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Short Communication

Livestock wastewater treatment using aerobic granular sludge

Inawati Othman [a], Aznah Nor Anuar [b,*], Zaini Ujang [b], Noor Hasyimah Rosman [a], Hasnida Harun [a], Shreeshivadasan Chelliapan [b]

[a] Department of Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[b] Institute of Environmental and Water Resource Management, WATER Research Alliance, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

HIGHLIGHTS

- Matured aerobic granules were observed in the reactor with the size up to 4.1 mm.
- Aerobic granules grown in livestock wastewater had excellent settling properties.
- Removal efficiency of 74% COD, 73% TN and 70% TP can be achieved at 4-h cycle time.

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ABSTRACT

The present study demonstrated that aerobic granular sludge is capable of treating livestock wastewater from a cattle farm in a sequencing batch reactor (SBR) without the presence of support material. A lab scale SBR was operated for 80 d using 4 h cycle time with an organic loading rate (OLR) of 9 kg COD m^{-3} - d^{-1}. Results showed that the aerobic granules were growing from 0.1 to 4.1 mm towards the end of the experimental period. The sludge volume index (SVI) was 42 ml g^{-1} while the biomass concentration in the reactor grew up to 10.3 g L^{-1} represent excellent biomass separation and good settling ability of the granules. During this period, maximum COD, TN and TP removal efficiencies (74%, 73% and 70%, respectively) were observed in the SBR system, confirming high microbial activity in the SBR system.

1. Introduction

In the past, a number of research was performed using aerobic granular sludge in laboratory-scale reactors treating different types of wastewater such as soybean-processing wastewater (Su and Yu, 2005), brewery wastewater (Wang et al., 2007), abattoirs wastewater (Cassidy and Belia, 2005), dairy wastewater (Schwarzenbeck et al., 2005), saline wastewater (Figueroa et al., 2008), and palm oil mill effluent (POME) (Abdullah et al., 2011). Although aerobic granular sludge has been investigated extensively using synthetic wastewater, there is hardly any in aerobic granular sludge under real wastewater.

The growth of Malaysian's livestock industry increased significantly and accelerated gradually each year (Ngo, 2004). In general, livestock wastewater contains high chemical oxygen demand (COD), biological oxygen demand (BOD), color, nitrogen, phosphorus and suspended solids (Lee and Shoda, 2008). High levels of phosphorus and nitrogen in discharging livestock wastewater contribute to eutrophication of receiving wastewater particularly lakes and slow moving rivers. Therefore, a specific treatment process is required in treating wastewater.

In the past, small quantity of livestock wastewater was discharged without proper technology and contributed substantially to environmental pollution. Most of the livestock industries are employing conventional process for livestock wastewater treatment. The negative impact will be greater if the volume and frequency of the untreated discharged of livestock are higher. Since high costs of the reagent and poor performance of physico-chemical process in removal of soluble organics, biological treatment process are most preferred. Aerobic granular sludge is one of the biological treatment technologies that can successfully cultivated in treating livestock wastewater in a sequencing batch reactor (SBR).

Therefore, this study attempts to demonstrate the cultivation of aerobic granules applied for the effective bioprocess that is able to treat livestock wastewater. The study focuses on the aerobic granular sludge removal efficiency and the effluent quality treating real wastewater. Moreover, biomass profile and settling properties for the treatment of livestock wastewater were also presented in this study. Considering the advantages of aerobic granular sludge over conventional sludge flocs, aerobic granular sludge is a reasonable

* Corresponding author. Tel.: +60 19 7785616; fax: +60 7 5531575.
E-mail address: aznah@utm.my (A.N. Anuar).

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option as well as for its application in the treatment of high strength industrial wastewater.

2. Methods

2.1. Experimental procedure and reactor operation

A cylindrical column type SBR with a total volume of 5.4 L and a working volume of 4 L were used in the experimental study. The column reactor was designed with internal diameter of 10 cm and total height of 68.5 cm. Air was introduced by a fine air bubble diffuser at the bottom of the reactor during reaction phase. Air flow was set at 1 L min^{-1}. A set of two peristaltic pumps were used to feed and to discharge the wastewater in the reactor system. The influent was introduced in the reactor through a port located at the bottom of the column. The wastewater effluent was collected at an outlet port located at the middle of the reactor height which had a volumetric exchange ratio of 50%. The reactor was operated continuously in a successive cycles of 4 h (240 min and 6 cycles a day) at room temperature (27–30 °C). Feeding was 10 min, settling 15 min, discharge and idle 5 min each, giving total of 205 min reaction phase. The reaction phase consists of aerobic (185 min) and anaerobic phase (20 min).

