludge granulation at high temperatures for domestic wastewater treatment

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HIGHLIGHTS

- Formation of aerobic granular sludge (AGS) at different high temperatures (30, 40 and 50 ± 1 °C).
- AGS showed excellent removal of organics and nutrients with a complete cycle time of 3 h.
- The AGS were successfully cultivated with influent loading rate and COD/N ratio of 1.6 kg COD m^{-3} d^{-1} and 8, respectively.

ARTICLE INFO

Article history:
Received 31 December 2014
Received in revised form 2 March 2015
Accepted 4 March 2015
Available online 11 March 2015

Keywords:
Aerobic granules
SBR
High temperature
Start-up
Wastewater treatment

ABSTRACT

With inoculum sludge from a conventional activated sludge wastewater treatment plant, three sequencing batch reactors (SBRs) fed with synthetic wastewater were operated at different high temperatures (30, 40 and 50 ± 1 °C) to study the formation of aerobic granular sludge (AGS) for simultaneous organics and nutrients removal with a complete cycle time of 3 h. The AGS were successfully cultivated with influent loading rate of 1.6 COD g $(L\,d)^{-1}$. The COD/N ratio of the influent wastewater was 8. The results revealed that granules developed at 50 °C have the highest average diameter, (3.36 mm) with 98.17%, 94.45% and 72.46% removal efficiency observed in the system for COD, ammonia and phosphate, respectively. This study also demonstrated the capabilities of AGS formation at high temperatures which is suitable to be applied for hot climate conditions.

1. Introduction

Domestic wastewater treatment in urban areas is one of the crucial elements to be considered in the development of a country in order to sustain individual's health and welfare. Untreated wastewater can lead to spreading of disease in the form of several types of endemic and epidemic illnesses (Ahmad et al., 2008). There are various kind of wastewater treatment applications nowadays ranging from modest, low priced, and less efficient processes to very advanced, highly efficient and pricey operations. The selection among these processes should acknowledge local area circumstances such as climate and weather, social attributes, economy, availability of enforceable standards, availability of land and power, demanded operation skills and its availability, monitoring actions, effluent discharge options as well as effluent reuse applications and conditions (Ahmad et al., 2008). Currently, several types of the widely-used wastewater treatment technologies include activated sludge process (ASP), sequencing batch reactor (SBR), up-flow anaerobic sludge blanket reactors associated with facultative aerobic lagoon (UASB–FAL) and constructed wetlands (CWs) (Kalbar et al., 2012).

Aerobic granular sludge (AGS) has been widely studied in recent years (de Kreuk et al., 2005a). AGS is made up of a dense cluster of symbiotic organisms, with good biological activity performance and excellent mass transfer efficiency. Aerobic granular sludge-based reactors represent an appealing option over conventional activated sludge systems due to their small footprint and low excess sludge production (de Bruin et al., 2004). The sludge

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http://dx.doi.org/10.1016/j.biortech.2015.03.024
0960-8524/

developed in such systems acquires high biomass concentration, better settling properties, high chemical oxygen demand (COD) removal efficiency, and good phosphorus removal capacity (de Kreuk et al., 2005b). In addition, simultaneous nitrification–denitrification can occur simultaneously in granules due to the bulk oxygen concentration and granule size (Mosquera-Corral et al., 2005). Aerobic granular sludge has mainly been cultivated using sequencing batch reactor (SBR) systems, some using airlift or bubble column reactors. Several lab scale studies have broadly identified the most crucial aspects influencing the development of aerobic granular sludge such as organic loading rate, settling time, hydrodynamic shear force and substrate composition (Adav et al., 2008). However, the formation of aerobic granular sludge is a challenging ecological process, in which many components need to be further inspected.

Research on aerobic granular sludge using SBR system (AGS-SBR) has generally been conducted at ambient temperature, e.g., 20–25 °C (de Kreuk and van Loosdrecht, 2004; Whang and Park, 2006) or lower (de Kreuk et al., 2005a). Even though some studies on aerobic granular sludge have been performed at high temperature (Zitomer et al., 2007; Song et al., 2009; Ebrahimi et al., 2010), detailed knowledge regarding the high temperature effects on aerobic granulation is still confined. The main aim of the present study is thus to investigate the granulation process, stability, density and performances of aerobic granules at high temperature namely, 30 °C, 40 °C and 50 °C. Aerobic granulation was cultivated in SBR using sludge collected from the wastewater treatment plant in Madinah city, Saudi Arabia as a seed sludge. Madinah climate is of a desert type with temperature reaching close to 50 °C during summer time. The morphology of granular sludge, their settling properties and treatment efficiencies were also investigated and discussed. This research will help intensify the knowledge of cultivation procedure, and encourage the application of aerobic granular sludge in wastewater treatment especially for hot climate areas such as Saudi Arabia.

