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RAPID COMMUNICATION

AEROBIC GRANULAR SLUDGE—A CASE REPORT

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Abstract—Aerobic granular sludge was observed in a Sequencing Batch Reactor (SBR) in which a synthetic urban wastewater containing sodium acetate as an organic substrate was fed, and dissolved oxygen (DO) was controlled at low concentration (0.7–1.0 mg/l) Microscope examination showed that the morphology of the granules was nearly spherical (0.3–0.5 mm in diameter) with a very clear outline. The granular sludge had a good settleability (Sludge Volume Index (SVI) between 80–100 ml/g) and high COD removal and nitrification activities (2.16 g(TOC)/g(SS) · d and 0.24 g(NH_3-N)/g(SS) · d). With granular sludge, high quality effluent was obtained for treatment of synthetic wastewater under low DO. © 1998 Elsevier Science Ltd. All rights reserved

Key words—granular sludge, aerobic SBR, low dissolved oxygen, morphology, activity

INTRODUCTION

The performance of an activated sludge process highly depends on the quality of the sludge formed in the reactor. The sludge should be easily separated from the liquid and maintained in the reactor. Generally, a dense, floc-like sludge is observed in normally-operated activated sludge processes. The shape, porosity and density of the floc are determined by both composition of the wastewater to be treated and operating parameters, such as loading rate, DO concentration and sludge retention time. Granular sludge may be developed in some anaerobic (Lettinga et al., 1980) and anoxic (Green et al., 1994) processes like up-flow sludge blanket (USB). This kind of sludge has a good settleability and can be easily maintained in the reactor. Therefore, high loading rates can be gained. In anaerobic condition, only floc-like sludges are reported up to now.

In this paper, we report the formation of granular sludge in an aerobic sequencing batch reactor (SBR) fed with a synthetic urban wastewater. Some preliminary characteristics of the granules are presented.

A lot of sewage treatment plants are subject to short-time or long-time overloads which lead to either a short hydraulic retention time (HRT) (when flow rate exceeds design values) or low DO in the aeration tanks (in high loading conditions). In both circumstances, process treatment efficiency will be reduced. In the second situation, filamentous bacteria like *Sphaerotilus natans*/Type 1701 and *Haliscomenobacter hydrossis* (Wanner, 1994) may grow, which will lead to a decrease of the sludge settleability, even to the process failure. One possible solution may be to change the inflow pattern from continuous to discontinuous. The primary objective of the study was to investigate the effect of low DO concentration on the performance of the process.

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MATERIALS AND METHODS

Reactor description

A 5 l SBR was inoculated with a low DO bulking activated sludge (SVI: 250–300 ml/g) containing filaments (Fig. 1a) and fed with a synthetic wastewater whose composition was the following: sodium acetate, 800 mg/l; ammonium chloride, 250 mg/l; K_2HPO_4/100 mg/l; $CaCl_2 \cdot 2H_2O$/70 mg/l; $MgSO_4 \cdot 7H_2O$/30 mg/l, microelement solution/50 μl/l. The microelement solution contained: $CaCl_2 \cdot 2H_2O$/7.34 g/l; $MgCl_2 \cdot 6H_2O$/25.07 g/l; $FeCl_3 \cdot 6H_2O$/4.8 g/l; $MnCl_2 \cdot 4H_2O$/1.03 g/l; $ZnCl_2 \cdot 2H_2O$/0.01 g/l; $CuCl_2 \cdot 2H_2O$/0.112 g/l; $NaMoO_4 \cdot 2H_2O$/0.0025 g/l.

Operating parameters were as follows: hydraulic retention time (HRT): 8 h; sludge retention time (SRT): 20 days; DO in the bulk liquid: 3.5–4 mg/l at the beginning of the experiment (about 20 days). The filling, reaction, settling and withdrawing periods were respectively 0.5, 0.75, 2.5 and 0.25 h long, which means 6 cycles a day. The reactor was thermostatically regulated at 25°C and stirred at 400 rpm to ensure good mixing and oxygen transfer.

