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Performance of electro-osmotic dewatering on different types of sewage sludge

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ABSTRACT

The feasibility of pressure-driven electro-dewatering (EDW) on sludge samples taken after different biological processes, stabilisation methods or mechanical dewatering techniques was assessed. First, the influence of potential values on EDW of anaerobically and aerobically stabilised, mechanically dewatered, sludge samples was investigated. Preliminary tests carried out by applying a constant potential (10, 15 and 20 V) in a lab-scale device confirmed the possibility to reach a dry solid (DS) content of up to 42.9%, which corresponds to an increase of 15% of the dry content in dewatered sludge without the application of the electrical field. Dewatering increased with the applied potential but at the expense of a higher energy consumption. A potential equal to 15 V was chosen as the best compromise for EDW performance, in terms of DS content and energy consumption. Then, the influence of the mechanical dewatering was studied on aerobically stabilised sludge samples with a lower initial DS content: the higher initial water content led to a lower final DS content but with a considerable reduction of energy consumption. Finally, the biological process, studied by comparing sludge samples from conventional activated sludge and membrane bioreactor processes, didn't evidence any influence on EDW. Experimental results shown that DS obtained after mechanical dewatering, volatile solids and conductivity are the main factors influencing EDW. Anaerobically digested sludge reached the highest DS content, thanks to lower organic fraction.

1. Introduction

About half of the organic pollution load treated by the activated sludge process is oxidised and converted into water and carbon dioxide, while the remaining is converted into biomass, called "excess biological sludge" or "waste sludge". At present, this technique is the cheapest way to remove colloidal and soluble organic pollutants from sewage, but it produces a huge amount of liquid waste sludge, with a dry solid (DS) content of 2–5%, rich in organic substances, mostly biodegradable. Therefore, it needs further processes to reduce (i) its volume, by decreasing its water content, and (ii) its polluting potential, due to its high content of biodegradable organic matter. Mechanical dewatering (belt pressing, filter pressing, centrifuging, etc.) of sludge produced by wastewater treatment plants (WWTPs) hardly gets more than 20–25% DS content (Lee et al., 2002; Yang et al., 2011; Zhan et al., 2016). Therefore, the high dryness demanded for thermal valorisation of sludge cannot be achieved by mechanical techniques. Conventionally, thermal drying removes water from sludge to significantly higher degree than the best mechanical dewatering processes and sometimes it is considered a necessary step to reduce volumes of sludge to be transported and to increase its calorific value for incineration (Flaga, 2006).

Seeking new and efficient methods for dewatering, many authors (Yoshida, 1993; Barton et al., 1999; Gingerich et al., 1999) exploited electro-osmosis in order to improve water removal from sludge, being the resulting process usually defined as electro-dewatering (EDW). The application of an electric field, sometimes in combination with pressure, seems capable to increase the DS content in sludge up to 45%, much higher than the values commonly achievable by mechanical methods (Mahmoud et al., 2010; Weng et al., 2013; Feng et al., 2014). The high sludge dryness that is reached by the EDW process is a promising alternative to the thermal drying technique, thanks to the

Abbreviations: AS, Activated sludge; DC, direct current; DS, dry solids; DS,, dry solids at beginning of the test; DS,, dry solids at the end of the test; DSA®, Dimensionally Stable Anode, a registered trade mark of Industrie De Nora Milan; E, electric field (V/cm); EDW, electro-dewatering; MBR, Membrane bioreactor; P, pressure (kPa); PTFE, polytetrafluoroethylene; PTT, poly(trymethylene terephtalate); t_P, duration of pressure application (min); t_V, duration of potential application (min); TiMMO, titanium coated with mixed metal oxides; V, potential (V); VS, volatile solids; VS/DS, organic fraction of DS; WWTPs, wastewater treatment plants

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lower energy consumption involved. Sludge thermal drying indeed requires, at industrial scale, energies ranging from 617 $Wh/kg_{evaporated\ water}$ (the enthalpy of water vaporization) to as high as 1200 $Wh/kg_{evaporated\ water}$ (Olivier et al., 2014). On the contrary, depending on the potential and pressure values applied, EDW process is capable to reduce the energy consumption by 10–25% of the theoretical thermal drying energy (Mahmoud et al., 2011).

Although chemical-physical phenomena involved in pressure-driven EDW are not fully understood yet, many authors suggest that water is removed from sludge according to the following processes (Barton et al., 1999; Mahmoud et al., 2010; Mok, 2006):

(1) Applied pressure reduces the volume of the pores and squeezes out free water (if any);
(2) The charged particles (usually negative colloids) are still free to move in the fluid suspension. They tend to migrate towards the electrode carrying the opposite charge (usually the anode);
(3) When the cake has formed, the particles are locked in their position and hence unable to move; water is transported through the porous medium by electro-osmosis towards the cathode;
(4) Electrochemical reactions at the electrodes are essential to restore charge equilibrium;
(5) Finally, water ceases to be the continuous phase in the cake, and the electrical resistance rises, leading to ohmic heating; we should keep this effect at the lowest possible level, as it would lead to higher energy consumption, with very little increase in final DS content.