2. Methods

2.1. Experimental procedures and bioreactor set-up

Experiments were carried out in three similar double-walled cylindrical glass column bioreactors (internal diameter of 6.5 cm and total height of 100 cm) with a working volume of 3 L. 1.5 L of activated sludge from Madinah city municipal sewage treatment plant was added into each bioreactor during the start-up period as inoculums. Feeding pump, discharge pump and aerator pump with the setting time for each phase in the bioreactors were controlled by a programmable logic controller (PLC). Each bioreactor was operated under sequencing batch mode at a cycle of 3 h: 60 min of feeding from the bottom of the bioreactor without stirring, 110 min of aeration, 5 min of settling and 5 min of effluent withdrawal. Synthetic wastewater was used in all experiments. The synthetic wastewater was fed and discharged by a set of two peristaltic pumps. Fine air bubbles were supplied by diffusers which were placed at the bottom at a volumetric flow rate of $0.24\ m^3\ h^{-1}$ ($2.0\ cm\ s^{-1}$ superficial air flow velocity) during the time for aeration. The effluent was discharged through the outlet ports which had a volumetric exchange ratio (VER) of 50% and located at the middle height in the glass column. The sludge retention time (SRT) was determined by the discharge of total suspended solids (TSS) with the effluent. 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 and pH level. The bioreactors are referred to as SBR_{30}, SBR_{40} and SBR_{50}.

2.2. Synthetic wastewater characteristics and seed sludge sample collection

The reactors were fed with the same composition of synthetic wastewater used by de Kreuk et al. (2005a) as shown in Table 1. The two stock solutions were prepared and mixed with tap water prior to feeding. 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. 1.5 L of inoculum was used with a mixed liquor suspended solid (MLSS) concentration of $4.3\ g\ L^{-1}$, a mixed liquor volatile suspended solid (MLVSS) concentration of $3.8\ g\ L^{-1}$ and a sludge volume index of $144.5\ mL\ g^{-1}$. The seed sludge was brown in color with fluffy loose structure.

2.3. Analytical methods

Mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS), chemical oxygen demand (COD), ammonia (NH_3), nitrite(NO_2^-), nitrate (NO_3^-) and phosphate (PO_4^{3-}) were performed as described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). The pH and DO sensors were inserted in the bioreactor to continuously monitor the value of pH and DO and these values were recorded by a pH/DO meter (Orion 4-Star Benchtop pH/DO Meter). The sludge volume index (SVI) measurements were carried out using the method explained by de Kreuk et al. (2005b). A stereo microscope equipped with digital image analyzer (I-Solution Premium) was used to visualize periodically the morphology and structure of the developed aerobic granular sludge. Observations of the microstructure compositions within the cultivated granules at different high temperatures were carried out using scanning electron microscope (SEM) (SU8020, Hitachi, Japan). The granules were prepared according to Diao et al. (2004) before platinum sputter coating for 60 s (Q150R S, Quarum, UK) was applied as a pre-treatment procedure for SEM image.

3. Results and discussion

3.1. Formation mechanism of aerobic granular sludge at different high temperatures and morphology observation

This study presents the findings regarding the effect of high temperature on granule formation and morphology as summarized in Table 2. At the beginning of the experiments, the fresh sludge appeared as irregular, fluffy and having loose-structure morphology with the presence of filamentous microorganisms. Towards the end of the experiments, the sludge color slowly turned from dark brown to yellowish brown. The loose flocs-like sludge was apparently broken up into small size particles during early experimental period (first week) under vigorous shaking conditions.

Table 1
Composition of synthetic domestic wastewater.

Component	Concentration (mM)	Component	Concentration (mM)
Solution A		Solution B	
CH_3COONa	65.1	NH_4Cl	35.2
$MgSO_4·7H20$	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, $ZnSO_4·7H_2O$ 15.3, $CaCl_2·2H_2O$ 111.3, $MnCl_2·4H_2O$ 51.1, $FeSO_4·7H_2O$ 35.9, $Na_2Mo_7O_{24}·2H_2O$ 2.7, $CuSO_4·5H_2O$ 12.0, and $CoCl_2·6H_2O$ 13.5.