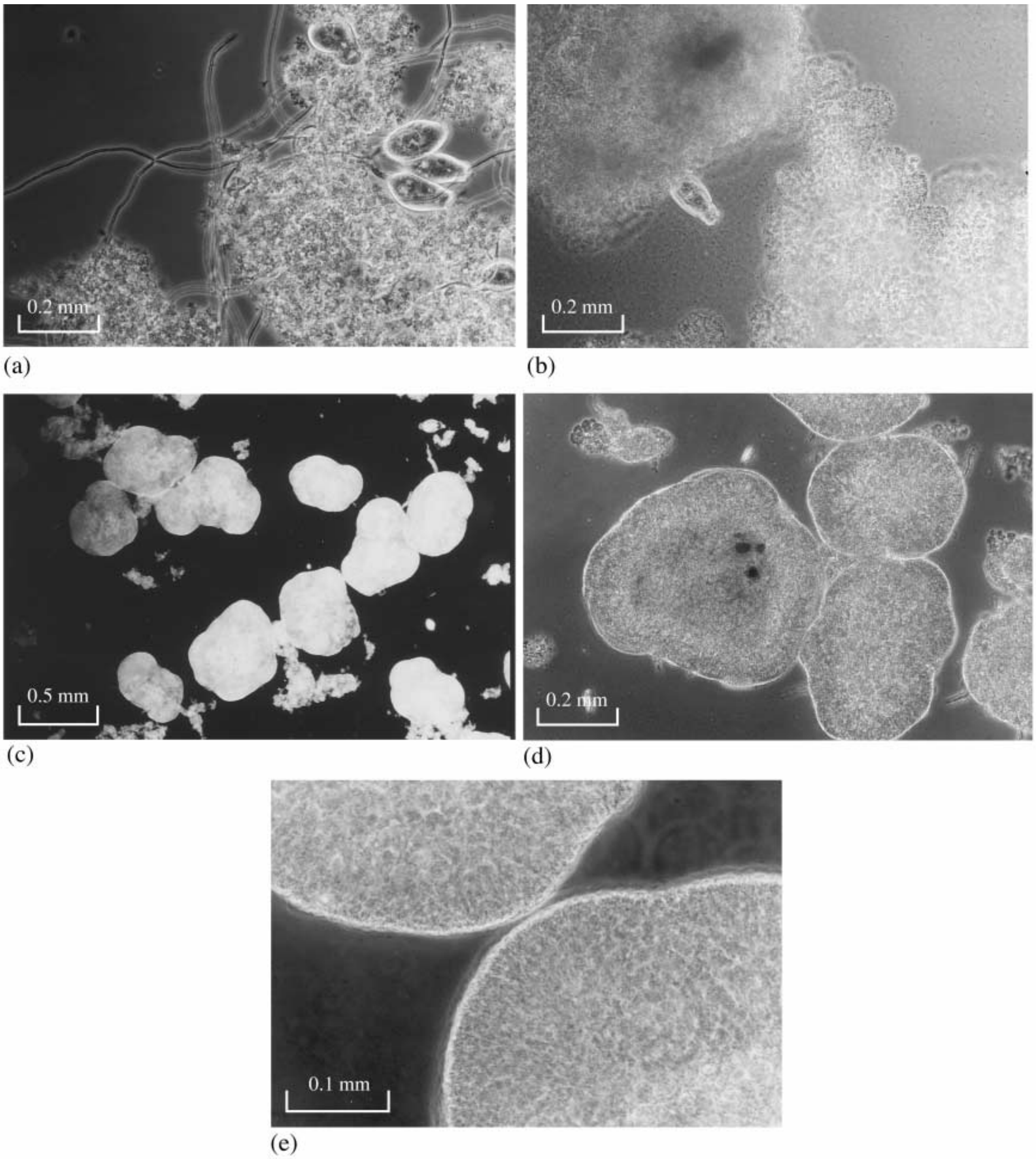

Fig. 1. Evolution of the activated sludge in the reactor: (a) seeding sludge; (b) floc-like sludge; (c), (d), (e) granular sludge.

