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Cultivation of aerobic granular sludge with a mixed wastewater rich in toxic organics

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ABSTRACT

Aerobic granular sludge was successfully cultivated in a sequencing batch reactor fed with a mixture of chemical industrial wastewater rich in toxic organics and the effluent from an anaerobic acidogenic reactor. After 30-day operation, stable granules with a size of 1.0–3.0 mm were obtained. These granules appeared to have rougher surface than those cultivated with the carbohydrate- or acetate-rich wastewaters. There exhibited a "core" in the internal structure of the granules, which might benefit microorganisms to survive and resist the harsh environment. The formation of granules significantly improved the ability of sludge to withstand the toxic substances. The chemical oxygen demand removal efficiency of the granule-based reactor could reach around 80%, while its ammonia and total nitrogen removal efficiencies reached 90% and 40%, respectively. The aerobic-granule-based reactor showed an ability to resist the wastewater toxicity.

1. Introduction

Aerobic granulation represents an innovative technology for biomass immobilization in biological wastewater treatment [1–4]. In this process, the light and dispersed flocs are washed out gradually, while the denser sludge particles are retained and accumulated through a repetitive selection in sequencing batch reactor (SBR) operations, leading to the formation of compact and fast-settling granules [5–8]. Such granule systems have been used to treat a wide variety of wastewaters, such as nutrient-rich diary wastewater [9–11], soybean-processing wastewater [12], and textile wastewater [13]. Kishida et al. [10] cultivated granules using a synthetic wastewater and through gradually adding the diluted livestock wastewater into the influent, and used them for simultaneous nitrogen and phosphorus removal from livestock wastewater. Apart from the frequently cited advantages, such as high biomass retention, protection of microorganisms against predation and resistance to external disturbance, aerobic granules also show high resistance to toxic compounds. It has been demonstrated that granules were able to tolerate and degrade toxic organics such as phenol, p-nitrophenol and 2,4-dichlorophenol at levels that were known to cause the breakdown of conventional activated sludge systems [14–16]. This is partially attributed to the unique structure of granules, where the dense discrete microbial cells and extracellular polymeric substances (EPS) matrix [17] set a barrier for mass transfer and lower the concentration of toxics on the inner cells.

The high toxic resistance and degradation ability of aerobic granules are of particular interests for industrial wastewater treatment, which usually contains a large amount of toxic compounds. The cultivation of granules using toxic-containing wastewater has been demonstrated in several previous studies [14–16]. However, synthetic wastewaters with a simple content of certain toxic compounds were generally used in these studies, while the cultivation of aerobic granules for treatment of complex toxic substance-containing wastewaters has not been reported so far.

To this end, a mixed wastewater composed of a chemical industrial wastewater rich in toxic organics and the effluent from an anaerobic acidogenic reactor was used for the cultivation of aerobic granules in this study. The structural and biological properties of the cultivated granules were characterized, and the long-term performance of the granule-dominated reactor was investigated in terms of organic and nitrogen removals. This is an attempt to cultivate

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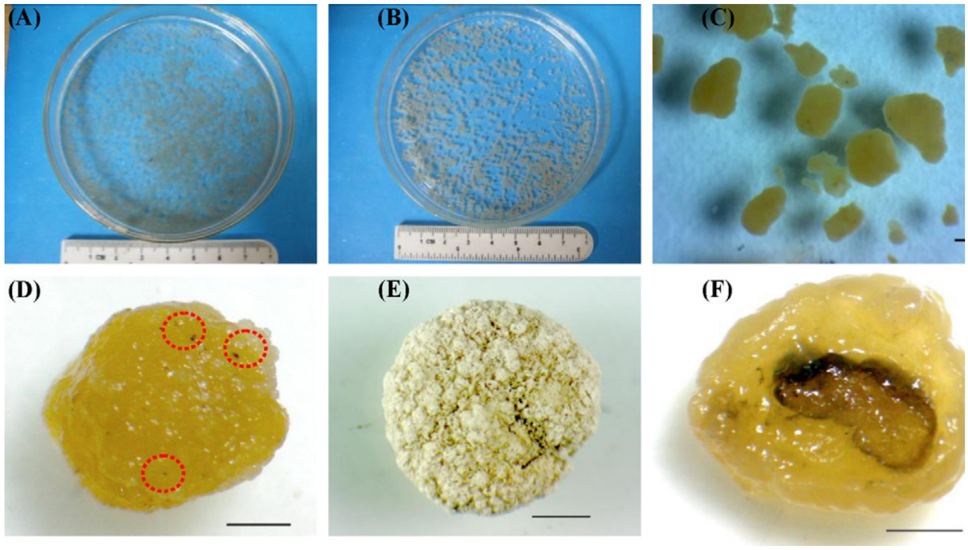

Fig. 1. Images of sludge in the granulation process: (A) seeding sludge; (B) sludge on Day 14; (C) granules on Day 30; (D) a single granule; (E) a freeze-dried granule; and (F) cross-section of a fresh granule (scale bar 1.0 mm).

