Science of the Total Environment 650 (2019) 941–950

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Synergistic strengthening mechanism of hydraulic selection pressure and poly aluminum chloride (PAC) regulation on the aerobic sludge granulation

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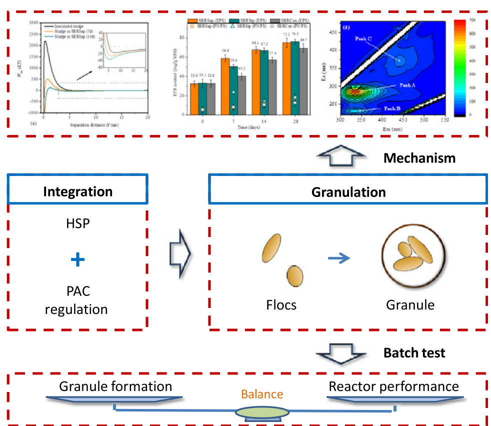
HIGHLIGHTS

- Integrated operations could accelerate the aerobic granulation obviously.
- HSP and PAC regulation played different roles on the granulation enhancement.
- Sludge characters improved by HSP were favorable for PAC regulation.
- Balance between granule formation and reactor performance was managed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 May 2018
Received in revised form 26 August 2018
Accepted 27 August 2018
Available online 29 August 2018

Editor: Zhen (Jason) He

Keywords:
Aerobic granulation
Hydraulic selection pressure (HSP)
Poly aluminum chloride (PAC)
Wastewater treatment
Mechanisms

ABSTRACT

This study aimed to enhance aerobic granulation by the integration of hydraulic selection pressure (HSP) and poly aluminum chloride (PAC) regulation. Based on an investigation of sludge characteristics, microbial aggregation and extracellular polymeric substances (EPS) secretion, the synergistic mechanisms of HSP and PAC regulation were revealed. For granule formation, HSP primarily improved the cell hydrophobicity and extracellular protein production, while PAC regulation markedly neutralized the surface charge of cells and reduced the interaction energy between them. In addition, biomass retention was also facilitated by the PAC dosing. Notably, the results of total interaction energy and flocculating ability imply that prior HSP screening could significantly promote PAC regulation on microbial aggregation. To optimize the balance between granule formation and reactor performances, five kinds of integrated strategies for HSP and PAC regulation were conducted in batch test. According to the results, 4.3 g/L initial mixed liquor volatile suspended solids (MLVSS) was preferred before the addition of PAC.

1. Introduction

Compared with conventional activated sludge, granular sludge exhibits a larger and denser aggregate structure, better solid-liquid

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https://doi.org/10.1016/j.scitotenv.2018.08.389

separation property, higher biomass concentration and higher endurance to withstand shock loadings (Sarma et al., 2017). However, the mechanisms involved in aerobic granule formation are still not fully understood, and several months would be required for the granulation with different types of wastewater. In Schwarzenbeck et al. (2004), 147 days were needed to accomplish the complete granulation in a reactor with malting wastewater. In Ni et al. (2009), to achieve 85% granulation in a reactor treating low-strength municipal wastewater, more than 300 days were required. Such long start-up period is a major challenge to be addressed before aerobic granulation can gain wide application in wastewater treatment.

Several factors have been believed to affect the granulation process, such as seed sludge, substrate composition, organic loading rate, aeration intensity and production of extracellular polymeric substances (EPS) (Wilen et al., 2004; Tay et al., 2002; Tay et al., 2004; Tay et al., 2001; Zhang et al., 2007). As an operational parameter of sequencing batch reactor (SBR), settling time is also involved, and the sludge washout caused by a short settling time will create the hydraulic selection pressure (HSP) to promote the formation of granules (Adav et al., 2009). It was speculated that high biomass concentration in a reactor leads to the uneasy separation of dispersed flocs from dense aggregates owning to the zone settling behavior with high biomass concentration, by which the settling of dense aggregates was impeded by other dispersed flocs (Zhang et al., 2006). By applying a short settling time, the assembly between dispersed flocs and dense aggregates weakens along with the decrease in the biomass concentration, and only large and fast-settling microbial aggregates are selected to remain in the reactor (Y.Q. Liu et al., 2010; X.M. Liu et al., 2010). In this case, the microbial community structure and the dominant strains in the sludge flocs also shift under the HSP (Adav et al., 2009).

