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Research article

Treatment of tapioca processing wastewater in a sequencing batch reactor: Mechanism of granule formation and performance

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ABSTRACT

The formation of aerobic granular sludge was carried out in a sequencing batch reactor (SBR) for tapioca processing wastewater treatment. The effect of organic loading rates (OLRs) in the range of 2.5–10.0 kg COD m^{-3} day^{-1} on the granulation was investigated. The size and settleability of the aerobic granular sludge increased with increasing OLR from 2.5 to 7.5 kg COD m^{-3} day^{-1}. The mature granules had an average size of 2.5 mm and good settleability with the sludge volume index (SVI) lower than 50 mL g^{-1}. The granules had a layered structure consisting of anoxic sludge core with nematodes and an outer aerobic layer surrounded by stalked ciliates. Removal efficiencies of chemical oxygen demand (COD) and NH_4^+-N reached 90.0%–93.0% and 86.6%–92.5%, respectively. Simultaneous nitrification and denitrification at the OLR of 7.5 kg COD m^{-3} day^{-1} resulted in the improvement of total nitrogen (TN) removal efficiency to 66.1%.

1. Introduction

Tapioca processing wastewater is one of the sources that cause serious environmental pollution in Vietnam since it contains a high concentration of organic compounds and nitrogen. Thus far, the traditional biotechnology as conventional activated sludge process has been applied for this wastewater treatment. The effluent water quality might not meet the discharge standards in terms of chemical oxygen demand (COD) and nitrogen. Moreover, the traditional treatment systems require a large footprint owing to the low organic loading rate (OLR) withstanding and the poor settling ability of sludge.

In recent years, aerobic granular sludge technology has attracted considerable attention from many researchers. Compared to the conventional activated sludge, aerobic granules exhibit good settleability, capacity to withstand high organic loading rate and toxic compounds (Dai et al., 2015; Li et al., 2016; Wang et al., 2017; Zhang and Tay, 2016), and the simultaneous occurrence of nitrification and denitrification (Beun et al., 2001; De Kreuk et al., 2005; Van den Akker et al., 2015). Therefore, this technology can reduce the construction area fourfold compared to the conventional activated sludge process (Val del Río et al., 2012).

Although the aerobic granular sludge has been studied for nearly 30 years, it has not been as practical as activated sludge because of the difficulty in controlling real wastewater treatment operation. Aerobic granulation has been studied mainly in terms of synthetic wastewater by using simple carbon sources such as glucose (Tay et al., 2002b) and acetate (Ab Halim et al., 2016; Deng et al., 2016; Liu et al., 2016). Even some aerobic granules have also been cultivated successfully for real wastewater treatment (Liu et al., 2011; Val del Río et al., 2012). However, information associated with real wastewater is still limited. The results indicated that the characteristic of aerobic granular sludge was different for various types of wastewater and operational conditions. So far, there is no report concerning the treatment of tapioca processing wastewater using an aerobic granular sludge sequencing batch reactor (SBR). It has been reported that granular sludge is synthesised at high organic loading rates while it normally exists as

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floc at lower COD loading rates (Liu and Tay, 2015). Meanwhile, tapioca processing wastewater has a high concentration of organic compounds and nutrients, and it is therefore appropriate for the formation of aerobic granules.

For the above reasons, this study was carried out in the granular sludge SBR to treat tapioca processing wastewater. The main objective of this work was to investigate the formation and stability of aerobic granular sludge. Biological performance of the SBR was also determined in terms of COD and nitrogen removal. For a thorough understanding of the mechanism of granulation, microorganism communities within the granules were also characterised. Finally, mass balances of COD and nitrogen were calculated to clarify substrate removal ability of aerobic granular sludge. The obtained results are expected to provide insightful information of suitable operating conditions to develop aerobic granules for real wastewater treatment.

2. Materials and methods

2.1. Reactor setup and operation

This study was performed in the cylindrical-column SBR with the working volume of 3.3 L (Fig. 1). The reactor was made of a 2-mm-thick acrylic material, having the internal diameter of 6.5 cm and a height of 100 cm. Air was supplied by an air pump (Taiwan, model: ACO-003, output: 65 L min^{-1}, pressure: 0.027 MPa, 35 W, 220 V) through the pumice stone at the reactor bottom in order to provide mixing as well as shear at the airflow rate of 5 L min^{-1} (in proportion to the surface air velocity of 2.5 cm s^{-1}). Wastewater was fed into the reactor by a dosing pump (Tacmina, Japan, model: PZD-500-VTCF, max discharge volume: 32.4 L h^{-1}, pressure: 0.2 MPa, 100–240 V). The effluent was discharged through the port with the electromagnetic valve (Uni-D, Taiwan, model: UW-15, pipe size: ½″, 220 V) located at a height of 40 cm from the bottom of the reactor with a volumetric exchange ratio of 50%. This system was automatically controlled by a programmable logic controller (PLC) (Logo Siemens, model: 12/24RC, 4 relay/10 A, 220–240 V).

