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Sewage sludge drying method combining pressurized electro-osmotic dewatering with subsequent bio-drying

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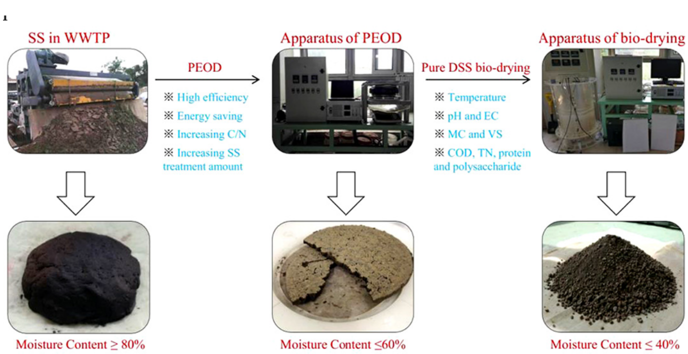
GRAPHICAL ABSTRACT



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ABSTRACT

In this study, pressurized electro-osmotic dewatering (PEOD) as a pretreatment process, instead of the conventional practice of adding bulking agents, for sewage sludge bio-drying was proposed. Initially, various parameters were optimized for obtaining dewatered sewage sludge (DSS), treated by an efficient, quick, and energy-saving PEOD process. The results show that the moisture content (MC) of sewage sludge could decrease from 83.41% to 60.0% within 7.5 min in the optimum conditions of the PEOD process. Subsequently, two DSS bio-drying tests were carried out to investigate the effects of inoculation. The highest temperature (68.1 °C) was obtained for T2 (inoculation), which was 3.6 °C higher than that for T1 (non- inoculation). The MC accumulative removal rate for T1 (41.49%) was slightly less than that for T2 (44.60%). Lastly, the volatile solid degradation dynamics model parameters were measured. The degradation rate constants (k) for T1 and T2 were 0.00501 and 0.00498, respectively.

1. Introduction

With the upgrading and expansion of wastewater treatment plants (WWTPs) in China, increasing amounts of sewage sludge (SS) are produced (Wu et al., 2015). Before final disposal, extended SS dewatering is often required because the moisture content (MC) of sludge cake after mechanical dewatering in most WWTPs in China is still as high as 80–85% (Cai et al., 2016). Recently, bio-drying processes have gained wide popularity, owing to their associated benefits, such as the hygienization of waste, their cost effectiveness and the conversion of waste into value-added products (Qian et al., 2014; Onwosi et al., 2017; Winkler et al., 2013). Bio-drying is a technology that aims to remove

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water from a material using the microbial heat originating from organic matter degradation (Cai et al., 2016). As such, bio-drying has been developed as an environmentally friendly and economical alternative method for treating solid, organic waste in recent years.

Mechanically dewatered sludge from WWTPs cannot be bio-dried alone, because its high moisture content and small particle size would cause poor gas permeability (Zhao et al., 2016). The conventional method to dry SS is to add bulking agents, such as straw, cotton wastes, sawdust, wood chips, and bio-dried product (Zhao et al., 2012; Cai et al., 2012; Gea et al., 2007; Iqbal et al., 2010; Yañez et al., 2009) to modify the properties of SS during bio-drying (Yuan et al., 2017; Iqbal et al., 2010). These bulking agents not only increase the cost of sludge disposal but also cause some trouble in sludge processing, such as it was difficult to collect and not likely to be reused (Zhou et al., 2014). In particular, problems arise in the utilization of bio-dried sludge for the manufacture of fired clay brick, which requires lower levels of organic matter in sludge. Apparently, it is necessary to develop a new strategy to treat dewatered sludge from WWTPs before the bio-drying process. Besides, SS resource utilization, such as in building materials, is needed to increase the amount of sludge treatment capacity and to avoid the addition of other materials to the sludge. Electrical dewatering, a new treatment method for sludge, has drawn attention due to its cost-effectiveness (Mahmoud et al., 2011) and the fact that is adds no additional chemicals to the sludge.

On the other hand, using conventional, mechanical dewatering methods, it is very difficult to reduce the water content of sewage sludge to 60%. While Visigalli et al. (2017) showed the fact that only some of the free water and the interstitial water in sludge could be removed by mechanical dewatering methods. In recent decades, some researchers combined electric fields with mechanical pressure to make better use of mechanical dewatering technology; this process is called pressurized electro-osmotic dewatering (PEOD) (Orsat et al., 1999; Nair et al., 2015). The PEOD process can decrease SS moisture content to approximately 60% with relatively low energy consumption. Mahmoud et al. (2011) concluded that the energy consumption of the PEOD process required less than 10% and 25% of that of the theoretical thermal drying process for the low and moderate voltage cases, respectively. As we all know, the solid content of SS impacts the efficiency of electrical dewatering when using the PEOD process. According to these experimental findings, solid content higher than 40% significantly improved energy consumption, while less than this percentage required relatively lower energy consumption (Conrardy et al., 2016; Zhang et al., 2017). Meanwhile, solids content of SS around 40% has viable idoneity in bio-drying. Therefore, it is speculated that PEOD combined with bio-drying, will be a new, cost-effective and environmentally-friendly technology for SS deep dewatering.