In terms of accelerating the aerobic granulation, exogenous carrier dosing has also been proven to be effective. It is believed that positive divalent and trivalent ions could promote the formation of granules by binding to negatively charged cells to form microbial nuclei and stimulate the EPS production of sludge (Wang et al., 2012). Furthermore, granules formed under these conditions present superior settleability and mechanical strength. In Li et al. (2011), aerobic granulation was completely achieved with low-strength wastewater by adding granular activated carbon to the seed sludge, and these granules with strong cores were beneficial for maintaining their own long-term stability. In addition, aerobic granulation could be accelerated by the addition of biochar and the granules formed with biochar possessed high biomass retention and excellent degradation ability (Zhang et al., 2017). All of these abovementioned strategies appeared to be effective in reducing the start-up time of aerobic granulation. Moreover, compared with HSP, the exogenous carrier that had been added obviously acted in a different way to enhance the formation of aerobic granules. In this case, combining these two kinds of approaches may be feasible to optimize the aerobic granulation enhancement, and some trials have already been conducted. Using the integration of HSP and crushed granule addition, Pijuan et al. (2011) successfully reduced the startup time of aerobic granulation. Additionally, in Liu et al. (2014), the poly aluminum chloride (PAC) dosing and HSP were also integrated together to enhance the formation of aerobic granules. However, the previous work mainly focused on the roles of exogenous carriers. The mechanism of the complete granulation process has not been fully revealed. In particular, it is currently not known how HSP and the regulation that caused by the exogenous carriers to cooperate during the granule formation. An understanding of this synergistic mechanism is necessary for providing support to further optimize the technology.

Therefore, in this study, HSP and PAC regulation were integrated in various ways to enhance the formation of aerobic granular sludge. The synergistic strengthening mechanism of HSP and PAC regulation was revealed as well. Key physicochemical characteristic parameters of sludge were monitored to assess the effectiveness of the enhancements. Based on the Derjaguin–Landau–Verwey–Overbeek (DLVO) theory, sludge interactions at various stages were analyzed, and the flocculating ability of these sludge samples was correspondingly determined (Y.Q. Liu et al., 2010; X.M. Liu et al., 2010). Moreover, an analysis of EPS content and components was performed. Furthermore, to manage the balance between granule formation and reactor performance, a batch test was also conducted. The information derived from this study would be valuable to optimize the aerobic granulation process.

2. Materials and methods

2.1. Reactor setup

Three laboratory scale sequencing batch reactors (SBR), 1.5 m in height, 0.05 m in diameter and 2.0 L of working volumes were used to cultivate aerobic granules, as described in Liu et al. (2014). SBRSap and SBRStp denote the two reactors which operated with both HSP and PAC dosing: in the former, HSP and PAC dosing were applied simultaneously; in the latter, the PAC dosing was applied after the implementation of HSP. The rest was the control – SBRCon, in which the settling time kept at 15 min. The detailed configurations for these reactors are listed in Table 1. The effluent withdrawal point was located at a height of 65 cm, resulting in 50% volume exchange per cycle. These three reactors were operated in sequential mode for a 6-h cycle with 5 min of feeding, 315–330 min of aeration (corresponding to the settling time), 5 min of settling, 5 min of decanting and 15 min of idling. For the settling time, it was set as shown in Table 1. For the duration of the experiment, the pH of suspended liquor was controlled at 7.0 by adding $NaHCO_3$, and the temperature was artificially remained at 25 ± 1 °C. The SBRs were aerated with a constant gas upflow rate of 2.0 L/min and porous diffusers making small bubbles for aeration and mixing.

2.2. Feeding

Activated sludge from the sludge reflux of the secondary clarifier at Xi'an fourth wastewater treatment plant (A^2/O), was inoculated into the reactors with a mixed liquor volatile suspended solids (MLVSS) concentration of 6.4 g/L. The chemical compositions of synthetic wastewater fed to the reactors were as follows: COD (chemical oxygen demand, as glucose) 800 mg/L; NH_4^+-N (ammonia nitrogen, as ammonium chloride) 160 mg/L; $MgSO_4 \cdot 7H_2O$, 25 mg/L; $FeSO_4 \cdot 7H_2O$, 20 mg/L; $NaHCO_3$, 600 mg/L; KH_2PO_4, 25 mg/L; $CaCl_2 \cdot 2H_2O$, 30 mg/L; $FeCl_3 \cdot 6H_2O$, 1.5 μg/L. The composition of the trace element solution was derived from previous literature (Liu et al., 2016).

Commercial grade PAC (Gongyi Fuyuan Water Purification Materials Co., purity: 30% w/w Al_2O_3, China) was applied in this study and the performance of the PAC dosing has been described in Liu et al. (2016): after each drainage, 50-mL fresh PAC solution with a concentration of 20 g/L was pumped into the SBR (with 500-mg/L PAC inside), and the suspensions were homogenized by an aquarium air pump; meanwhile, the stirrer was switched on and operated at a speed of 100 rpm for 5 min; then, slow mixing at 50 rpm for another 5 min followed and the aeration idled. In the control (SBRCon), the same manipulations were also conducted except for the PAC dosing.

Table 1
Detailed operational conditions of the sequencing batch reactors.

Time (d)	SBRSap		SBRStp		SBRCon	
	PAC[a]	Settling[b]	PAC	Settling	PAC	Settling
1–7	+	15–5	−	15–5	−	15
8–14	−	5	+	5	−	15
15–35	−	5	−	5	−	15

[a] PAC dosing (+: applied; −: no appliEd.).
[b] Settling time (15–5: decreased from initial 15 to 5 min during 7 days; 5: fixed at 5 min; 15: fixed at 15 min).