Aerobic granulation for real domestic sewage treatment at hot and low humidity climate condition

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Abstract
With inoculum sludge from a conventional activated sludge wastewater treatment plant, a sequencing batch reactor fed with real domestic wastewater was operated at 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 excellent settling ability and demonstrated exceptional performance in the organics and nutrients removal with influent loading rate of 1.2 kg COD m^{-3} d^{-1}. Stable, regular, dense and fast settling granule (average diameter, 2.0 mm and sludge volume index, 73.501 mL g^{-1}) were developed in a single reactor. In addition, 89 % COD removal efficiency was observed in the system at the maturation stage of the granulation, while its ammonia nitrogen removal efficiencies were up to 99 %. The study demonstrated the capabilities of AGS formation in a single, high and slender column type-bioreactor at high temperature which is suitable to be applied for hot climate and low humidity condition (e.g. Saudi Arabia).

Keywords
Aerobic granular sludge; sequencing batch reactor; high temperature; hot climate; domestic wastewater; wastewater treatment

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 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 (Beun et al., 2001; 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 (Morgenroth et al., 1997; 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 fed with real domestic wastewater is still confined. The main aim of the present study is thus to investigate the granulation process, stability, density and performances of aerobic granules fed with real domestic wastewater at 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 and low humidity areas such as Saudi Arabia.

MATERIALS AND METHODS

Experimental procedures and bioreactor set-up

Experiments were carried out in a double-walled cylindrical glass column bioreactor (internal diameter of 10 cm and total height of 54.5 cm) with a working volume of 4 L. 2 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. Real domestic 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 0.6 $m^3 h^{-1}$ (2.1 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 temperature for the bioreactor was controlled at 50 ± 1 °C using water bath sleeves and a thermostat without controlling the dissolved oxygen and pH level.

Domestic wastewater characteristics and seed sludge sample collection

The reactors were fed with domestic wastewater. 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. 2 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 colour with fluffy loose structure.

Analytical methods

The reactor was fed with domestic wastewater. 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. 2 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 colour with fluffy loose structure.

RESULTS

Aerobic granular sludge formation and morphology observation

During the early stage, seed sludge appeared as a fluffy, irregular, loose-structure morphology and rich with filamentous organisms under microscopic examination as shown in Figure 1. The sludge color progressively turned from dark brown to light yellowish brown throughout the experimental period due to the washout of the microorganisms and low concentrations of biomass because of poor settling properties of the young sludge. During the initial stage of granulation, the loose flocs were also easily broke up into small pieces if placed under vigorous shaking.

After few days, the flocs-like sludge started to disappear and changed to small granules with average diameter 0.9 mm. Under high shear force, the flocs became denser causing the aggregation of the biomass to secrete more exopolysaccharides (EPS) (Dulekgurgen et al., 2008). Interactions between inter-particle bridging process among EPS, microbial cells and ion contributes to the evolution of seed sludge from flocs to granules (Sheng et al., 2010). EPS can promote the cell hydrophobicity and change the surface charges on the microorganisms (Zhu et al., 2012), which can increase microbial cell adhesion and granulation.

In the following weeks, the small granules became more regular in shape and progressively increased in size, while more flocculent sludge washed out from the bioreactor, resulting in the accumulation of the aerobic granules with high settling ability. Finally, mature granules formed after 30 days of inoculation with average diameter of 2.0 mm. The compact mature granules were smooth with a solid surface and contributes to a stable operation of the bioreactor.

Organics and nutrients removal efficiencies of granules

At the beginning of the bioreactor operation with the concentration of influent COD was 400 mg L^{-1}, the removal rate of COD dropped from 63% to 41%, probably due to the adapting process of the sludge with synthetic wastewater. In the first 18 days, the removal rate of COD kept increasing but with sporadic decrease. Thereafter, the COD removal efficiency improved uniformly and became stable for the remaining period. When the granular sludge started to evolve from flocculent sludge in the bioreactor system, it enhanced the degradation ability for COD removal efficiency up to 89%, which is comparable to previous work done by Abdullah et al. (2011) in treating palm oil mill effluent (POME) and Rosman et al. (2013) in treating rubber wastewater using aerobic granular sludge. This result indicates the high biological activity occurred during microbial aerobic degradation process of synthetic wastewater.

The ammonia nitrogen removal efficiency was 72% at the beginning of the bioreactor operation with the concentration of influent ammonia nitrogen was 50 mg L^{-1} and then dropped significantly to 61%. Subsequently, the removal rate of ammonia nitrogen improved when granules started to form. The removal efficiencies for ammonia nitrogen kept increasing but with occasional decrease. Afterwards, the removal efficiencies for ammonia nitrogen increased gradually and achieved steady state at about 99% during day-30. The ammonia nitrogen concentration in the effluent shows a significant better quality and maintained below 10 mg L^{-1} upon the formation of aerobic granular sludge which indicates an effective ammonia nitrogen removal efficiency. Nitrifying bacteria population within the aerobic granules became predominant after the biodegradation of organics which help in nitrification process. Belmonte et al. (2009) stated that nitrification process could be improved by promoting the development of granules that enhance the retention of large amounts of nitrifying bacteria in the bioreactor system leading a higher removal efficiency for ammonia. The sufficient oxygen level supplied in the bioreactor system enabled a good oxidation for ammonia nitrogen and more than 90% of ammonia nitrogen being removed during the aerobic reaction phase which shows a stable and excellent nitrification process happened in the system.

CONCLUSIONS

Development of a stable and compact aerobic granules in SBR system fed with real domestic wastewater was successful with an excellent settling ability and an average diameter of 2.0 mm. A good COD removal rate of 89 % was achieved after 30 days of operation with influent loading rate of 1.2 kg COD m^{-3} d^{-1}. In addition, 99% ammonia nitrogen removal rate was also observed in the single bioreactor system. Therefore, the study presented herein suggested feasibility of the developed aerobic granular sludge for the treatment of domestic wastewater at high temperature of 50°C which is suitable to be applied for hot climate and low humidity condition for instance in Saudi Arabia.

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