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Effects of short-time aerobic digestion on extracellular polymeric substances and sludge features of waste activated sludge

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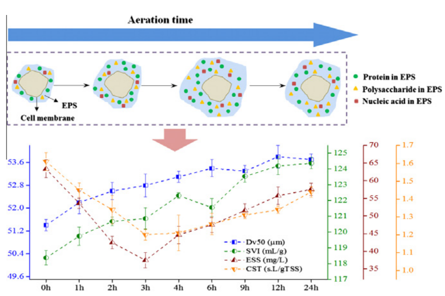
HIGHLIGHTS

- Effects of short-time aerobic digestion on EPS and sludge features were ascertained.
- Both EPS concentration and sludge floc size increased with extending digestion time.
- Sludge settleability gradually became poor during the aerobic digestion process.
- Short-time aerobic digestion could promote sludge flocculability and dewaterability.
- Sludge features showed close relations to proteins and polysaccharides in EPS.

GRAPHICAL ABSTRACT



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ABSTRACT

Aerobic digestion is an important stabilization process for waste activated sludge. However, extended aerobic digestion consumes substantial oxygen and increases the running cost (oxygen demand and sludge production) and CO_2 emission. To tackle these issues, this study investigated the effects of short-time aerobic digestion (STAD) on microbial extracellular polymeric substances (EPS), sludge features, and their correlations. The levels of proteins and polysaccharides in EPS consistently increased as the aerobic digestion time increased. Nucleic acid in EPS increased only within the first 4 h and then decreased. With an extended digestion time, sludge floc size (Dv50) increased by 4.67%, and the sludge volume index (SVI) increased by 5.06%, indicative of a deteriorating settleability. The sludge after STAD exhibited better flocculability and dewaterability than that after the prolonged aerobic digestion. Proteins and polysaccharides in the EPS significantly correlated with Dv50 ($R^2 = 0.97$, $P = 0.00$ and $R^2 = 0.92$, $P = 0.00$, respectively), SVI ($R^2 = 0.88$, $P = 0.00$ and $R^2 = 0.93$, $P = 0.00$, respectively), effluent suspended solids (ESS, $R^2 = 0.68$, $P = 0.01$ and $R^2 = 0.82$, $P = 0.00$, respectively) and the normalized capillary suction time (CST, $R^2 = 0.66$, $P = 0.01$ and $R^2 = 0.78$, $P = 0.00$, respectively). No significant correlation

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was found between nucleic acid and these sludge features. These results indicated that proteins and polysaccharides in EPS may govern sludge floc size, settleability, flocculability and dewaterability. Interestingly, good sludge flocculability and dewaterability were observed when the proteins and polysaccharides in EPS were lower than 21.55 and 12.27 mg/g VSS, respectively.

1. Introduction

Activated sludge process is a common biological process used in municipal and industrial wastewater treatment plants (WWTPs) [1]. One of the drawbacks of this technology is that a significant amount of waste activated sludge (WAS) is produced during the process. According to the China National Information Infrastructure (CNII), the yield of wet sludge (water content 80%) in urban sewage treatment plant reached 33.59 million tons per year, that is, 92 thousand tons per day [2]. WAS generally contains pathogenic organisms, toxic organic substances and heavy metals, and inorganic nutrients such as phosphate and ammonium, which threats the environment and public health [3]. Therefore, it is imperative to develop effective disposal processes for WAS to meet the stringent environmental regulations [4].

Anaerobic and aerobic digestion processes are the two main biological treatment methods for the stabilization and reduction of WAS [5]. Anaerobic digestion is commonly used in large-sized WWTPs to convert WAS to biogas (e.g., methane or hydrogen) or value-added products (e.g., organic acids) [6]. On the other hand, aerobic digestion is applied in medium-sized and small-sized WWTPs for economic considerations [7]. As a promising process for sludge treatment, aerobic digestion has been received extensive attention in recent years due to the short sludge retention time, fast degradation rate and efficient pathogen inactivation [8]. In aerobic digestion, organic matter is oxidized and products such as carbon dioxide, nitrate and phosphate are generated with release of heat [9]. In addition, aerobic digestion of activated sludge is known as a stabilization process in which biologically stable products are produced and both the sludge mass and volume are reduced. Up to the end of 2014, 1808 WWTPs were in operation in China and over 70% of them were medium- and small-size plants with the processing capacities of wastewater lower than 10 thousand tons per day [2]. Accordingly, aerobic digestion process could be a better choice for the treatment of WAS in WWTPs due to its economy and practicability.

