Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Novel electro-dewatering system for activated sludge biosolids in bench-scale, pilot-scale and industrial-scale applications

Shuting Zhang[a], *Zengjun Yang*[a], *Xuebin Lv*[a], *Suli Zhi*[b], *Yiwei Wang*[c], *Qian Li*[a], *Keqiang Zhang*[b,*]

[a] *School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China*
[b] *Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin 300191, China*
[c] *SJHY Environmental Protection Technology Co., Ltd, Changzhou 213018, China*

ARTICLE INFO

Article history:
Received 24 September 2016
Received in revised form 8 February 2017
Accepted 28 February 2017
Available online 8 March 2017

Keywords:
Electro-dewatering
Energy consumption
Processing capacity
Economic benefit

ABSTRACT

To optimize the economics of electro-dewatering system in a new multi-layer vertical electric field for activated sludge biosolids, different-sized experiments were carried out in this study, including bench-scale, pilot-scale and industrial-scale applications. A bench-scale system was established to determine the optimal parameters of the new structure, including the mechanical pressure level, dewatering extent, processing time and sludge cake thickness. Then, a pilot-scale automated electro-dewatering system was developed to investigate the cathode fouling problems during continuous operations. A complete industrial-scale electro-dewatering system was established with 80 t/d of sludge dewatering capacity based on the above work. The operational stability, the service life of the core parts and the economics were evaluated during a long time operating. Under various optimized parameters and control modes, 69% of the moisture in mechanically dewatered sludge could be reduced within 7–8 min. The average energy consumption was 0.123 $kWh/kg_{dewater}$ at 41 $kg_{dewater}/(m^2h)$ of anode processing capacity and the anode side temperature was lower than 65 °C, when the anode utilization efficiency was 88.2%. The industrial-scale tests with optimized parameters demonstrated considerable economic benefits.

1. Introduction

Disposing of sewage sludge is problematic for municipalities and industries (Clayton et al., 2006). Dewatering is a major problem related to sludge disposal (Citeau et al., 2016), and mechanical dewatering (MD) via filtration and compression is widely used in the fields of chemical and pharmaceutical production, mineral extraction and wastewater processing (Vaxelaire and Cézac, 2004). However, MD cannot achieve a sufficient solid content (only 15%–25% w/w) for many applications. Therefore, a number of studies have proposed potential alternatives to enhance the dewatering ability of conventional processes (Christensen et al., 2015). Electric field-assisted dewatering, which is also referred to as electro-dewatering (ED), is a high-efficiency, energy-saving and organic composition-maintaining method for sludge dewatering. ED is considered an advisable method after MD, especially for achieving the low moisture content range that MD cannot reach (Iwata et al., 2013).

A large number of studies have been conducted on ED, and they mainly focused on the operating factors and sludge properties, such as the mechanical pressure (Tuan et al., 2008), temperature (Navab-Daneshmand et al., 2015), polyelectrolyte (Saveyn et al., 2005), electrical conductivity (Turner, 1976), pH (Citeau et al., 2011), current density (Iwata et al., 2007), electric field intensity (Yukawa et al., 1971), electrical resistance (Conrardy et al., 2016), solid content (Li et al., 2007), time (Yuan and Weng, 2003), colloidal particle sizes (Sprute and Kelsh, 1981), and organics (Tuan and Sillanpää, 2010). However, few reports have focused on the commercial applications of ED. In a recent review of this

* *Corresponding author*.
E-mail address: keqiangzhang68@163.com (K. Zhang).
http://dx.doi.org/10.1016/j.cherd.2017.02.035
0263-8762/

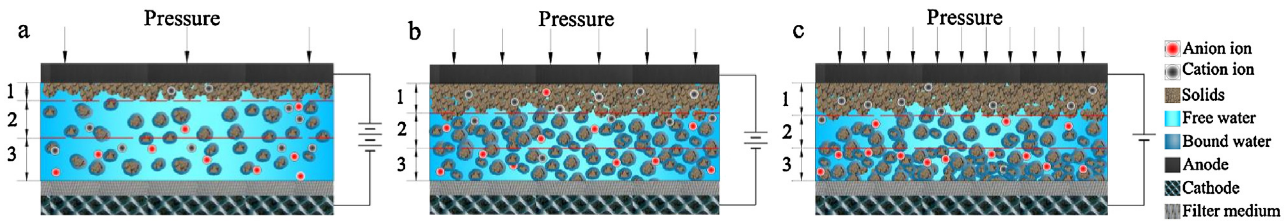

Fig. 1 – Typical sludge cake solids distribution characteristics during mechanical pressure/electric field force dewatering: large electric field intensity with small mechanical pressure (a) (Orsat et al., 1999); moderate electric field intensity and mechanical pressure with better dryness (b) (Tala et al., 2012); and large mechanical pressure with small electric field intensity with obvious characteristics of pressure dewatering (c) (Barton et al., 1999; Lee et al., 2007).

technology, Mahmoud et al. (2010) noted that certain problems inhibit the widespread commercialization of ED. The continuous application of an electric field is problematic because of its high energy consumption, which was even as high as that of thermal technology under non-optimal parameters. Additionally, ED requires corrosion-resistant electrodes which was costly. Therefore, we must better understand the key roles of ED parameters on the dewatering rate, dewatering extent and energy consumption for this process, which was viable at a large commercial scale.

