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Dynamic changes in the characteristics and components of activated sludge and filtrate during the pressurized electro-osmotic dewatering process

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ABSTRACT

The performance and process of pressurized electro-osmotic dewatering (PEOD) technology for activated sludge (AS) were investigated. In PEOD process, a single pressure of 600 kPa only removed a small amount of free water and bound water in AS, whereas both kinds of water further decreased to 0.24 g g^{-1} dry solid and 0.25 g g^{-1} dry solid after the application of 50 V voltage at electrical compression (EC) stage. During the PEOD process, the loosely network structure was gradually ruined, and a quantity of narrow and parallel slits generated in dewatered AS at EC stage. The contents of organic matters in filtrate increased at all PEOD stages and humic acid-like organics formed at EC stage. Using the response surface method (RSM), the optimum dewatering conditions were determined as a combination of 401 kPa pressure and 50 V voltage, which gave a dry solids content and energy consumption of 41.90% (wt%) and 0.153 kWh per kg removed water.

1. Introduction

The dewatering and disposal of sewage sludge are essential in municipal wastewater treatment plants, accounting for approximately 50% of all costs in wastewater treatment. This high consumption is mainly caused by the high content of water in raw sludge. However, the removal of water from raw sewage sludge to a favorable level for the following transport and disposal processes is difficult because of the colloidal nature of particles and the gel-like structure of the sludge [1,2]. The commonly used chemical and mechanical methods are only efficient for the reduction of free water that has no interaction with sludge particles [2]. Indeed, the bound water, which is defined as an immobilized water that is bound chemically or physically (or both) onto the flocs or is held by the solid state either by sorption, is not fully separated from the sludge particles.

Pressurized electro-osmotic dewatering (PEOD) technology is considered as one of the most efficient electro-osmotic dewatering methods for enhancing dewatering efficiency, especially for the separation of bound water from sludge [3–6]. In PEOD technology, conventional pressure is combined with electric field to improve liquid/solid separation, increase the final dry solids content, and accelerate the dewatering process [7]. Due to the fixed negative surface charge at the sludge biosolids interface, an electrical double layer (EDL) yields on solid–liquid interface and constitutes an ionized mobile region on the liquid side. Under the effect of the electric field, the propagation of ionized mobile region is forced into flowing and subsequently drives the neutral liquid in the central channel via the molecular viscosity, promoting water displacement. Therefore, an electro-osmotic flow occurs [8].

The dewatering effect of PEOD is mainly influenced by applied voltage (or current) and pressure [4,9,10]. Increase in voltage results in a dryer sludge and a quicker dewatering speed. Increase in pressure has also been shown capable of improving the performance of PEOD. Ultimately, the application of higher voltage and pressure further enhances the dewatering efficiency of the PEOD, but increases energy consumption as well. The response surface method (RSM) has been recently used to investigate the main effects of the factors (voltage and pressure) on the dewatering efficiency and to determine the optimum operation conditions [7]. The combination of final dry solids content and energy consumption is treated as the response of the RSM, which provides the optimum conditions for such response. Using RSM, Mahmoud et al. [7] determined that the optimum dewatering performance for AS can be achieved at voltage of 40 V and pressure of 728 kPa.

In the PEOD system, both the electro-osmosis and electrophoresis depend on the surface charge of the sludge particles. The former drives the charged fluid of the diffusive double layer around the

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colloidal particles moving to the cathode, whereas the latter drives the colloidal particles transportation to the anode; water is electrolyzed at the electrodes [11]. Combining these electrokinetic effects, numerous changes would occur not only in the water content in the sludge, but also in the organic matters and metals. Tuan et al. [12] proposed that an application of electric field could induce the migration of negatively charged organic matter from the cathode to the anode, and thus, the filtrate at the anode contained higher levels of COD and total organic carbon (TOC), whereas lower levels of COD were observed at the cathode. Hwang and Min [9] and Tuan et al. [13] noticed a decrease in the content of heavy metal (Zn, Mn, Pb, Cd, and Ni) in the sludge after electro-dewatering. Moreover, the microorganisms in the sludge, such as coliform [14], can be inactivated by the application of electric field, as confirmed by Huang et al. [15].

Most studies on the PEOD process have focused on its performance and the corresponding operating conditions. Indeed, the use of an electric field is the main cause for the enhanced dewatering efficiency of sludge by reduction of bound water. However, the contribution of the PEOD process to the reduction of free water and bound water requires further quantitative investigation. Moreover, little attention has been paid to the changes in the inner structure of the sludge during the PEOD process caused by the decrease in the water content and the transitional distribution between free water and bound water. The change in the porosity of sludge has a significant influence on the dewatering flux of electroosmosis.

