The Influence of Aluminum on the Flocculation of Activated Sludge with Different Concentrations

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Abstract. The mechanism governing the flocculation of activated sludge (AS) with different concentrations of aluminum was studied in this paper. The AS samples were cultivated in sequencing batch reactors at 22 ℃. The sludge retention times (SRT) was 15 d. The dosages of Al^{3+} were 0.00, 0.0625, 0.125, 0.250, 0.500, 1.00, 2.00 and 4.00 meq/L. The experimental results indicated that the dosage of Al^{3+} could enhance sludge flocculation, but deteriorate sedimentation. It was also found that as Al^{3+} dosage (≤ 2 meq/L) increased, the total interaction energy, and loosely bound extracellular polymeric substances (LB-EPS) content decreased, indicating that the dosage of Al^{3+} could enhance sludge flocculation.

Introduction

Activated sludge (AS) systems are the most widely used biological wastewater treatment process. The quality of effluent has a close relation to the efficient solideliquid separation. Al^{3+} is the most common flocculant in wastewater treatment. The flocculation of activated sludge is affected by physical, chemistry and biological factors [1]. All theories about intermolecular force can be used to explain the binding of AS entities such as polymer bridging, Derjaguin–Landau–Verwey–Overbeek (DLVO) theory, hydrophobic interactions, multivalent bridging theory, and steric interactions [2,3,4].

The DLVO theory, named after its developers, Derjaguin, Landau, Verwey, and Overbeek, is a classical colloidal theory that describes charged particles as having a double layer of counterions surrounding the particle. It is often used to interpret colloid stability and to describe the microorganisms and AS flocculation [3]. EPS, which accounts for about 80% of the dry weight of AS, mainly consists of polysaccharide, protein, nucleic acid and humic compounds [4]. It plays an important role in the ion bridging theory. Researchers found that the interior layer of the EPS was tightly bound EPS (TB-EPS), which had a certain shape and stuck to the cellular surface closely and stably, whereas the exterior layer of the EPS was loosely bound EPS (LB-EPS), which was a loose and dispersible slime layer and had no clear boundaries [5]. EPS also play an important role in maintaining AS floc structure and function. Therefore, most researchers believed that EPS was the main influence factor of AS flocculation performance.

In the study, all the reactors were controlled at a solid retention time (SRT) of 15 days, and Al^{3+} was added to AS with different dosage. The mechanism governing the flocculation of activated sludge (AS) was studied.

Materials and Methods

The activated sludge (AS) used in this study were cultivated in sequencing batch reactors (SBRs), and each of them had a volume of 4 L. The reactors were seeded with activated sludge (approximately 2500 mg/L) from Qu Yang WWTP in Shanghai, China. Temperature was maintained at 20±1 ℃. The activated sludge was collected for the experiments on the condition that the fluctuation of these parameters such as the COD, turbidity and SVI in the effluent was less than 20%. All the activated sludge samples were wasted during the last 10 min of the aeration phase, which guaranteed the SRT is 15 d.

Eight AS samples, each of which had a volume of 100 mL, were collected separately from 8 SBRs, and each of the AS samples was placed in a 250-mL beaker. Then, the 8 AS samples underwent a two-step flocculation process: rapid mixing with a stirrer at a speed of 117 rpm for 5min, followed by slow mixing at 50 rpm for 5 min; the operational conditions were identical for the 8 beakers. After flocculation, the bulk solution, LB-EPS, TB-EPS, and the pellet were extracted as follow methods.

The stratification structure and extraction protocol for the AS in this study were modified based on previous research [6]. A 25-mL sample of sludge suspension was centrifuged at 4000 g for 5min at 4 ℃, and the supernatant that was carefully collected was the bulk solution. A NaCl solution with the same conductivity as the AS sample was prepared and preheated to 70 ℃; then, it was used to re-suspend the AS material in the tube at its original volume before the bulk solution was removed. With no delay, the AS suspension was sheared by a vortex mixer for 1 min; then, it was centrifuged at 4000 g for 10 min at 4 ℃, and the supernatant was collected as LB-EPS. The AS sample left in the tube was resuspended again to its original volume of 25mL with the NaCl solution and then put in a water bath at 60 ℃ for 30 min. It was centrifuged again at 4000 g for 15 min at 4 ℃ and the supernatant collected was TB-EPS, and the AS sample left was the pellet.

Results and discussion

The influences of aluminum on the flocculation-related characteristics of AS. The influence of aluminum on the flocculation-related characteristics of AS are listed in Table 1. The effluent turbidity clearly declined as the Al^{3+} dosage increased. However, when the dosage of Al^{3+} continuously increased, the decrease rate declined. When the Al^{3+} dosage was 2 meq/L, the effluent turbidity reached a minimum (2.72±0.23 NTU). Then the dosage of Al^{3+} reached 4 meq/L, the effluent turbidity increased (3.69±0.13 NTU). This indicates that Al^{3+} dosing can improve activated sludge flocculation effectively, however, over added lead to the decline of flocculation.