In numerous experiments, the most widely used approach had been a combination of mechanical pressure and electric fields (Weber and Stahl, 2003; Feng et al., 2014), which was characterized by the following benefits: firstly, mechanical pressure caused sludge cakes to contact with the anode well; secondly, it forced water to flow rapidly from the filter medium (Gazbar et al., 1994); thirdly, it was able to compress gas layer to reduce the contact resistance (Mahmoud et al., 2010); and lastly, the isotropic pressure also reduced the water gradient layers of the sludge cakes. Different mechanical pressure levels combined with different voltages could result in different dewatering effects. However, there were relative limited studies on the combined devices of mechanical pressure and electric fields in previous research, which needs to be further investigated. In the study, the combined devices of mechanical pressure and electric field were divided into three categories. The first was typical ED assisted by mechanical pressure, which was represented by round roll-type ED equipment (Elode, ACE Incorporation, Korea, 1992) and characterized by high voltage and low pressure (Kondoh and Hiraoka, 1990). To achieve rapid dehydration and satisfactory moisture content, this type of ED must impose a higher voltage to compensate for the lack of pressure (only 0.1 bar or less) due to the mechanical components. And all of these factors induced excessive energy consumption and high temperatures in sludge cakes (Orsat et al., 1999). The solid distribution characteristics of dewatered sludge cakes for this type equipment are shown in Fig. 1a. Area 1 with high solid content was relatively thinner; areas 2 and 3 with high moisture content were thicker, showing obvious electro-dewatering characteristics. The second category was typical MD assisted by an electric field, represented by diaphragm-type ED equipment (Sound Group, China, 2015), which was characterized by high mechanical pressure (8 bar–24 bar) and weaker electrical intensity. The internal distribution diagram is shown in Fig. 1c. The thickness of the area 1 in Fig. 1c was greater than that in Fig. 1a; moisture contents were lower in areas 2 and 3 in Fig. 1c than that in Fig. 1a, and moisture content of area 3 was lower than that of area 2 in Fig. 1c. High pressure conserved energy in this system (Larue et al., 2001), however there were several problems such as the high filtration resistance, filter medium blocking and cathode fouling. The problems were difficult to effectively handle and the main obstacles that limit the development of diaphragm-type ED equipment. The third category was a combination of an appropriate mechanical pressure and electric field which could guarantee a thicker area 1 and low moisture in areas 2 and 3 (Fig. 1b). As a filter medium area, area 3 in Fig. 1b did not present obvious dewatering properties of mechanical pressure, which significantly reduced filter medium blocking (Lee et al., 2007). However, the devices such as Fig. 1b were scarcely reported, so the purpose of this study was to develop a moderate pressure ED system which used mechanical pressure in harmony with electric field force as shown in Fig. 1b. To be viable at a commercial scale of this system, in this study we further researched the key ED parameters including the dewatering rate, dewatering extent, energy consumption and economic benefits.

Table 1 – Physicochemical characteristics of the activated sludge biosolids.

Parameters	Measured values	Method
Dryness	16.1–18.2% w/w	105 °C, 24 h, oven
Volatile solids	55.3–61.5% w/w	500 °C, 1 h, muffle
pH	6.1–7.5	pH meter
Zeta potential	−19.2 to −14.3 mV	Zeta potential meter
Conductivity	2.3–6.1 mS/cm	Conductivity meter
Capillary suction time	384.5–415.8 s	CST tester
Particle size distribution	45–280, D_{50} 210 μm	Mastersizer 2000

2. Materials

2.1. *Sludge*

The activated sludge biosolids that were used in this study were obtained from a sludge blending tank of a power plant in Changzhou, China. The COD load of the sludge was approximately 40% from municipal sources and 60% from industrial sources (mainly printing and dyeing, pulp and paper, and food industries). The biosolids were obtained from 3 major waste water treatment plants (WWTPs) (Jiangbian WWTP, Chengbei WWTP, Xiyuan WWTP in Changzhou city, Jiangsu province, China), and mechanically dewatered by belt filter presses and centrifuges. The physicochemical characteristics of the sludge are listed in Table 1. A bench-scale test was performed in a laboratory of Tianjin University. This sludge was transported to the laboratory and stored at 4 °C before use. The pilot-scale and industrial-scale experiments were respectively performed in the yards and electro-dewatering workshop of the previously mentioned power plant.

2.2. *Core parts of the ED system*

2.2.1. *Anode*

The anode used in the study was IrO_2–Ta_2O_5-coated titanium anode, which was widely used in the chlor-alkali industry (Xu et al., 2009). It was produced by the thermal decomposition method to low the production costs. To prolong the anode service life, a coating thickness more than 10 μm and current density less than 650 A/m^2 were chosen. Moreover, the Ir/Ta ratio was appropriately adjusted. And nano IrO_2 grains were added to partly replace H_2IrCl_6 in the precursor solution, which increase the effective active points on anode surface. However, the concentrations of cyanide ions, fluorine ions and bromine ions which could corrode the titanium substrate,