Previous studies reported that aerobic digestion could significantly affect the WAS properties or features that influence settleability, flocculability, dewaterability and the downstream treatment efficiency. Murthy and Novak [10] found that aerobic digestion caused poor dewatering properties and increased biopolymer content. Murthy and Novak [11] also found that aerobic digestion reduced sludge dewaterability due to the increase of dissolved extracellular polymeric substances (EPS). Murthy and Novak [10] reported that the increase of dissolved EPS during aerobic digestion was mainly caused by the increase of proteins, similar to anaerobic digestion. Moreover, the increase of dissolved EPS could also be attributed to carbohydrates [9]. Thus, the dewaterability of aerobically digested sludge may depend on the interplay of dissolved EPS and carbohydrates, which remains elusive so far. Liu et al. [12] have employed the classical Derjaguin–Landau–Verwey–Overbeek (DLVO) theory to describe the *Rhodopseudomonas acidophila* flocculation, and they reported that the surface characteristics of *R. acidophila* could be changed and its flocculability might be improved by manipulating the content and component of bacterial EPS. Most of the studies focused on the effects of EPS on WAS properties in long-time aerobic digestion. A large amount of oxygen required by the long-time digestion will increase the cost of sludge treatment and disposal. Short-time aerobic digestion (STAD), which can markedly decrease the demand of oxygen, would be a more economically viable sludge treatment. However, it is difficult to apply the STAD process to the sludge treatment when few characteristics of the process are known.

To understand the characteristics of the STAD process for the sludge treatment, this study investigated the effects of STAD on EPS and WAS features, including flocs size, settleability, flocculability and dewaterability, and further analyzed the correlations between EPS and these sludge features.

2. Materials and methods

2.1. Sludge samples and aerobic digestion reactor

The WAS samples used in the aerobic digestion system were the secondary settling tank return sludge from a full-scale municipal WWTP in Shanghai, China. Anaerobic–anoxic–aerobic process was applied in the WWTP with a capacity of 60,000 m^3/d. After gravity concentration of the sludge, its main parameters were as following: pH 6.8–7.5, total suspended solids (TSS) 9.0 ± 1.0 g/L, and the ratio of volatile suspended solids to TSS (VSS/TSS) 65 ± 8%. Sludge samples were stored at 277.15 K and used within 2 d.

A 6.0-L (Φ12 cm × 53 cm) plastic cylindrical barrel was used as the aerobic digestion reactor and placed on an accurate strengthen electronic stirrer (JJ-1, Changzhou, China). The effective volume of the reactor was 5.0 L. The sludge in the reactor was well mixed at 300 rpm. The reactor was continuously aerated from the bottom through a microporous aeration disk to maintain dissolved oxygen (DO) of 2–3 mg/L. Schematic of the reactor can be found in Fig. 1. The experiments were carried out under room temperature

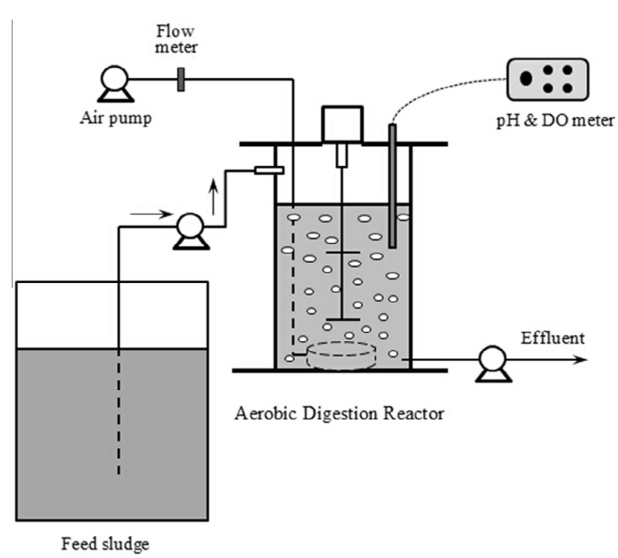

Fig. 1. Schematics of the aerobic digestion process.