Water Research 100 (2016) 194–200

Contents lists available at ScienceDirect

Water Research

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

Electro-dewatering of activated sludge: Electrical resistance analysis

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ARTICLE INFO

Article history:
Received 18 February 2016
Received in revised form
2 May 2016
Accepted 9 May 2016
Available online 11 May 2016

Keywords:
Electro-osmotic dewatering
Activated sludge
Electrical resistance
Solid/liquid separation

ABSTRACT

The significant risk of ohmic heating and the high electric energy consumption at terminal stages of the dewatering are two problems that hamper the development of the electro-dewatering (EDW) technology. In the future prospect of studying these two issues, it is important to provide and analyse quantitative data relative to the behavior of the electric resistance in EDW. It was the main goal of this study. It showed that the electric resistance of the complete system (cake + filter cloth) depended on the cake dryness. It increased sharply when the solids content exceeded around 45%.The solids loading also influenced the apparent resistance at the beginning of the process. The electric resistance of the filter cloth represented about 20% of the total resistance. It remained relatively constant over the process except at the terminal stage where it generally increased sharply. The use of conductive filter, such as metallic cloth, enabled to decrease the electric resistance and reduce the energy consumption of the process.

The electric resistance decreased across the cake from the anode to the cathode. This behavior may be explained by several phenomena such as the ions migration and their interaction with the solid, the decrease of dry solids content from the anode to the cathode and the gas presence at the anode (due to electrolysis reaction).

1. Introduction

The enforcement of current environmental regulations on wastewater treatment is resulting in an increased volume of sewage sludge. This sludge has to be dewatered mainly to reduce storage capacities and transport costs. Volume reduction is commonly achieved by mechanical dewatering processes due to its low energy requirement in comparison to thermal drying (Vaxelaire et al., 1999). However wastewater sludge is generally difficult to dewater. It is a flocculated system consisting of micro-organisms (mainly bacterial) embedded in a bio-polymeric network (Christensen et al., 2015). Its particular structure constitutes a highly porous fractal-like network containing colloidal particles which behaves more like a gel-like material than as a classical particulate suspension (Raynaud et al., 2012).

Current research tends to propose potential alternatives to enhance the dewatering ability of the sludge or/and the efficiency of conventional processes. Treatments prior to dewatering can be considered to enhance the ability of sludge to dewater. For example thermal pre-treatments have shown interesting results (Neyens and Baeyens, 2003). Concerning the improvement of conventional processes, different options have been studied (Mahmoud et al., 2013), such as the addition of a thermal field (Clayton et al., 2006; Couturier et al., 2007; Peteers, 2010), an acoustic field (Smythe and Wakeman, 2000) a shear field (Vaxelaire and Olivier, 2014) or an electric field (Mahmoud et al., 2010; Tuan et al., 2012; Iwata et al., 2013). In the case of wastewater sludge, the electro-dewatering (EDW) which consists in the application of a continuous electric field during the mechanical compression stage is one of the most promising at laboratory scale (Mahmoud et al., 2010). Few industrial realisations and commercialisation attempts can be mentioned: two Korean processes, one called Elosys (Korean Water Technology) and the other E-Lode (ACE Korea Incorporation associated to Siemens for the product distribution), two press systems, one called Dehydris Osmo (Degemont) and the other Ovivo CINETIK® and one process proposed by the society Electrokinetic. However, the electro-dewatering technology is still not commonly used in industry. In a recent paper, Citeau et al. (2016) highlighted four main problems that hampered the development of the EDW technology: “(1) significant risk of ohmic heating, (2) high electric energy consumption at terminal stages of the dewatering, (3) alkalization and acidification of filtrate and filter cake due to

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http://dx.doi.org/10.1016/j.watres.2016.05.033
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Nomenclature

I	electric current (A)
K	empirical constant
P_{cake}	power dissipated in the cake (W)
P_{extr}	power used for filtrate extraction (W)
P_{joule}	power lost by ohmic heating (W)
P_{tot}	power dissipated in the device (W)
Q_f	filtrate flowrate ($L.s^{-1}$)
R_{app}	electric resistance of the full system (Ohm)
R_{filt}	electric resistance of the filter cloth (Ohm)
S	cake dryness ($\%_{wt}$)
U_{cake}	voltage drop across the cake (V)
U_{filter}	voltage drop across the filter cloth (V)
U_{thermo}	voltage drop due to the pH gradient (V)
U_{tot}	voltage drop between the two electrodes(V)
η_{anode}	anode overvoltage (V)
$\eta_{cathode}$	cathode overvoltage (V)

electrolysis reactions, and (4) electrode corrosion". Consequently, further research is required for better studying these phenomena and then for proposing technical procedures to limit their impact on the process.

