Assessing the influence of long-chain fatty acids on aerobic granular sludge stability in a sequencing batch reactor

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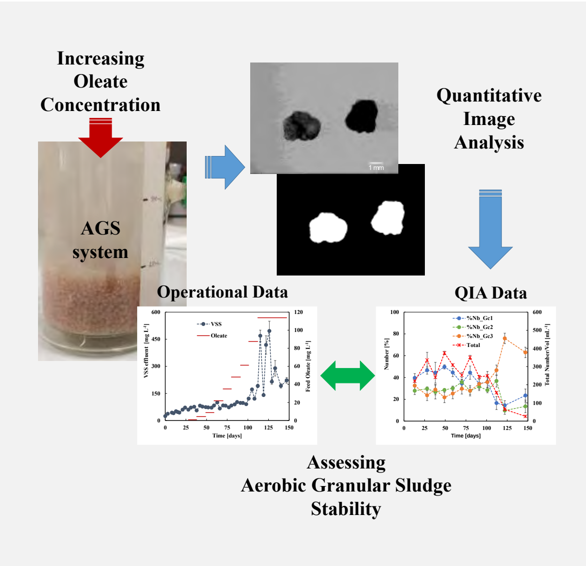

The presence of long-chain fatty acids (LCFA) in biological wastewater treatment systems can cause various operational issues. This study evaluated the effect of LCFA, at typical concentrations found in domestic wastewater, on the performance and stability of aerobic granular sludge (AGS) in a sequencing batch reactor. At an oleate concentration of 61 ± 2 mg L^{-1}, oleate started to accumulate in the reactor, resulting in an increase of volatile suspended solids concentration in the effluent. This caused small granules to be washed out due to their larger specific surface area for oleate adsorption. Selecting large granules could minimize oleate adsorption, preventing sludge washout and maintaining the reactor stability. Overall, the study demonstrates the feasibility of using AGS systems for treatment of oleate-containing wastewater for concentrations below 61 ± 2 mg L^{-1} and highlights the importance of limiting oleate adsorption for the stability of AGS systems.

Introduction

AGS technology is a promising alternative to conventional activated sludge systems for wastewater treatment due to its higher energy efficiency and cost-effectiveness [1]. However, AGS instability limits its widespread use. LCFA result from lipids hydrolysis, one of the most significant components of organic matter present in wastewaters, which may cause microbial inhibition and sludge settling problems in biological treatment systems [2,3]. However, the impact of LCFA on AGS systems is not yet fully understood, particularly at typical concentrations found in domestic wastewater. Quantitative image analysis (QIA) has emerged as a valuable tool for monitoring the morphology of sludge aggregates in both aerobic and anaerobic treatment processes, providing insight into the granulation process and stability of AGS systems [4]. By analyzing the morphology, size and content of granules, QIA can anticipate potential problems and assess process stability. This study aimed to investigate the impact on the stability of AGS systems of different concentrations of LCFA commonly found in domestic wastewater. The potential effects of LCFA on the morphology, size and content of granules using QIA was also evaluated.

Methods

A sequencing batch reactor (SBR) with a working volume of 1 L and dimensions of 18.5 cm height and 9 cm diameter (H/D = 2) was operated at room temperature with cycles of 6 h. The reactor was inoculated with AGS produced from activated sludge and fed with sodium acetate as carbon source. After 28 days, sodium oleate was added to the feed at concentrations ranging from 1 ± 0.03 mg L^{-1} to 114 ± 4 mg L^{-1}. Oleate was used as the model LCFA due to its prevalence in raw products, sewage grease deposits, and wastewater treatment plants. The volatile suspended solids in the effluent ($VSS_{effluent}$) and the sludge volume index at 5 min (SVI_5) and 30 min (SVI_{30}) were determined according to standard methods [5]. Oleate concentration was determined by gas chromatography according to [6]. The morphological changes of AGS, due to the increase in oleate concentration, were evaluated by QIA. Granules images were captured using an Olympus SZ-40 stereomicroscope (Olympus, Shinjuku, Japan) at a 15× magnification. After images pre-treatment, segmentation, and debris removal, binary images of the granules were created, and further used to determine the granules' size, content and morphology [7]. The granules were characterized into three size classes based on their equivalent diameter (Deq): small - Gc1 (0.2 mm ≤ Deq ≤ 0.6 mm), intermediary - Gc2 (0.6 mm < Deq < 1 mm), and large - Gc3 (Deq ≥ 1 mm). Image analysis was conducted using Matlab™ 8.5 (The MathWorks Inc, USA).

