Effects of Extracellular Polymeric Substances on Sludge Properties

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Extracellular polymeric substances (EPS) represent the complex high-molecular-weight mixture of polymers excreted by microorganisms generated from cell lysis as well as adsorbed inorganic and organic matter from wastewater. EPS exhibit a three-dimensional, gel-like, highly hydrated matrix that facilitates microbial attachment, embedding, and immobilization. EPS play multiple roles in containments removal, and the main components of EPS crucially influence the properties of microbial aggregates, such as adsorption ability, stability, and formation capacity. Moreover, EPS are important to sludge bioflocculation, settleability, and dewatering properties and could be used as carbon and energy sources in wastewater treatment.

extracellular polymeric substance wastewater microbial aggregation sludge contaminant carbon source

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1. Introduction

The activated sludge process is widely used, and the production of waste sludge is an inevitable drawback inherent in the system. Serious pollution problems will be caused if large quantities of waste sludge are not appropriately treated and disposed of [1]. During sludge treatment, sludge settling and dewaterability are the main obstacles faced by wastewater treatment plants [2]. Extracellular polymeric substances (EPS) are the important components of activated sludge and play a specific role in sludge bioflocculation, settling, and dewatering properties [3].

2. Effects of Extracellular Polymeric Substances on Flocculation Ability

The flocculation ability of microbial aggregates is essential to achieve high quality and low turbidity in effluent. The effects of shear rate on the floc size distribution and the correlation between flocculation dynamic parameters (such as collision efficiency and breakage rate coefficient) and velocity gradient have been investigated widely in previous studies. In fact, the zeta potential of flocs and the organic matter contents of EPS are also important for activated sludge flocculation [3][4][5][6][7]. Bioflocculants, such as microbial EPS, are natural organic macromolecule substances, flocculating suspended bacterial cells, solids, and colloidal solids [8]. The highly hydrated gel matrix produced from EPS keeps the cells together [9], while the interactions between EPS and cells have significant effects on microbial flocculation ability, showing EPS of flocs as the key factor [10]. Adding a certain dose of LB-EPS or TB-EPS to the sludge solution after EPS extraction could induce the aggregation of sludge, and the aggregation capacity of sludge was restored to more than 80% [5][6][7].

The flocculation ability of microbial aggregates decreases with the total EPS increasing and increases with protein contents increasing or humic substance contents decreasing [11]. Proteins constitute more than 43% of the total amount of EPS, while humic substances constitute 15–42% [11]. However, no obvious relationships were found between nucleic acid and sludge characteristics. Proteins and polysaccharides in EPS significantly affected the flocculability of sludge, and the sludge had good flocculability when the proteins and polysaccharides in EPS were less than 21.55 and 12.27 mg/g VSS, respectively [12]. Thus, the proportion of the main EPS components might have effects on microbial flocculation [13]. Xing et al. also emphasized that EPS easily extracted were more beneficial for flocculation. Some studies reported that the concentration of EPS was an important influencing factor for bioflocculation [14], and too high or too low a concentration of EPS would lead to a reduction in flocculation activity [15]. Recently, studies have demonstrated that the spatial distribution of EPS also affected the bioflocculation, settling, and dewatering properties of activated sludge [16].

EPS promote or bate cell aggregation with flocculation and settling. The flocculation dynamic parameters are linearly correlated with the EPS content and zeta potential. The floc size will gradually increase, while the flocculation balance factor will decrease with increasing EPS content or decreasing absolute values of the zeta potential. Although high EPS favored large flocs aggregation, the flocs containing high EPS were more prone to large-scale fragmentation [17]. Although EPS was essential to biofloc formation, excessive EPS in the form of LB-EPS would weaken cell attachment and deteriorate the activated sludge floc structure, thereby resulting in poor biosolid–water separation [18].

It was reported that both LB-EPS and TB-EPS substantively affected sludge aggregation, but the contributions to sludge aggregation were different [4]. LB-EPS fraction did not play an important role in bioflocculation, but the active part (i.e., TB-EPS fraction), considered to be the most active fraction in wastewater-activated sludge, was responsible for the high flocculation rate [19]. Similarly, Bezawada et al. found that TB-EPS demonstrated the highest flocculation activity and dewaterability compared to LB-EPS [15], due to the presence of a large number of macromolecules (330–1200 kDa) and trivalent cations [19].