As a side effect, electro-migration may reduce the concentration of heavy metals in the sludge, as they tend to migrate towards the cathode, where water is collected (Mahmoud et al., 2010). As shown by Tuan and Sillanpää (Tuan and Sillanpää, 2010), EDW can also reduce the concentration of ions like Na^+ and K^+, which migrate towards the cathode, and organic matter (fatty acids and humus), which migrate towards the anode, in the sludge cake. Moreover, inactivation mechanisms of bacteria such as *Salmonella* spp., faecal coliforms, total coliforms and *Escherichia coli* have been investigated (Daneshmand et al., 2012; Huang et al., 2008). EDW seems to be efficient in inactivating bacteria thanks to the rise of temperature due to Joule effect, while the low pH plays a secondary role (Daneshmand et al., 2012). These effects may improve sludge quality for its use in agriculture.

Many experimental factors can influence the reduction of water content and, consequently, the process yield. The main critical processing factors affecting pressure-driven EDW are (i) the properties of the sludge, such as the ratio between volatile and dry solids (VS/DS), particle size distribution, zeta potential; (ii) process parameters, such as applied voltage (or current), temperature, pressure, process duration; (iii) chemical conditioning (Mahmoud et al., 2010, 2011).

Many authors (Feng et al., 2014; Mahmoud et al., 2011; Yuan and Weng, 2003; Tuan et al., 2008; Pham et al., 2010) investigated the influence of process parameters such as pressure, potential (or current) values, tests duration and cake thickness. Citeau et al. (2011) also studied the influence of polyelectrolyte type and dosing on EDW efficiency. However, so far the high variability of sludge samples produced by different WWTPs (in terms of DS, VS/DS, conductivity) prevented from building a general model capable of predicting EDW efficiency for all the sludge types. Therefore, further investigations are strongly required, especially in the view of developing prototypes for full-scale application.

In the present work, the parameters affecting pressure-driven EDW were investigated by means of a lab-scale device, using several types of sewage sludge, differing in biological processes, stabilisation methods or mechanical dewatering techniques. In preliminary tests, the EDW of anaerobically and aerobically stabilised, mechanically dewatered, sludges with similar initial DS content (DS_i) was studied. In detail, EDW performance on different sludge samples was compared, in terms of DS increase and energy consumption, at different potential values (10, 15 and 20 V), by keeping constant pressure and cake thickness. Later, the influence on EDW performance of the mechanical dewatering method, resulting in different DS_i values, was assessed. Finally, the influence of biological process was investigated by considering sludges from different WWTPs, comparing conventional activated sludge and membrane bioreactor (MBR) processes.

2. Material and methods

2.1. Sludge samples

Four different WWTPs around the metropolitan area of Milan were selected for this research. A preliminary sampling campaign was performed on these WWTPs to determine the average characteristics of produced sludges and to design the experimental activities.

Subsequently, preliminary pressure-driven EDW tests were performed by studying two different sludges: an anaerobically digested sludge, dewatered by centrifuge (sludge A), and an aerobically stabilised sludge, dewatered by filter press (sludge B), both originated by conventional activated sludge processes. The influence of stabilisation method on EDW was studied by treating sludge samples with similar DS content.

Later, two other sludges were selected in order to study the influence of wastewater treatment processes on EDW: sludge C originated from a conventional activated sludge process and sludge D from a WWTP equipped with MBR process. Both samples were mechanically dewatered by a belt press and had similar DS_i.

Prior to use, sludge samples were stored at 4 °C up to a maximum of 1 week in order to keep their properties constant. DS and VS were measured according to Standard Methods (APHA and WEF, 2012). pH was measured by a pH-meter Metrohm 827 pH Lab and electrical conductivity by a conductivity meter (B & C Electronics-C 125.2). pH and conductivity were measured in the liquid sludge before dewatering.

The main characteristics of sludge samples are listed in Table 1.

2.2. Lab-scale device

Experiments were performed by means of a lab-scale device able to produce both a mechanical pressure and an electric field (Fig. 1). The reactor is composed of a cylindrical glass vessel 176 mm high, with a diameter of 80 mm, equipped with a double effect cylinder with a 200 mm stroke (SMC-CP96SDB32-200). The reactor was also provided of a cooling water jacket to keep the temperature constant during the

Table 1
Characteristics of sludge samples used for pressure-driven EDW tests.

Sludge samples		Biological process + Stabilisation	Mechanical dewatering	DS [%]	VS/DS [%]	pH	Conductivity [mS/cm]
WWTP	No.						
A	7	AS + Anaerobic	Centrifuge	22.2 ± 3.43	61.6 ± 3.84	7.0 ± 0.19	4.6 ± 0.54
B	7	AS + Aerobic	Filter press	23.6 ± 2.78	71.9 ± 2.26	5.9 ± 0.74	1.3 ± 0.17
C	6	AS + Aerobic	Belt press	17.5 ± 1.81	70.1 ± 3.25	6.6 ± 0.39	1.5 ± 0.26
D	4	MBR + Aerobic	Belt press	14.9 ± 1.33	73.6 ± 1.52	6.9 ± 0.17	1.2 ± 0.67