The current study investigates the dynamic changes in the characteristics and components of activated sludge (AS) matrix during the PEOD process under typical operational conditions. The differential scanning calorimetry (DSC) was used to investigate the variations in the distribution of free water and bound water in AS. The sludge samples after each PEOD stage were paraffin sectioned and the inner structure of the sludge was identified using micro-image and fractal methods. The results are expected to provide support for investigations on the performance and mechanism of the PEOD process.

2. Material and methods

2.1. Sludge samples

AS was sampled from a municipal wastewater treatment plant in Beijing, China, which treats 6.0×10^5 tons of wastewater daily by using an Anaerobic–Anoxic–Oxic (A^2/O) process. After sampling, AS was stored at 4 °C for a maximum five days to reduce its biochemical change. The main characteristics of AS are given in Table 1. In this study, due to the variability of original AS samples and the strong heterogeneity among different AS, each PEOD experiment was performed at least in triplicate using three or more AS samples that belonged to the same batch to ensure the reproduction of result. In addition, the volatile solids (VS), total solids (TS), chemical oxygen demand (COD) and soluble chemical oxygen demand (SCOD) of the sludge were measured with the standard method recommend by [16].

2.2. Experimental setup

Fig. 1 shows a laboratory scale setup for PEOD, which consists of a cylindrical laboratory filtration/compression cell (diameter of 70 mm and volume of 2 L) made of plexiglass, a DC power supply (DH1719A-4, Dahua Co., China), a beaker, and a precision balance (PL2002-IC, Mettler Toledo, Switzerland). In the filtration/compression cell, a compression piston made of Teflon was designed to compress the water from the anode side. The bottom of the cell was covered with a polypropylene filter cloth with a 5 μm aperture. A dimensionally stable anode was fixed on the bottom of the piston, and a perforated disk cathode was placed under the filter cloth and sieve plate. Titanium-coated mixed metal oxide was used as the electrode to prevent electrical chemical corrosion.

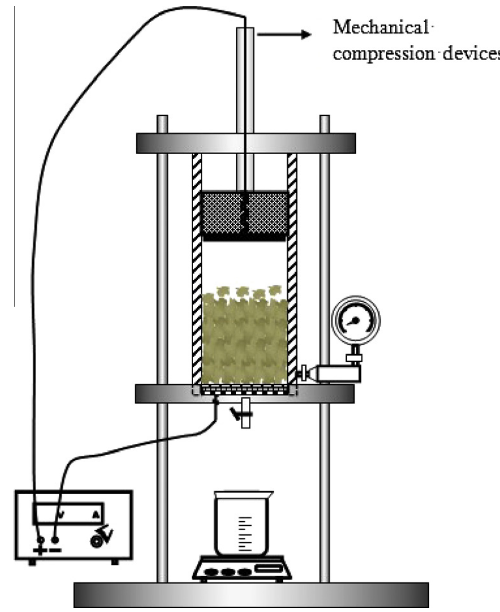

Fig. 1. Schematic representation of the laboratory-scale PEOD device.

2.3. Experimental procedure

2.3.1. Conditioning

The conditioning experiments were conducted using a six-paddle stirring apparatus (JTY-6, Tangshan Dachang Chemicals Ltd., China). The cationic polyacrylamide (CPAM) (WD4960, Shanghai Weidu Water Treatment Technology Ltd.) was employed as the flocculant, which had an average molecular weight of 20–25 MDa and a charge density of 60%. Prior to conditioning, 2 L of AS was maintained in open air to let it reach room temperature. Then, 1 L of AS (containing 8.34 ± 0.08 g dry solid) was transferred to a standard beaker and then 0.1% working solution of CPAM was added under agitation of 800 rpm. The mixture was subjected to rapid mixing for 1 min, followed by gentle agitation at 62 rpm for 5 min. The conditioned sludge was withdrawn from the beaker for the CST test. The optimum dose of polyelectrolyte was determined to be 4.00 (kg ton^{-1} dry sludge), at which the CST values of the conditioned sludge reached minimum. Then, conditioned sludge at the optimum dosage was decanted, and both the sediment and the supernatant or filtrate was weighed. The dry solids content in the dewatered AS and the water removal percentage were determined as follows:

Table 1
Characteristics of the AS samples.

Moisture content (%)	TS (g/L)	VS/TS (%)	pH	Conductivity (mS/cm)	CST (s)	COD (mg/L)	SCOD (mg/L)
99.11 ± 0.04	8.34 ± 0.08	67.97 ± 0.20	7.12 ± 0.02	1.39 ± 0.01	53.5 ± 3.10	6500 ± 510	1800 ± 290