Analytical methods

Samples were centrifuged at 6000 ***g*** for 10 min before analysis to remove suspended solids. The supernatant liquors were diluted as required prior to analysis.

Ammonium was determined by the titrimetric method after distillation using a Büchi apparatus (Rodier, 1975). Nitrate and nitrite were analyzed by ion chromatography system using conductivity detection (Dionex-100). Separation and elution of the anions were carried out on IonPac AS12A analytical column utilizing a carbonate/bicarbonate eluant and AutoSupression technology. Integration was done using a PC fitted with Peaknet Software.

Total organic carbon (TOC) was titrated by UV oxidation with a Dohrman DC 80 apparatus. Carbon compounds were oxidized in potassium persulfate at a low temperature. The carbon dioxide formed was detected by infrared adsorption. Water was diluted twice with orthophosphoric acid at 10%. The carbon dioxide contained in the samples was previously eliminated by bubbling with oxygen for 5 min. COD was measured by potassium dichromate/ferrous ammonium sulfate method.

Total suspended solids (TSS) and volatile suspended solids (VSS) were determined using Standard Methods (APHA, 1985).

RESULTS AND DISCUSSION

Granular sludge formation

After about 20 days, filamentous bacteria in the sludge disappeared and the sludge SVI decreased to 100–150 ml/g. Afterwards, DO in the reactor was reduced to 0.8 mg/l (set point); actual ranges were between 0.7–1.0 mg/l during the aeration period, nearly zero at the beginning of this period.

At the beginning, the sludge in the reactor changed to flocs and SVI increased to 150–200 ml/g. Freely-moving bacteria were also observed in the liquid phase (Fig. 1b). However, the floc-like sludge changed gradually to granular sludge with time. After one month of operation at low DO concentration, the sludge in the reactor was nearly completely granulized (Fig. 1c). At this point, COD, NH_3-N and nitrogen removal efficiencies were as high as 95, 95 and 60%, respectively. No filamentous bacteria were observed and SVI was between 80–100 ml/g even though DO in the reactor was lower than 1.0 mg/l. After three months of operation, the reactor was still working and the granular sludge in the reactor was stable.

Some preliminary characteristics of the aerobic granular sludge

Morphology and architecture. Microscopic examination showed that the morphology of the granular sludge was completely different from the floc-like sludge. The shape of the granules is nearly spherical (Fig. 1d) with a very clear outline (Fig. 1e). It is generally agreed that activated sludge flocs are organized on three levels (Scuras et al., 1998). The lowest level, the individual particles, are preliminary living cells, lysed decaying cells, non-biodegradable cell debris, and influent solids and of the order of 0.5–5 μm. The next level consists of aggregates of individual particles that are encapsulated in a clearly defined polymer matrix to form microcolonies which are observed to be roughly spherical in flocs. Within this matrix, it is believed that the particles are held in constant positions stabilized relative to one another. These microcolonies are of the order of 5–50 μm in size. The highest level of structure is the floc which is made up of numerous individual particles and microcolonies enmeshed in exopolymers to form a floc. The granule described here seems to be arranged also on three levels. The first and second levels are the same as the floc-like sludge since microcolonies can be seen clearly in the granule (Fig. 1d). The numerous microcolonies accumulate together with exopolymers to form the third level, the granule.

The size of the aerobic granules was also different from that of anaerobic and anoxic granules. In anaerobic or anoxic reactors, the granules can grow up to 2–3 mm in diameter. Here, the average diameter of the aerobic granules is only between 0.3–0.5 mm. The granule did not grow bigger even though a long period of time was run. This may be because the strength of mixing in the aerobic reactor is higher than that in the anaerobic and anoxic reactors. The strong shearing force produced by mixing and aeration could prevent the development of high diameter granules.

Settleability. The granular sludge had a good settleability. During the experiment, suspended solids (SS) concentration in the reactor was as high as 4–4.5 g/l. However, the sludge SVI stabilized between 80–100 ml/g. Settling and separation of the sludge from the liquid were very good.

