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Novel insights into destruction mechanisms in a hybrid membrane process for simultaneous sludge thickening and digestion by characterization of dissolved organic matter

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ABSTRACT

Three-dimensional excitation–emission matrix (EEM) fluorescence spectroscopy and gel filtration chromatography (GFC) were employed to characterize dissolved organic matter (DOM) in a hybrid membrane process for simultaneous sludge thickening and digestion (MSTD). The MSTD process was operated under a sequencing batch mode, and the operating time of each cycle was 15 d from the initial fresh sludge to the final thickened and digested sludge. Results showed that the molecular weight (MW) distribution of DOM in sludge supernatant became broader after the MSTD process, and three main peaks including Peak A and Peak B related to protein-like substances and Peak C associated with humic acid-like substances could be identified from the EEM fluorescence spectra of all DOM samples in the MSTD process. The quantitative analysis of the fluorescence spectra of DOM in sludge supernatant showed that the fluorescence intensity (FI) of Peak A and Peak B in sludge supernatant correlated well with the concentration of soluble protein, MLSS destruction efficiency and mean particle size, suggesting that the variations of EEM fluorescence spectra of DOM in sludge supernatant could be used to evaluate the floc destruction mechanisms of the MSTD process. It was also found that the FI of Peak A slightly increased before 8 d but rapidly went up after 8 d, and the FI of Peak B changed slightly before 8 d but increased after 8 d, which implied that the floc destruction mechanisms were varied in one cycle of the MSTD process.

1. Introduction

In China, the amount of waste activated sludge (WAS) generated from the municipal and industrial wastewater treatment practices has increased in recent years due to the expansion of wastewater, the increase of wastewater treatment plants (WWTP) and the advancement of treatment technologies. Before ultimate disposal of WAS such as sludge landfill, it should be firstly pretreated in the WWTP to realize the reduction in volume and mass. In general, thickening or dewatering is practiced for volume reduction of WAS, and digestion is a common biological process for mass reduction of WAS [1,2].

In order to combine the thickening and digestion of WAS in a reactor, a hybrid membrane process for simultaneous thickening and digestion of WAS (MSTD) was proposed [3]. In the MSTD process, sludge thickening and digestion are achieved in the favor of the separation of membrane modules and microbial metabolism, respectively. It has been demonstrated that the MSTD process could simultaneously achieve over 30 g/L concentrated sludge and 45% mixed liquor volatile suspended solids (MLVSS) destruction efficiency [4,5]. Compared to the conventional sludge treatment processes, it has many advantages such as small footprint, high effluent quality and stable thickening efficiency due to the utilization of advanced membrane separation technology [3–5].

In previous studies, the destruction mechanism of MSTD process including floc destruction and cell lysis was investigated, and the results indicated that it was different from the mechanisms of conventional aerobic and anaerobic digestion [6]. The WAS in the MSTD process was likely treated under aerobic and anaerobic conditions in series due to the variations of dissolved oxygen (DO). The special destruction mechanism could ensure the MSTD process to achieve the destruction efficiency of approximately 50% with less operating time of 15 d compared to the conventional aerobic digestion with the SRT of more than 20 d, and it is very essential to understand the destruction mechanism prior to the application of the MSTD process. Therefore, more works are needed to better understand the destruction mechanisms of the MSTD process.

The stabilization mechanism of aerobic digestion is that the aerobic micro-organisms consume their own protoplasm to obtain energy for cell maintenance reactions, while the anaerobic micro-

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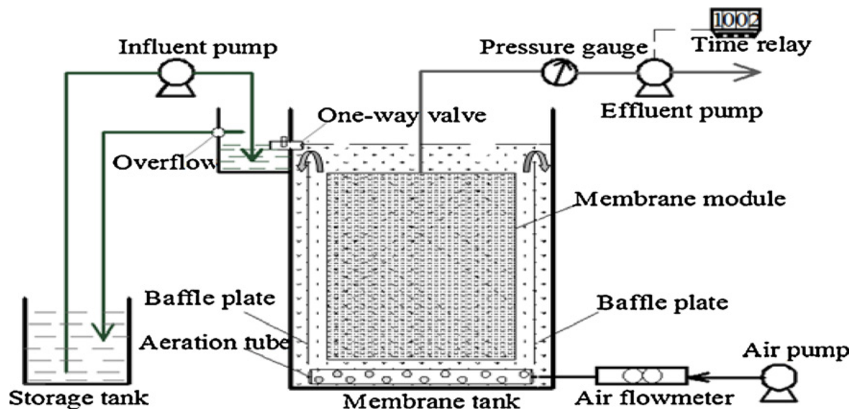

Fig. 1. Schematic flow diagram of the pilot-scale MSTD reactor.