Many studies of the PEOD process mainly focus on the effects of operating conditions on energy consumption, such as different types of SS, electrical resistance analysis and industrial-scale applications (Visigalli et al., 2017; Mahmoud et al., 2011; Conrardy et al., 2016; Zhang et al., 2017). None of these studies worked on the application of the dewatered sludge after PEOD. On the other hand, there are many papers reporting that some important parameters have key roles in the bio-drying process, including the air-flow rate, turning frequency, aeration strategy, bulking agents, inoculation time, bacterial communities, temperature, and humidity (Cai et al., 2016; Zhao et al., 2012; Zhao et al., 2010; Zhang et al., 2015; Zhang et al., 2009). Currently, there are few reports of SS dewatering by PEOD and subsequent bio-drying, where the highest efficiency and energy savings will be achieved in the PEOD process, and bulking agents cannot be added in bio-drying.

The objective of this research is to evaluate the feasibility of SS dewatering by PEOD and subsequent bio-drying in a laboratory scale reactor. In preliminary tests, operating condition optimization was conducted for attaining the energy saving potential of the PEOD process. Subsequently, two DSS bio-drying trials (one with inoculation and one without inoculation) were monitored and compared regarding temperature, pH, electrical conductivity (EC), MC, and volatile solid (VS). Meanwhile, DSS biological degradability was analyzed for COD, total nitrogen (TN), protein, and carbohydrate during the bio-drying process.

Table 1
Characteristics of SS and inoculums.

Parameters	SS	Inoculums
Conductivity (ms/cm)	2.37	4.97
TS (%)	16.59	92.88%
VS/TS (%)	66.19	34.87%
TCOD (mg/kg_{TS})	882257.06	428931.9
SCOD (mg/kg_{TS})	73436.38	84221.25
TN	47880.11	592868.45
TAN (mg/kg_{TS})	10963.83	3414.79
Carbohydrates (mg/kgTS)	34978.47	663990.62
Scarbohydrates (mg/kgTS)	1398.50	76148.89

2. Materials and methods

2.1. Sludge samples and microbial inoculants

The SS sample used in the study was obtained from the Xianyanglu wastewater treatment plant (Tianjin, China) and stored at 4 °C before use. The bio-drying raw materials were of two types: one type was only DSS (T1), and the other was DSS with added microbial inoculants (T2). The microbial inoculants were taupe and powder-like and came from the Wuhan Water State Environmental Protection Technology Co., LTD (Wuhan, China). The main components of the microbial inoculants were bacillus subtilis (more than 10 billion per gram), yeasts, penicillium, and trichoderma. The bio-drying inoculation proportion was 5‰. The main characteristics of SS and inoculums are shown in Table 1. Because the DSS after PEOD was a cake with a diameter of 400 mm, the DSS was smashed and passed through an 8-mm mesh by mechanical means before bio-drying. There was some loss of moisture in the crushing process.

2.2. Apparatus

The experimental set-up used for SS dewatering by PEOD, as shown in Fig. 1, which had already been developed and described by Zhang et al. (2017). The features of the filter cloths are shown in Table 2.

The bio-drying experiments were performed in a column reactor (100 cm height, 40 cm internal diameter) made of PVC plastic, as shown in Fig. 1. Heat losses were reduced by a double-layer, vacuum insulation outer wall. A 100 mm high layer, filled with cobblestone (diameter about 5 mm), was placed at the bottom of each column for leachate drainage and air distribution. A whirlpool pump (XGB-8, Penghu Co., Shanghai, China) and a gas flow meter (LZB-10, Shanghai Instrument Co., Shanghai, China) were used for aeration of sludge floc and for adjusting the aeration flow. Temperature was monitored by a thermometer (WMY-01C, Huachen Co., Shanghai, China) with sensor probes located at the top, middle, and bottom points along the longitudinal axis of the column. The transient temperature for six minutes at a time was recorded on the PC.

During the 13-day bio-drying period, the pile was aerated intermittently (i.e., static for 20 min and aeration for 20 min at an aeration rate of 30 L/min at the bottom of the reactor), and it was mechanically turned (on day 3 in T1, and day 4 in T2). The ambient temperature was 23–32 °C.

2.3. Sampling and analytical methods

Every day, bio-drying samples (80 mg) were collected at the center