Results

Oleate accumulation in the reactor (solid and liquid fractions) was detected when a concentration of 61 ± 2 mg L^{-1} was added to the feed. However, increasing the oleate concentration in the feed up to 114 ± 4 mg L^{-1} did not result in further accumulation inside the reactor (Figure 1A). At the highest oleate concentration, $VSS_{effluent}$ increased drastically to 496 ± 55 mg L^{-1} (Figure 1B). The observed phenomenon is likely due to the adsorption of oleate onto granules, leading to sludge flotation and subsequent washout from the system. Before the addition of oleate, the sum of the fraction of small (%Nb_Gc1) and intermediary (%Nb_Gc2) granules (i.e., Deq < 1 mm) represented 70% of the AGS, while the large granules (%Nb_Gc3) accounted for the remaining 30% (Figure 1C). The granules distribution changed when AGS was exposed to the highest concentration of oleate, accompanied by a decrease in the total number of granules (Figure 1C). On day 122, the prevalence of granules with Deq < 1 mm (Gc1 and Gc2) decreased to 25% and granules with Deq ≥ 1 mm (Gc3) became predominant in the system. Thus, the sludge was selectively washed out, primarily consisting of smaller granules (i.e., Deq < 1 mm), while larger granules (i.e., Deq ≥ 1 mm) were able to persist in the system (Figure 1C).

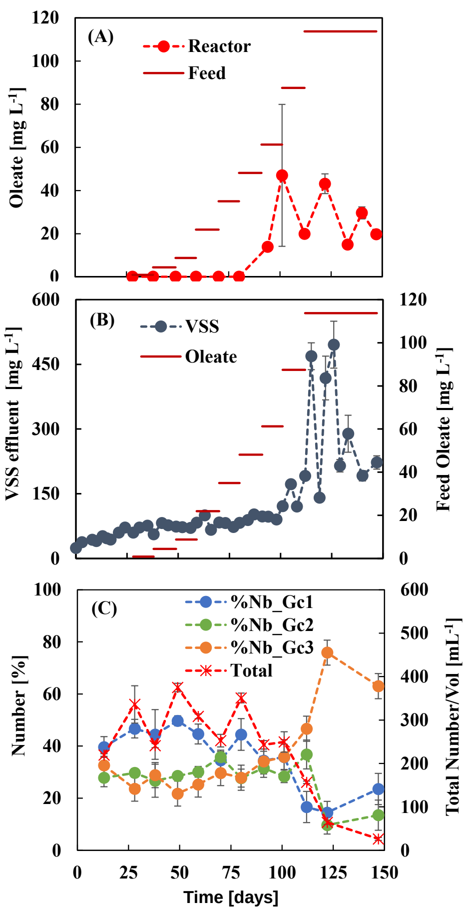

Figure 1. Operation and AGS profiles during the SBR operation. (A) Oleate concentration in the reactor and in the feed. (B) VSS concentration in the effluent. (C) Number distribution of small (%Nb_Gc1), intermediary (%Nb_Gc2) and large (%Nb_Gc3) granules.

Although the sludge exhibited good settling properties throughout the experiment, the settling velocity of the granules decreased when large granules were predominant (Figure 2A). In fact, the Deq of the overall granules size increased considerably from 0.8 ± 0.03 mm (at day 80) to 2.0 ± 0.2 mm (at day 147), confirming that mostly large granules were able to endure in the system (Figure 2B). A significant decrease in the convexity of the overall granules underlined the appearance of protruding filaments on the granules outer layer, concomitant to the decrease of the sludge settling properties (Figure 2AB).

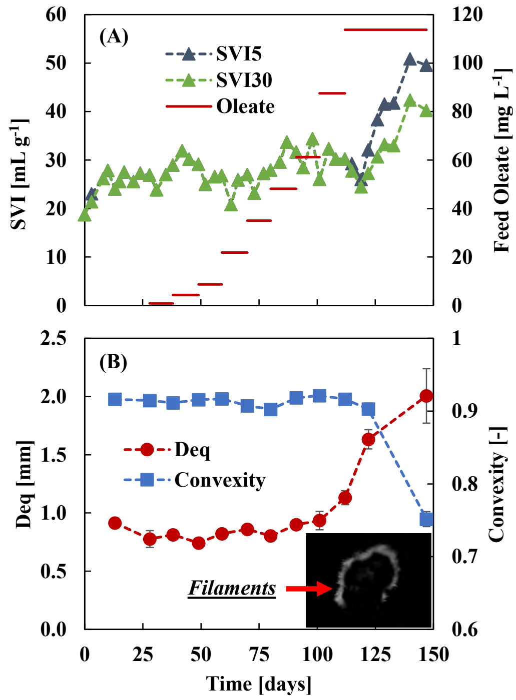

Figure 2. AGS profile during SBR operation. (A) Sludge volume index. (B) Equivalent diameter (Deq) and convexity of the overall granules.

Conclusions

This study suggests that oleate can have significant effects on the operation of an SBR system with AGS. The adsorption of oleate onto granules led to sludge flotation and washout from the system. Granules with Deq < 1 mm were selectively removed from the system due to their larger specific surface area, while larger granules remained. Limiting oleate adsorption appears to be a key factor in maintaining AGS stability in the presence of oleate-containing wastewaters. In this sense, the impact of oleate adsorption onto AGS could be minimized through the selective use of large granules, thus preventing extreme sludge washout.

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