organisms degrade the organic components in sludge and produce the biogas [7]. Both aerobic and anaerobic digestion will lead to sludge floc destruction and cell destruction or lysis. A sludge floc is a heterogeneous mixture of particles, microorganisms, colloids, extracellular polymeric substances (EPS) and cations [8]. Considering that such a large fraction of activated sludge comprises EPS, researchers have proposed that the fate of EPS in sludge digestion is a critical factor for evaluating the destruction mechanisms [9]. Since the EPS are crucial to the flocculation of activated sludge [6,10], the size of particles in activated sludge could be changed due to the deflocculation of the sludge flocs when the EPS were degraded under aerobic or anaerobic digestion conditions. Furthermore, a portion of biopolymers and cations will be released into solution under both aerobic and anaerobic digestion conditions accompanying the destruction of sludge flocs [9,11–13]. Based on the fact that the release patterns of biopolymers under aerobic and anaerobic digestion conditions are different, the concentrations and variations of biopolymers in supernatant could be used to distinguish the destruction mechanisms. Dissolved organic matter (DOM), of which the majority is soluble microbial products (SMP) originated from bound EPS, is ubiquitous in wastewater and sludge [14,15]. The supernatant DOM comprising the biopolymers of polysaccharides and proteins might be used to represent the soluble biopolymers. Thus, information on characterization of DOM obtained in aerobic and anaerobic digestion should be very useful for understanding the destruction mechanisms. To date, the report of using characterization of DOM to evaluate the destruction mechanisms could hardly be found in the literature.

The objectives of this research are, therefore, to investigate the destruction mechanisms of the MSTD process by the characterization of DOM. The DOM samples collected from a pilot-scale MSTD reactor were characterized by a three-dimensional excitation–emission matrix (EEM) fluorescence spectroscopy and a gel filtration chromatography (GFC).

2. Materials and methods

2.1. Experimental setup

The pilot-scale MSTD reactor with a total volume of 456 L (40 cm × 60 cm × 240 cm length × width × height) is shown in Fig. 1. Two flat-sheet membrane modules with a total membrane surface area of 1.46 m^2 were immersed in the reactor. The membrane modules were made of polyvinylidene fluoride (PVDF) with mean pore size of 0.20 μm. A complete description of the pilot reactor could be found in the previous papers [4,5].

The pilot-scale reactor was located in a municipal WWTP of Shanghai, which employs anaerobic/anoxic/oxic process to treat municipal wastewater (93% domestic and 7% industrial sewage). The influent sludge of the MSTD process was directly pumped from an aerobic basin of the municipal WWTP, and the downstream process of the MSTD system was centrifugal dewatering. The properties of the influent sludge have been listed by Wang et al. [4] and Wu et al. [5]. Air was provided by a compressor, and the effluent filtered through membrane modules was obtained by suction pumps connected to the modules. The effluent flow rate and the transmembrane pressure (TMP) were monitored by a water flow meter and a pressure sensor, respectively. A water-level sensor was used for maintaining a constant water level in the reactor over the experimental period.

2.2. Operating conditions

The MSTD process was operated under a sequencing batch mode, and the operating time of each cycle was about 15 d from the initial fresh sludge to the final thickened and digested sludge. In every cycle, the influent sludge was pumped continuously, and the thickened sludge was not discharged until the end of the cycle. In order to maintain the hydraulic retention time (HRT) of the MSTD process at about 20 h, the flux of flat-sheet membrane module was kept constant at about 15 L/(m^2 h), and a suction cycle of 10 min filtration followed by 2 min pause was employed. In addition, the coarse bubble aeration intensity was kept at 6.0 m^3/h in order to achieve the superficial gas velocity of about 0.69 cm/s, and the chemical cleaning in-place procedure (0.5% (v/w) NaClO solution, 2 h duration) would be carried out if the TMP reached about 30 kPa during the operation. The temperature during the whole experiment was in the range of 20–25 °C.

2.3. Analytical methods

In each cycle, the water samples and sludge samples were collected from the effluent, sludge storage tank and the MSTD reactor every two days, respectively. The water samples were measured for chemical oxygen demand (COD), ammonia (NH_3–N), total nitrogen (TN) and total phosphorus (TP), and the sludge samples were monitored for mixed liquor suspended solids (MLSS) and MLVSS according to Chinese NEPA standard methods [16]. Particle size distribution of the sludge samples was determined by a Coulter Ls230 that measures particle size from 0.1 to 300 μm by laser diffraction, and the DO concentration in the reactor was measured everyday by a dissolved oxygen meter (Model YSI 58, YSI Research Incorporated, OH, USA).

DOM samples were obtained by filtering 100 ml collected samples of influent sludge, sludge in the reactor and membrane effluent through a filter paper with a mean pore size of 0.45 μm. The