2.2. Livestock wastewater characteristic

Raw undiluted livestock wastewater was collected weekly from cattle farm at Kempas, Malaysia. The raw livestock wastewater contains urine, washing water, blood and feces which were sieved with a mesh of 1.0 mm to eliminate large debris and solid materials. The collected livestock wastewater was stored at 2–4 °C until it was fed to the reactor system to prevent from degradation process of microbes in wastewater. The characteristic of the raw livestock wastewater are given in Table 1.

2.3. Seed sludge

A mixture of an equal volume of seed sludge from a municipal wastewater treatment and sludge from a cattle farm was used in this experiment. The seed sludge was taken from an aeration tank in Taman Harmoni, Municipal Wastewater Treatment Plant, Johor Bahru, Malaysia and Sumber Cahaya Farm, Kempas, Malaysia. The seed sludge was acclimatized for one month by gradually increasing the concentration of wastewater to accustom the activated sludge. The seed sludge having fluffy, irregular and loose morphology was inoculated into the reactor [mixed liquor suspended solids (MLSS), 2.41 g L^{-1} and sludge volume index (SVI), 242.5 ml g^{-1}].

2.4. Analytical methods

The pH was measured using an Orion 4-Star Benchtop pH/DO meter. The morphological and structural observations of the granules were carried out by using a stereo microscope equipped with digital image processing and analyzer (PAX-ITv6, ARC PAX-CAM). The microbial structure composition in the granules was observed using scanning electron microscope (FESEM-Zeiss Supra 35 VPFE-SEM). The aerobic granules were examined using Perkin Elmer Analyst 400 Flame Atomic Absorption Spectrophotometer (FLAA) to observe the composition of the mineral. Other parameters such as mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS), Chemical oxygen demand (COD), Total nitrogen (TN) and Total phosphorus (TP) were analyzed according to Standard Methods (APHA, 2005). The aerobic granules developed in the SBR were analyzed for their physical characteristics such as size, settling velocity and sludge volume index (SVI).

Table 1
Characteristics of livestock wastewater.

Parameters[a]	Livestock wastewater (cattle farm)
pH	8.05
Chemical oxygen demand (COD)	3600
Biochemical oxygen demand (BOD)	1750
Total suspended solid	230
Total dissolve solid	1380
Total nitrogen	650
Total phosporus	380

[a] All other parameters are in mg L^{-1} except pH.

3. Results and discussion

3.1. Morphology of aerobic granular sludge

Observations of aerobic granules development were made using stereomicroscope a week after inoculums. At the beginning, majority of the initial seed sludge was still present in the form of sludge flocs with a fluffy, loose and irregular shape. After 2 weeks, the sludge flocs gradually disappeared from the reactor and replaced by small dark brown granules with an average diameter of 1.5 mm. At this stage, developed aerobic granules were unstable and could easily break up. Four week after inoculums, the aerobic granules steadily increased and become compact and denser. The size of the aerobic granules from week 4 was between 2.5 and 3.0 mm, but increased to 3.5–4.1 mm in week 7. Moreover, the characteristics of aerobic granules at the end of experiment were spherical, smooth and clearer outer morphology, indicating dense and high settling ability of the granules. Generally, the formation of aerobic granules is a gradual process from initial seed sludge, flocs to matured and stable granules (Liu and Tay, 2004). Microscopic examination showed that morphology of seed sludge was completely different from the morphology of aerobic granules in the system.

Scanning electron microscope (SEM) was used to observe the microstructure of the aerobic granules. The formation of aerobic granules was greatly related to the ability of the microbes attached to each other and producing extrapolysaccarides (EPS). In addition, EPS can establish a stable network structure in cell and essential for the formation of dense and stable structure of aerobic granules (Zhu et al., 2012). Microbes attached with each other and form a smooth spherical shape of aerobic granules with the EPS distributed throughout the granules. The aerobic granules in the present study had a very compact microstructure with coccobacillus bacteria linked together with the conglutination of EPS. Meanwhile, the formation of cavities appears on the surface of granules due to limitation of substrate. However, Muda et al. (2010) claimed that the cavities were responsible to allow smooth mass transfer of the substrate to the granules.

3.2. Biomass profile and settling characteristics

Fig. 1 illustrates the profile of biomass concentration and SVI throughout 80 days of the experimental period. During the first few days of experiment, the reactor experienced a large amount of seed sludge wash out from the reactor because of poor settling properties. Only fast settling of seed sludge was selected in the reactor. Muda et al. (2010) reported similar condition when developing granular sludge using textile wastewater. In the first few days, the MLSS reduced from 3.9 to 1.9 g L^{-1} mainly due to the short settling time and short effluent withdrawal from the reactor. After 10 days of operation, the MLSS increased sharply from 4.7 to 10.6 g L^{-1}, confirming high biomass growths in the reactor. In addition, flocculent sludge attached to the reactor wall prevented solid washout. During this period, microorganisms react with wastewater at higher rate and the sludge seen to be foaming at the reactor