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Electro-dewatering of wastewater sludge: An investigation of the relationship between filtrate flow rate and electric current

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ABSTRACT

Compared to conventional dewatering techniques, electrical assisted mechanical dewatering, also called electro-dewatering (EDW) is an alternative and an effective technology for the dewatering of sewage sludge with low energy consumption. The objectives of this study were to evaluate the dewatering performance and to determine the influence of the process parameters (e.g. applied electric current, applied voltage, and the initial amount of dry solids) on the kinetics of EDW-process for activated urban sludge. Also significant efforts have been devoted herein to provide comprehensive information about the EDW mechanisms and to understand the relationship between these operating conditions with regards to develop a qualitative and quantitative understanding model of the electro-dewatering process and then produce a robust design methodology. The results showed a very strong correlation between the applied electric current and the filtrate flow rate and consequently the electro-dewatering kinetics. A higher applied electric current leads to faster EDW kinetics and a higher final dry solids content. In contrast, the results of this work showed a significant enhancement of the dewatering kinetics by decreasing the mass of the dry solids introduced into the cell (commonly known as the sludge loading).

1. Introduction

Every year, the volume of municipal sewage sludge increases because of an intensification of water purification. Elimination cost of sewage sludge depends directly on both, volumes to be treated and their moisture content. The water in sludge is classically removed by mechanical processes such as centrifuges, belt filter presses or filter-presses. However the efficiencies obtained with wastewater sludge are generally low, a 35% (wt%) dryness seems to be around the highest value that can be reached (Chen et al., 2002; Raynaud et al., 2012). Consequently, for some years, researchers have started to intensify the existing mechanical processes by realizing convenient combinations, such as the addition of a thermal field, an acoustic field or an electric field (Smythe and Wakeman, 2000; Clayton et al., 2006; Couturier et al., 2007; Mahmoud et al., 2008, 2010, 2013; Peteers, 2010; Tuan et al., 2012; Iwata et al., 2013). One of the most effective hybrid processes with regards to the improvement of wastewater sludge dewatering is electro-dewatering (EDW) which is the application of an electric field during the mechanical

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Nomenclature

D (F m^{-1}) permittivity or dielectric constant
M_{DS} (g) mass of dry solids matter introduced into the laboratory electro-dewatering cell
$E_{t,0.5}$ (kWh/$kg_{water\ removed}$) instantaneous energy consumption required to increase the dryness by 0.5 point
i (A) electric current
i_{appl} (A) applied electric current for electro-dewatering test carried out under constant electric current (I-EDW)
i_{meas} (A) measured electric current for electro-dewatering test carried out under constant voltage (U-EDW)
k_e (m^2 s^{-1} V^{-1}) electro-osmotic conductivity
K_{I-EDW} (g s^{-1} A^{-1}) empirical constant for electro-dewatering test at constant electric current
M_f (g) mass of collected filtrate
M^0_{sludge} (g) total amount of sludge introduced into the laboratory electro-dewatering cell
Q_e (g s^{-1}) filtrate flow rate of electro-osmosis process
Q_f (g s^{-1}) filtrate flow rate of electro-dewatering
$Q_f^{0.5}$(kg s^{-1}) filtrate flow-rate removed to increase the dryness by 0.5 point
S ($\%_{wt}$) dryness of sludge cake
S^0 ($\%_{wt}$) dryness of sludge cake at the beginning of Stage 2
t (s) time
U (V) applied voltage for electro-dewatering test carried out at constant voltage (U-EDW)
$\Delta t_{0.5}$ (s) time required to increase the dryness by 0.5 point
$\Delta M_{f,0.5}$ (g) amount of filtrate removed to increase the dryness by 0.5 point
ζ (V) zeta potential
μ (Pa s) liquid viscosity
ρ_e (C m^{-3}) volume density of excess electric charge of fluid

compression of the sludge (Mahmoud et al., 2010, 2011, 2013; Tuan et al., 2012; Iwata et al., 2013; Olivier et al., 2014). Electrical phenomena used to improve the dewatering have been described in previous works (Mahmoud et al., 2010, 2013).

