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Cultivating aerobic granular sludge in a developed continuous-flow reactor with two-zone sedimentation tank treating real and low-strength wastewater

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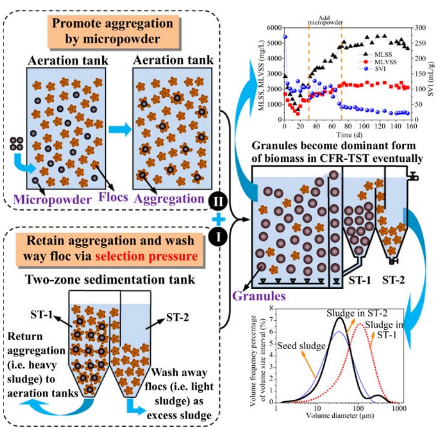
GRAPHICAL ABSTRACT



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ABSTRACT

A continuous-flow reactor with two-zone sedimentation tank (CFR-TST) was developed to evaluate the formation of aerobic granular sludge (AGS). Micropowder made of excess sludge was added for a while in the CFR-TST, and selection pressure associated with settling time was created by the two-zone sedimentation tank. To avoid AGS disintegration, an airlift system for sludge return was used. The results show that AGS (mean particle size of 105 μm; sludge volume index of approximately 26 mL/g) was formed successfully in the CFR-TST. The micropowder induced bacterial attachment by acting as nuclei. The two-zone sedimentation tank made the well settling granules (i.e., heavy sludge) always retained in the CFR and poorly settling flocs (i.e., light sludge) washed away. After granulation, the contents of extracellular polymeric substances and metal precipitations in sludge increased, and the microbial community changed obviously. Additionally, the effluent concentrations of COD_{Cr} and $NH_4{}^+$-N were relatively low after granulation.

1. Introduction

Aerobic granular sludge (AGS) process is an attractive technology for wastewater treatment since it offers many incomparable advantages compared with activated sludge, such as compact structure, high settling capacity, tolerance to high organic load and toxicity, possibility to degrade organic carbon and nutrients simultaneously, etc. (Gao et al., 2011; Zhang et al., 2016). Most of the previous basic research on AGS, for instance, Granule characterization, factors affecting granulation, and response of granules to various environmental and operating

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conditions, was conducted in laboratory-scale sequencing batch reactors (SBR) (Qin et al., 2004; Su and Yu, 2005; Li et al., 2015a). It is widely accepted that the ideal conditions for aerobic granulation could be easily controlled in the SBR, such as alternating feast and famine conditions, creating selection pressure including hydraulic shear force and settling time, etc. (Wana et al., 2009; Liu and Tay, 2015). Actually, in the last decade, almost all the pilot-scale or full-scale reactors for AGS cultivation are SBR (Ni et al., 2009; Li et al., 2014a; Pronk et al., 2015; Yang et al., 2016), implying SBR are the most common reactor type for the application of AGS in practice. However, SBR is difficult to implement for a large sewage treatment, and is unfavorable to connect to continuous operational constructions. By contrast, continuous-flow reactor (CFR) is more popular and widely applied in engineering due to low installation costs, high equipment utilization rate, and easy operation and maintenance (Juang et al., 2010). Therefore, for practical large-scale operation, it is meaningful and urgent to study the AGS formation and stability in the CFR.

Recently, some modified CFRs for AGS cultivation have been proposed by researchers (Juang et al., 2010). Our previous studies on AGS cultivation in a modified oxidation ditch and reverse flow baffled reactor also have proved AGS can be formed in the modified CFR under specific conditions (Li et al., 2014b, 2015b). Although great efforts have been made to cultivate AGS in a continuous-flow process, their efforts are not yet satisfactory (Juang et al., 2010; Liu et al., 2012). The AGS cultivated in a CFR seems to become unstable faster than those in a SBR in the long run (Chen et al., 2009). In fact, it is still very difficult to cultivate AGS directly and maintain long-term stability in a conventional CFR at present, mainly due to the lack of many critical conditions for sludge granulation. Moreover, though progress has been made in understanding how granulation occurs and how the process can be accelerated, the comprehensive mechanism is yet to be established (Zhang et al., 2016), further resulting in the difficulty of CFR design for AGS cultivation.