In the future prospect of studying the two first issues it seems important in a first step to study the variation of the electrical resistances during the process.

Only few studies have specifically discussed this particular aspect. As mentioned by Mahmoud et al. (2010) and Yoshida et al. (2013), the electrical current flow through the filter-cake depends on the resistivity of the solid and the liquid phase and also on the solid content.

The electrical current flow through the system induces an increase of temperature due to Joule effect. Navab-Daneshmand et al. (2012) have shown that the apparent resistivity was influenced by the temperature. When the system was cooled the electric resistivity and the energy used were higher. Yu et al. (2010) showed that the filter cloth electrical resistance also impacts the energy consumption. Citeau et al. (2012b) found from experiments that the electrical resistance of the filter cloth could be up to 75–88% of the total resistance of the filter chamber. Yu et al. (2010) have also shown that the filter thickness influenced the result, thicker filter leads to higher percentage, notably at the end of the dewatering. Citeau et al. (2012b) have also observed an influence of the filter thickness.

The location of the electrodes relative to the filter cloth (behind or before) also impacts the efficiency of the process. Placing the electrodes before the filter cloth (directly in contact with the cake) leads to higher cake solid contents at moderate energy consumption (Saveyn et al., 2006; Citeau et al., 2012b). Similar results were also reported by Yu et al. (2010) from experiments carried out with and without filter cloth. The energy consumption was significantly lower without filter cloth whatever the applied voltage (between 8 and 12 V).

Finally, the electrode material modifies as well the total electrical resistance of the system and the amount of power consumed to achieve the same amount of dewatering. In practice using lower conductivity electrodes leads to lower power consumption (Glendinning et al., 2010).

The goal of the paper was to complete works already published in the scientific literature and to provide quantitative data relative to the behavior of the electric resistance in EDW process. The impact of some operating parameters such as voltage, current intensity, mass loading was studied. The resistance distribution through the EDW system was also measured. All these results contributes to better highlight some of the mechanisms involved in the electro-dewatering of activated sludge.

2. Governing equations

The apparent electrical resistance (R_{app}) throughout the dewatering device can be calculated from the Ohm's law:

$$R_{app} = \frac{U_{tot}}{I} \tag{1}$$

where U_{tot} is the voltage drop between the two electrodes and I the current intensity.

In fact, U_{tot} is the sum of several voltage drops, as mentioned in the following equation:

$$U_{tot} = U_{thermo} + |\eta_{cathode}| + \eta_{anode} + U_{filter} + U_{cake} \tag{2}$$

U_{thermo} represents the voltage drop between the anode and the cathode due to the pH gradient induced by electrolysis reactions occurring at the electrodes. It is calculated with the Nernst's law (Mahmoud et al., 2010). For a pH difference of 10 units, between the anode and the cathode, U_{thermo} reaches 0.6 V.

$\eta_{cathode}$ and η_{anode} are the cathode and the anode overvoltage, respectively. They mainly depend on the reactions occurring and the nature of the electrode. For electrodes commonly used in EDW, values around 0.1 V for the cathode and 0.3 V for the anode have been mentioned (Vijh, 1999).

U_{filter} is the voltage drop induced by the filter cloth (where this latter is located between the electrode and the cake). Its value depends on the nature and the thickness of the cloth (Citeau et al., 2012b).

U_{cake} is the voltage drop through the cake. Usually, it is much higher than the sum of the other contributions presented above.

For the voltage used for electro-dewatering (usually ranging between 20 V and 60 V), the main part of the voltage drop is located in the cake. The electric resistance of the filter cloth remains nearly constant during the dewatering except when the cake reaches high dryness (higher than 45%, see Fig. 7), it generally increases significantly (see paragraph 4.2). Consequently, for cake dryness lower than 45% the total resistance of the system behaves in the similar way to the one of the cake resistance. Thus, the electric power supplied to the system is largely consumed in the cake and the apparent resistance can be reasonably linked to P_{cake}, the electric power dissipated into the cake.

$$R_{app} = \frac{U_{tot}.I}{I^2} = \frac{P_{tot}}{I^2} = \frac{P_{cake}}{I^2} + R_{filt} \tag{3}$$

The electric power dissipated into the cake (P_{cake}) can also be divided in two terms:

$$P_{cake} = P_{extr} + P_{joule} \tag{4}$$

P_{extr} corresponds to the power used to remove the water from the cake. This power is all the higher as the extracted water is bound to the solid (Vaxelaire and Cézac, 2004; Deng et al., 2011). When the electro-dewatering proceeds water more and more bound to the solids is removed. Consequently,P_{extr} can be written depending on the dryness of the cake (S):

$$P_{extr} = Q_f.f(S) \tag{5}$$

Q_f is the filtrate flowrate and the function $f(S)$ represents the