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Aerobic granules cultivated and operated in continuous-flow bioreactor under particle-size selective pressure

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ABSTRACT

A novel method based on the selective pressure of particle size (particle-size cultivation method, PSCM) was developed for the cultivation and operation of aerobic granular sludge in a continuous-flow reactor, and compared with the conventional method based on the selective pressure of settling velocity (settling-velocity cultivation method, SVCM). Results indicated that aerobic granules could be cultivated in continuous operation mode by this developed method within 14 days. Although in the granulation process, under particle-size selective pressure, mixed liquor suspended solids (MLSS) in the reactor fluctuated greatly and filamentous bacteria dominated the sludge system during the initial operation days, no obvious difference in profile was found between the aerobic granules cultivated by PSCM and SVCM. Moreover, aerobic granules cultivated by PSCM presented larger diameter, lower water content and higher specific rates of nitrification, denitrification and phosphorus removal, but lower settling velocity. Under long term operation of more than 30 days, aerobic granules in the continuous-flow reactor could remain stable and obtain good chemical oxygen demand (COD), NH_4^+-N, total nitrogen (TN) and total phosphorus (TP) removal. The results indicate that PSCM was dependent on the cultivation and maintenance of the stability of aerobic granules in continuous-flow bioreactors.

Introduction

Aerobic granular sludge is a promising technology with outstanding advantages, such as special structure, good settling velocity and high biomass concentration (Morales et al., 2012). In previous studies, aerobic granular sludge was often cultivated in batch reactors, such as the sequencing batch reactor and sequencing batch airlift reactor, which were characterized by batch influent, effluent and washing out of sludge (Zhao et al., 2011). However, batch operation mode is not suitable for large-scale sewage treatment and could lead to great changes in the growth environment for aerobic granules, possibly resulting in instability for granular reactors.

Developing continuous-flow bioreactors is becoming a new trend in research on aerobic granules. There have already been a few reports on the cultivation of aerobic granular sludge under continuous-flow operation, but the results have not been satisfactory (Liu et al., 2012b). The lack of fully continuous-flow operation is likely the main reason. In the reported continuous-flow bioreactor only continuous influent was achieved, with effluent and washing-out of sludge remaining in batch mode, therefore experiencing the disadvantages of both batch reactors and continuous-flow reactors, such as unstable environment and homogeneous feeding (Juang et al., 2010). The conventional cultivation method for aerobic granules is the bottleneck hindering the development of full continuous-flow bioreactors with aerobic granules. This is because in the conventional cultivation method, aerobic granules are cultivated based on the selective pressure of the difference of settling velocity between granular and flocculent sludge, called settling-velocity cultivation method

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(SVCM) in this article, in which the processes of static settling and sludge washing-out are necessary (Jin et al., 2008; Winkler et al., 2011).

In order to solve the problem mentioned above, a novel cultivation method of aerobic granules was developed for continuous-flow reactors, called PSCM in this article, in which flocculent sludge was discharged under the selective pressure of particle size between flocculent and granular sludge. In PSCM, full continuous-flow was realized, namely continuous influent, effluent and sludge washing-out. Compared with the conventional cultivation method (SVCM), this developed method (PSCM) has several distinct features that make it a competitive aerobic granule cultivation alternative. First, by avoiding the processes of static settling and sludge washing-out, PSCM provides the possibility of cultivation and stable operation of aerobic granules in continuous-flow bioreactors. Second, with PSCM, granular sludge has a more stable environment for growth and operation. Once the conditions are reached for sludge granulation, aerobic granular sludge can maintain stability for a longer time. Third, aerobic granular bioreactors with PSCM are easy to operate and convenient for large-scale application.

Therefore, the aims of this study were to develop a novel method for the cultivation and maintenance of the stability of aerobic granules in continuous-flow bioreactors. By comparing this method with the conventional method of SVCM, the formation process, physical and biochemical characteristics and performances of the aerobic granules cultivated by PSCM were investigated.

1. Material and methods

1.1. *Reactor set-up and operating conditions*

Three column reactors, namely reactors #1, #2 and #3, were operated, all three of which had the same configuration, with internal diameter of 8.4 cm, height of 135 cm and working volume of 7.5 L, referenced to conventional aerobic granular reactors (Xiao et al., 2008). At the bottom of these reactors, fine bubble aerators were set to introduce air, provide dissolved oxygen for sludge and supply agitating power to keep granules suspended in water. In the three reactors, dissolved oxygen (DO) was in the range of 3.0–6.0 mg/L, pH was controlled about 7.0 and water temperature was about 20°C. In order to obtain selective pressure for sludge granulation under continuous-flow operation mode, a sludge selection reactor was installed following both reactors #2 and #3, in which a sieve was used to select sludge based on the difference of particle sizes. There were also several aerators installed at the bottom of the sludge selection tank, which were intermittently operated to avoid blocking of the sieve aperture by sludge. The diagram of reactor #3, the same as reactor #2, is shown in Fig. 1.

The three reactors were started up according to the operation modes listed in Table 1. In reactor #1, the aerobic granules were cultivated according to the conventional cultivation method, which was based on the selective pressure of the difference of settling velocities between granular and flocculent sludge (SVCM). In reactor #3, aerobic granules were cultivated by the developed method, which was based on the selective pressure of the difference of particle sizes between granular and flocculent sludge (PSCM). Continuous flow was adopted in reactor #3, in which the selective discharging process of flocculent sludge was as follows: wastewater was continuously fed at the bottom of reactor #3 while mixed liquor was continuously discharged at the top and entered into the sludge selection tank, where the discharged sludge from reactor #3, including aerobic granules and flocculent sludge, was separated based on particle size by a sieve. The granular sludge retained by the sieve, including a small amount of flocculent sludge, was then intermittently pumped into reactor #3 and flocculent sludge passing through the sieve was discharged. The granulation rate and biomass in reactor #3 could be controlled by adjusting the sieve aperture. In this test, the apertures of the sieve were in the range of 0.1–1.0 mm, with small apertures in the early stage and large apertures in the later stage. In reactor #2, the cultivation method was a combination of SVCM and PSCM. That is, part of the flocculent sludge was discharged through the selective pressure of settling velocity, and another part of the flocculent sludge was discharged through the selective pressure of particle size. Moreover, all of the hydraulic retention times (HRT) in reactors #1, #2 and #3 were controlled at 9.0 hr, that is, the wastewater exchange volume in reactor #1 was 20.0 L/day and the influent flow velocities in reactors #2 and #3 were 13.9 mL/min.

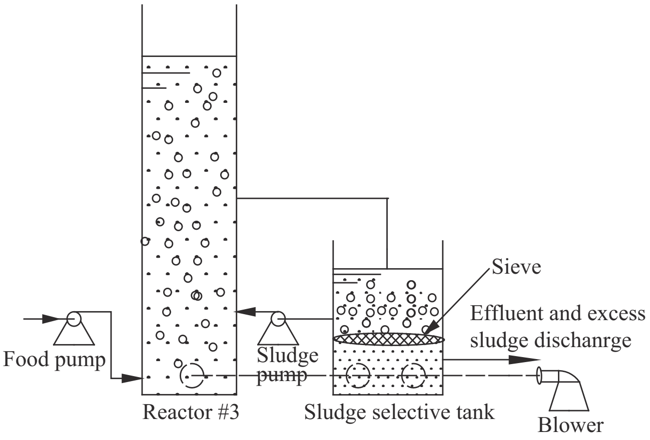

Fig. 1 – Diagram of reactor #3.