Up to now, the crystalline nuclei and selection pressure are widely regarded as the two main factors affecting sludge granulation according to previous substantial research in the SBR (Qin et al., 2004; Verawaty et al., 2012). Recent studies suggest that these two factors, especially the selection pressure, are also very important for sludge granulation in the CFR (Juang et al., 2010; Li et al., 2014b, 2015a,b). Different from the static settling in the SBR, the selection of different characteristic sludge in the CFR mainly depended on the separator. However, there is quite little successful experience of AGS separators that used directly for the conventional CFR until now. In addition, although a few studies have reported successful AGS formation in the SBR using low-strength municipal wastewater (Wang et al., 2008; Ni et al., 2009; Peyong et al., 2012), cultivating AGS in the CFR using real and low-strength complex wastewater is still rarely reported.

The aim of this study was to propose a novel designed AGS separator, namely two-zone sedimentation tank, which could be commonly used in the conventional CFR. Real and low-strength wastewater was used as an influent during the whole experiment. Aerobic granulation process in the CFR with two-zone sedimentation tank (CFR-TST) was investigated by monitoring the sludge characteristics and microbial community. Furthermore, the differences of sludge characteristics in the two-zone sedimentation tank were also compared in detail to reveal the granulation mechanism in the CFR-TST. The results of the present study will help to promote the understanding of AGS cultivation in the conventional CFR.

2. Methods and materials

2.1. Wastewater and seed sludge

Real and low-strength wastewater used in this study was collected from the effluent of a hydrolytic acidification tank in a wastewater treatment plant (WWTP) located in Zhejiang, China. The WWTP serves a coastal town with a population of 300 thousand people, and contains a hydrolytic acidification-anaerobic-anoxic-aerobic process. The wastewater was comprised of both municipal (25%) and industrial (75%) wastewater. The industrial wastewater mainly originated from the chemical, tannery, textile and dyeing industries. Since the developed CFR-TST did not contain the hydrolytic acidification process, the effluent of a hydrolytic acidification tank was used as the influent for the reactor. The main parameters of the real and low-strength wastewater were as follows: chemical oxygen demand (COD_{Cr}) 125 ± 36 mg/L, ammonia nitrogen (NH_4^+-N) 19 ± 4 mg/L, and biochemical oxygen demand (BOD_5)/COD_{Cr} 0.33 ± 0.06. Activated sludge obtained from the aerobic tank in the WWTP was used as the seed sludge for the CFR-TST at an initial sludge concentration of 3000 mg/L in mixed liquor suspended solids (MLSS). The ratio of mixed liquor volatile suspended solids (MLVSS) to MLSS (MLVSS/MLSS) was approximately 60% for seed sludge, and the sludge volume index (SVI) was approximately 270 mL/g.

2.2. Reactor setup and operation

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A CFR-TST with an effective working volume of 26.8 L was developed to cultivate AGS (Fig. 1). The CFR-TST mainly included an aeration tank (15 cm in width, 40 cm in length and 49 cm in height), a sludge return area (4 cm in width, 7.5 cm in length and 49 cm in height) and a sedimentation tank with two identical zones (first zone and second zone of the sedimentation tank were denoted ST-1 and ST-2,

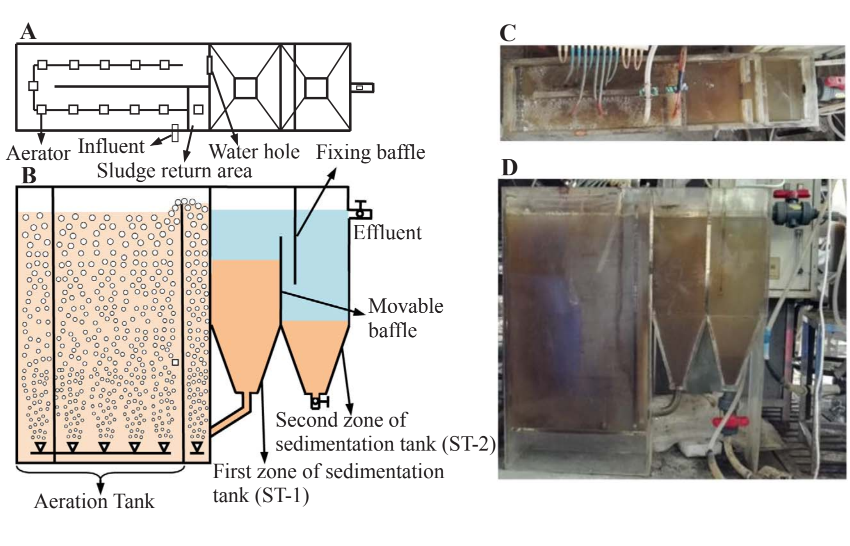

Fig. 1. Schematic diagrams and digital images of the continuous-flow reactor with two-zone sedimentation tank (CFR-TST) (A: top view of the reactor; B: front view of the reactor; C: digital image of the top view of the reactor; D: digital image of the front view of the reactor).