3. Effects of Extracellular Polymeric Substances on Settling Ability

Sludge settling properties are often regarded as the bottleneck in terms of upgrading or increasing the capacity of wastewater treatment plants [20]. The number of EPS was more important to the sludge settleability than the composition [19]. Some studies reported that sludge settled faster with lower EPS [21], whereas others reported the opposite [22]. Poxon and Darby [23] revealed that EPS contained a high proportion of bound water, producing highly porous sludge flocs with lower density, leding to poor sludge settleability. In addition, the increasing EPS concentration enhanced the cell surface charge and then increased the repulsive forces among cells, generating a decrease in activated sludge settleability [4].

The various components of EPS have different effects on the settling ability of activated sludge. The production of highly porous flocs with low density due to the increase of LB-EPS could induce irreducible water into the aggregates [18], expressing the negative effects on sludge settleability. However, the effects of the major components of EPS on the settleability of microbial aggregates are not clear. Proteins in EPS were found to have a positive relationship with SVI [24], but carbohydrates had no significant effects [25]. Additionally, no significant correlation had been observed between SVI and nucleic acid [12].

4. Effects of Extracellular Polymeric Substances on Dewatering Ability

Dewatering is a crucial process in sludge treatment and involves significant technical challenges. Reducing the water content of sludge cake is proven to be an efficient method of decreasing transportation and disposal costs. However, the highly hydrated and negatively charged EPS in sludge colloids can bind a large volume of water, i.e., bound water, within the sludge flocs and affect the charge and stability of the flocs. EPS are usually regarded as the key factor in the thickening and dewatering process of sludge [26][27]. There are two binding mechanisms of EPS and water molecules, including electrostatic interactions and hydrogen. The former played a major role in the permanent dipole of the water for the functional groups of EPS, and the latter rose the main function in hydroxyl groups of EPS and water molecules [28]. All these prevent sewage sludge from dewatering.

In general, the reason why the increase in EPS results in poor sludge dewatering ability may be that the steric resistance generated by EPS prevents contractions among cells. The macromolecules in EPS cause a large amount of water retained in the sludge floc and increase the amount of interstitial water. EPS can also form a stable gel preventing water seepage from the pores of flocs, which deteriorates the dewatering ability of the sludge [29]. Ni et al. reported that aerobic digestion increased dissolved EPS and reduced the sludge dewatering ability [30]. The effects of EPS on sludge dewatering ability may be related to the EPS contents and components. A previous study has shown that proteins with high water-holding capacity may induce an increase in dissolved EPS [31]. Therefore, the purpose of improving sludge dewatering ability can be achieved by reducing the protein portion in sludge EPS [32]. In addition, increasing the proportion of carbohydrates in EPS also would enhance the sludge dewatering [32]. Zhang et al. found that the proteins and polysaccharides in EPS may control dewaterability, and the sludge had good dewatering ability when the proteins and polysaccharides in EPS were no more than 21.55 and 12.27 mg/g VSS, respectively [12]. However, some studies have shown that with the increase of EPS content, the sludge dewatering ability improves [31]. Thus, the interaction of EPS and the dewatering ability of sludge needs to be further studied in the future, and the specific role remains elusive so far.

EPS can also be used by sludge flfloc as sources of carbon and energy in wastewater treatment. Short-chain fatty acids (SCFAs), generated from waste activated sludge (WAS) [33], have been considered a good carbon source needed for biological nutrient removal [34]. Enhancing SCFA production from WAS fermentation can substantially reduce the cost of biological nutrient removal and effectively reduce WAS volume. Recently, the relation of EPS with sludge reduction has been examined. Zhao et al. indicated that EPS in sludge were the main matrix to produce SCFAs supplying energy to sludge and helped to achieve sludge reduction [35]. However, the specific mechanism and process are still unknown and limited research is available.

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