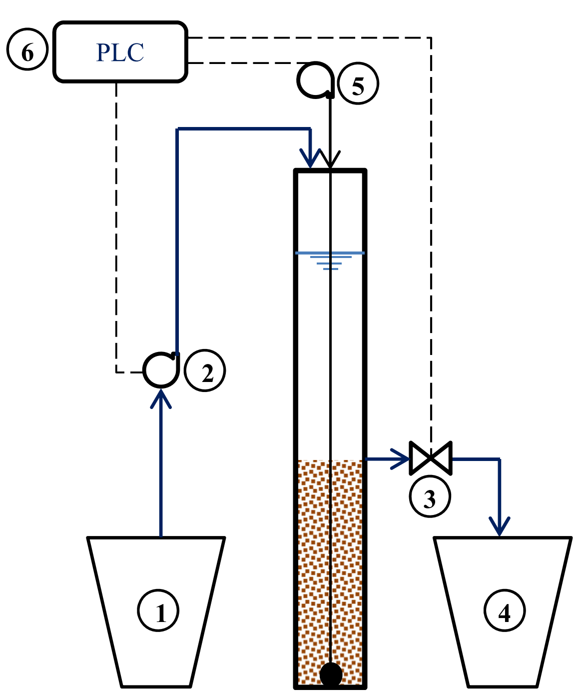

Fig. 1. Schematic diagram of the SBR: feeding tank (1), feeding pump (2), effluent valve (3), effluent tank (4), air pump (5), PLC controller (6).

The reactor was operated in the sequencing batch mode with a 3-h cycle consisting of four steps: 5 min of influent filling, 143–170 min of aeration, 3–30 min of settling, and 2 min of effluent discharge. Time for influent filling and effluent withdrawal remained consistent during the experiments. The settling time was decreased gradually from 30 min to 3 min once mature granules formed in order to wash the poor-settling sludge and to retain the granules with settling velocity around 8 m h^{-1}. The hydraulic retention time (HRT) in the reactor of a stable cycle was 5.67 h. OLRs were increased gradually from 0.5 to 1.2 kg COD m^{-3} day^{-1} at the acclimation phase to 2.5, 5.0, 7.5, and 10.0 kg COD m^{-3} day^{-1} by gradually increasing the influent COD, as presented in Table 1. All experiments were carried out in a laboratory and were operated at an ambient temperature range of 28–32 °C.

2.2. Media

2.2.1. Wastewater

Tapioca processing wastewater was produced every month by the traditional method in the laboratory and stored in a fridge at 5 °C. The composition of raw wastewater was as follows: pH: 3.9–4.5, COD: 4800–14000 mg L^{-1}, biological oxygen demand (BOD): 2500–11550 mg L^{-1}, CN^-: 2–75 mg L^{-1}, suspended solid (SS): 350–1000 mg L^{-1}, NH_4^+-N: 95–182 mg L^{-1}, total nitrogen (TN): 145–470 mg L^{-1}, total phosphorus (TP): 127–432 mg L^{-1}. Prior to being fed into the reactor, the raw wastewater was diluted with tap water until it attained the influent COD values listed in Table 1. The pH was maintained at 7.0 ± 0.5 using 0.1 N NaOH and 0.1 N HCl. The influent was supplemented by nutrient ingredients (NH_4^+-N, PO_4^{3-}-P) to ensure a COD:N:P ratio of 100:5:1 and macronutrient, micronutrient dosage as given by Nguyen et al. (2016).

2.2.2. Seed sludge

Activated sludge collected from a local municipal wastewater treatment plant was cultivated with tapioca processing wastewater in a bucket for a week. Then the acclimated activated sludge was inoculated into the reactor by a 3:8 vol ratio in proportion to mixed liquor suspended solid (MLSS) concentration of 3.2 g L^{-1} for start-up. The size of seed sludge was lower than 100 μm. The ratio of mixed liquor volatile suspended solid to mixed liquor suspended solid (MLVSS/MLSS) and the sludge volume index (SVI) were 76.3% and 220 mL g^{-1}, respectively.

2.2.3. Chemicals

All chemicals used in the experiments were of analytical grades obtained from Sigma and Merck chemicals.

2.3. Analytical methods

Granules were observed by an optical microscope (Olympus, Japan, model: BX 51) with an attached camera (Olympus, Japan, model: DP 71) and image analysis software (imageJ). The particle size distribution (PSD) was measured by the wet sieve method modified according to the method reported by Wang et al. (2010), in which 200 mL sludge sample was sieved by a series of standard sieves. The ranges of particle size are as follows: less than 0.15, 0.15–0.4, 0.4–1.0, 1.0–2.0 mm, and larger than 2.0 mm. Sludge having particles smaller than 0.15 mm was considered as flocculent sludge. Sludge retained in the sieve was taken by backwashing. The percentage of stable settled sludge volume for each particle-size range was used to determine PSD diagram. The granule structure was determined by scanning electron microscopy (SEM) (Hitachi, Japan, model: S-4800). Granules were dehydrated by drying at 60 °C for 24 h before the SEM analysis.