Table 1
Composition of raw chemical industrial wastewater and the mixed wastewater fed to the SBR.

Parameter	Raw water (mg/L, except pH)	Influent to SBR (mg/L, except pH)
COD	3000–10,000	1000 (Stages 1 and 2)500 (Stage 3)
NH_4	500–5000	50
TN	1000–10,000	100
TSS	100–1000	<10
TP	<10	10
pH	7.3	7.0

In Stages 1 and 2, the fraction of the raw chemical industrial wastewater in the influent of the SBR was 10%. In stage 3, the fraction was increased to 1/3 and the fraction of the UASB effluent was correspondingly reduced, resulting in an influent COD of 500 mg/L for the SBR.

aerobic granules using a wastewater rich in toxic organics. This work presents a valuable effort in expanding the practical application of aerobic granule technology in the wastewater treatment.

2. Materials and methods

2.1. Wastewater and reactor operation

The raw chemical industrial wastewater was the mixture of the effluents from a pesticide production plant, a chlor-alkali industrial plant and several other chemical plants which are located in Feidong Chemical Industrial Park, Hefei, China. This chemical industrial wastewater was characterized by complex compositions, a high microbial toxicity and a low biodegradability due to the presence of various toxic organics. Moreover, significant fluctuations in the water quality occur frequently, with the chemical oxygen demand (COD) changing remarkably from 3000 to 10,000 mg/L in different months (Table 1). To facilitate microbial growth, the dose of a certain amount of nutrients into this wastewater is necessary. Thus, a mixture of this industrial wastewater and the effluent from a laboratory-scale H_2-producing upflow anaerobic sludge bed (UASB) reactor was used as the feedstock for sludge acclimation and granule cultivation. This UASB effluent was chosen because it was rich in volatile fatty acids, nitrogen and phosphorus [18]. The distribution of VFA in the reactor effluent is listed in Table 2. The SBR operation was divided into three stages: the sludge acclimation and granule forming stage (about 30 days), the granule maturing stage (about 130 days) and the industrial wastewater treatment stage (about 140 days). At the first and second stages, the raw water was diluted, resulting in the influent COD of the SBR was approximately 1000 mg/L, in which the chemical industrial wastewater had a fraction of 10%. At the third stage, the industrial wastewater fraction was increased to a fraction of 1/3 and the fraction of the UASB effluent was correspondingly reduced. And the influent COD was kept at approximately 500 mg/L. The compositions of the raw wastewater and the SBR influent are summarized in Table 1.

2.2. Seeding sludge and reactor set-up

The seeding sludge was taken from an aeration tank in Wangxiaoying Municipal Wastewater Treatment Plant, Hefei, China. It had a mixed liquor suspended solids (MLSS) concentration of 2.6 g/L and a sludge volume index (SVI) of 74.2 mL/g. The specific gravity and the settling velocity were 1.006 g/cm^3 and 7.0 m/h, respectively. Experiments were carried out in a cylindrical column reactor with an internal diameter of 0.1 m and a height of 1.0 m (working volume of 7.4 L and volumetric exchange ratio of 50%). Aeration was provided by means of air bubble diffusers at a volumetric flow rate of 500 L/h (1.77 cm/s of superficial air flow velocity), which gave a minimum dissolved oxygen concentration of above 2.0 mg/L. The reactor was operated in an SBR mode with a total cycle duration of 6 h, including: 3 min of feeding, 349 min of aeration, 1 min of settling (when granules were formed in the reactor), and 5 min of effluent withdrawal. The mean sludge residence time was 31 days. The reactor temperature was maintained at 25 °C using a belt heater

Table 2
Distribution of VFA (in unit of mM) in the anaerobic acidogenic reactor effluent.

VFA					
Acetate	Propionate	i-Butyrate	Butyrate	Valerate	Caporate
3.97 ± 0.10	0.73 ± 0.07	0.18 ± 0.02	11.01 ± 0.10	1.74 ± 0.12	0.86 ± 0.04