The settling state of the aerobic granular sludge was also different from its anaerobic and anoxic analogues. The sludge existed in the granular state both under microscope and in aeration (the granules could be seen easily by the naked eye). However, when aeration stopped, the granules agglomerated together to form a big floc to settle.

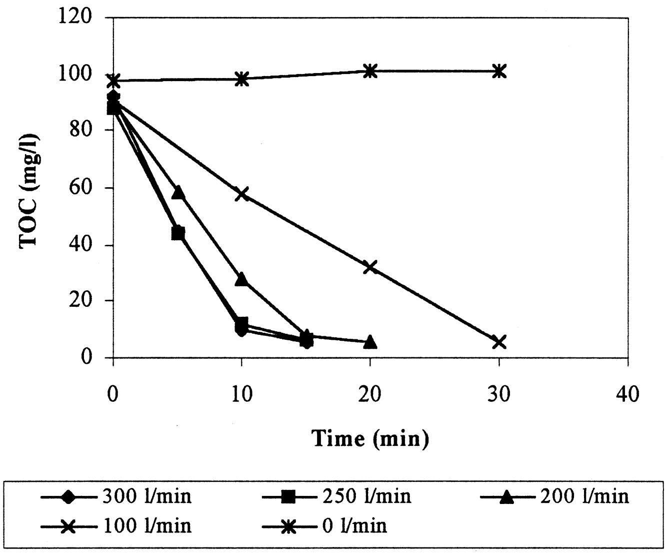

Fig. 2. Kinetic study of granular sludge under different aeration conditions.

Activity. The granular sludge had a high activity. Even though DO in the reactor was lower than 1.0 mg/l, organic and nitrogen loading rates reached 1.5 kg $COD/m^3 \cdot d$ and 0.18 kg NH_3-$N/m^3 \cdot d$.

COD in the reactor was always at a very low level (less than 20 mg/l), even during the feeding period. DO during the feeding period was nearly zero, but recovered very quickly to the set point (0.8 mg/l) after the end of feeding.

The length of the feeding period was reduced from 30 to 3 min (pulse feeding) and the COD removal activities were measured at different air flow rates (Fig. 2). It can be seen that the carbon-oxidizing activity increased with the increase of air supply flow rate. However, DO concentration in the reactor was nearly the same (less than 1% of saturation). When the air flow rate was increased to 300 l/h, DO in the reactor reached the set point but oxidizing activity did not increase any more. When the air supply was stopped, the activity stopped at the same time. This result suggested that the activity of the granules was strongly dependent on the oxygen supply, but not on the oxygen concentrations.

The granular sludge also had a high nitrification activity. In our experiment, the ammonium loading rate was 0.15–0.18 kg NH_3-$N/m^3 \cdot d$ and ammonium fed was completely nitrified even though the organic loading rate was as high as 1.5–2.0 kg $COD/m^3 \cdot d$ and DO concentration in the reactor was as low as 0.7–1.0 mg/l.

Microbiology. High microscope magnification showed that the granule was mainly constituted of rod-like bacteria which were arranged in such a way that the top of the rod was toward the centre. No filamentous bacteria were observed. This feature is nearly the same as that of anoxic granules (Kratochvil et al., 1996) but different with that of anaerobic granules which almost invariably contain filamentous bacteria like *Methanothrix*.

The fact that the structure inside the aerobic granule looked like that described inside the anoxic one, may be explained. Because DO in the reactor was controlled at a low concentration and more than 60% of ammonium supplied was denitrified, the centre part of the granule was certainly under anoxic condition. However, as a whole, the reactor was operated in aerobic condition.

CONCLUSION

Anaerobic granular sludge was formed in a bench scale SBR at low DO concentration. Comparing the aerobic granule with its anaerobic and anoxic analogue, some characteristics, such as morphology, architecture and microecology, are different while others, such as activity and settleability, are identical. Even though the formation of the aerobic granular sludge is still relatively unknown (not well studied), its benefits to the treatment process are evident, especially high pollutant degrading ability, settleability and efficiency of the process under low DO concentrations.

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