Table 1-The influence of aluminum on the flocculation-related characteristics of AS

	Concentration of aluminum(meq/l)							
	0	0.0625	0.125	0.25	0.5	1	2	4
Mean floc size [D(1, 0)] (lm)	78.8±9.4	82.8±5.6	80.1±2.1	80.6±3.4	80.7±5.3	89.6±7.3	107.5±3.2	130.5±2.5
Supernatant turbidity (NTU)	9.77±0.54	5.52±0.23	4.41±0.68	4.14±0.23	3.83±0.12	3.61±0.22	2.72±0.23	3.69±0.13
SVI (mL/g)	76.6±4.5	79.9±2.4	83.6±3.5	84.1±6.4	84.3±2.3	91.9±8.3	111.1±1.3	95.8±9.2

When the Al^{3+} dosage was lower (0.25 and 0.5 meq/L), the increase of SVI was slight (only 10 % increased). Moreover, as the dosage of Al^{3+} increased, the SVI was with with a sharp increase. When the Al^{3+} dosage was 4 meq/L, the SVI was significantly lower than the dosage was 2 meq/L, which was only 25 % increased than no Al^{3+} added. Though the lower dosage of Al^{3+} has little influence on sludge sedimentation, the Al^{3+} dosage can deteriorate the sludge sedimentation.

The influence of total interaction energy on AS flocculation. The total interaction energy curves of AS with different dosage of Al^{3+} was shown in Fig.1. Without the dosage of Al^{3+}, the was the highest (696 KT). As the Al^{3+} dosage increased, the total interaction energy declined. When the Al^{3+} dosage exceeded 0.5meq/L, the total interaction energy became negative, which has the similar trend with the effluent turbidity. This finding indicates that when the Al^{3+} dosage was lower than 2 meq/L, the decrease of the total interaction energy can improve activated sludge flocculation. However, when the dosage increased to 4 meq/L, the decrease of the total interaction energy could not improve activated sludge flocculation (Table 1).

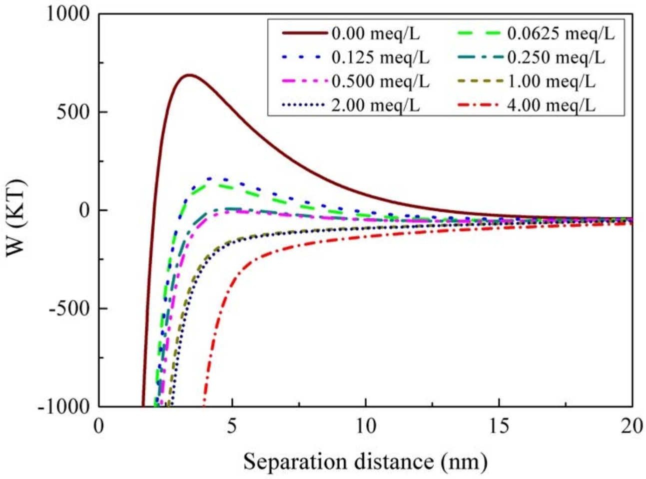

Fig. 1. The total interaction energy curves of AS with different concentrations of aluminum as additives.

The influence of LB-EPS content on AS flocculation. The influences of aluminum on the TOC contents in different parts of the AS was shown in Fig.2. The LB-EPS was declined with the dosage of Al^{3+} increased, which was the same as TB-EPS. When the Al^{3+} dosage was extremely low (0.0625 meq/L), the LB-EPS has an obviously declined (9 % reduction). When the Al^{3+} dosage was 2 meq/L, the reduction of LB-EPS and TB-EPS was 36 % and 8.4 %, respectively. When the Al^{3+} dosage reached 4 meq/L, the reduction of LB-EPS was 59 % and the TB-EPS was 42 %, which was much higher than other dosage of Al^{3+}. With the Al^{3+} dosage, the reduction in LB-EPS was obviously higher than that in TB-EPS, which was opposite with the effluent turbidity. This suggests that when the dosage of Al^{3+} was not over added, the reduction of LB-EPS can improve the sludge flocculation.

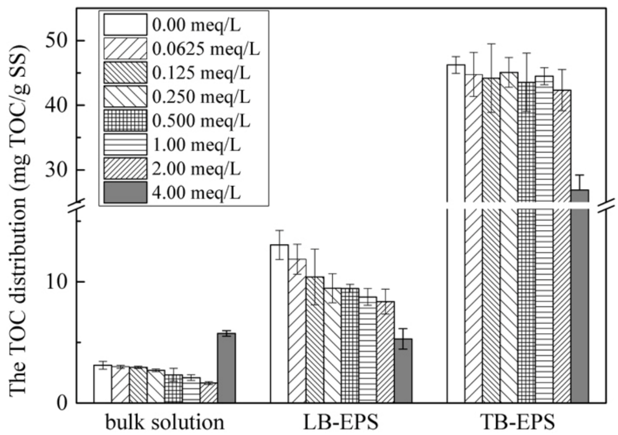

Fig. 2. The influences of aluminum on the TOC contents in different parts of the AS.

Conclusions

The present study examined the effects of Al^{3+} dosage on sludge flocculation and sedimentation. The main conclusions are outlined as follows:

i) Activated sludge flocculation and turbidity removal improved with the increasing Al^{3+} dosage, but sludge sedimentation deteriorated. The SVI values increased sharply as the dosage increased from 1 meq/L to 2 meq/L.

ii) The EPS content and interaction energy of AS reduced in gradient as the dosage of Al^{3+} increased, which suggested that Al^{3+} could improve AS flocculation.

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