As demonstrated in a number of investigations performed at lab scale, the specific energy consumption required for EDW of wastewater sludge to reach a final dryness in the range of 32–60% (wt%) (ca. 0.12–0.45 kWh/$kg_{water\ removed}$ for the activated sludge and ca. 0.14–0.55 kWh/$kg_{water\ removed}$ for the digested sludge) was significantly lower that required for thermal sludge drying (ca. 0.617–1.2 kWh/$kg_{water\ removed}$) (Mahmoud et al., 2011; Citeau et al., 2012; Mahmoud et al., 2013; Olivier et al., 2014).

Two different operating modes are generally used to conduct EDW with sewage sludge: a constant electric current (I-EDW) or a constant voltage (U-EDW). For I-EDW run, both the temperature of the filter chamber and voltage increase as the dewatering proceeds (Citeau et al., 2012b; Olivier et al., 2014). However, if the temperature increase is too large after a certain time it becomes necessary for the operator stop the process in order to prevent the deterioration of both, the filtering clothes and the electrodes used. For U-EDW run, an uncontrolled electric current peak and a peak of temperature were observed in the early dewatering period (Mahmoud et al., 2011; Olivier et al., 2014), they were followed by a gradually decrease of these two parameters until the shutdown of the dewatering. Many experimental factors can influence the reduction of water content and, consequently, the EDW-process performance. The critical processing factors are voltage (electric current or strength field), pressure, time/off-time interrupted, conditioning parameters, floc size distribution, type of sludge and its intrinsic characteristics (e.g. electrochemical properties), compressibility properties (volume fraction of particles, specific cake resistance and coefficient of compressibility), polyelectrolyte characteristics, sludge loading, electrodes materials, cell configuration, filter cloth type, ..etc. (Mahmoud et al., 2010, 2011, 2013; Citeau et al., 2011, 2012a,b; Olivier et al., 2014; Feng et al., 2014). However, the efficiency of EDW depends essentially on the applied electric current or the applied voltage and on the mass of dry solids (M_{DS}) introduced into the EDW-cell. For U-EDW mode, higher voltage leads to faster EDW kinetic and higher final dryness as reported by Gingerich et al., 1999; Saveyn et al., 2006; Yu et al., 2010; Mahmoud et al., 2011; Citeau et al., 2012b; Feng et al., 2014; Olivier et al., 2014. However, this operating mode induces an increase of the temperature in the filter chamber and the measured electric current, respectively (Mahmoud et al., 2011). For I-EDW mode, higher electric current leads to faster EDW kinetics (Lee et al., 2002; Hwang et Min, 2003; Citeau et al., 2012a, 2012b; Olivier et al., 2014), but the temperature and the measured voltage also increase (Citeau et al., 2012b). The uncontrolled electric current increase and the drastic temperature rise by ohmic heating will adversely affect the EDW-cell equipments (filtering clothes, electrodes) and ultimately hampering the EDW-process. In order to provide a better control of the ohmic heating effect, Citeau et al. (2012b) proposed to alternate initial I-EDW treatment by U-EDW treatment at late stage of electro-dewatering. Thus, the dewatering of the sludge can be extended leading to complete the EDW-process as much as possible. However, further investigations are required to optimize the transition point between I-EDW and U-EDW regimes. Previously, in order to control the temperature increase and consequently to prevent the overheating, Lee et al. (2007) investigated the EDW of waterworks sludge using a short time of electric field applied. However, the temperature in the filter press has continued to rise (from 20–23 to 65–85 °C). Overheating can also be prevented by an additional washing of the filter cake as mentioned by Larue et al. (2001, 2006). In general, in order to tackle the excessive overheating, a compromise can be made between the processing time, the strength of the electric field and the extent of sludge dewatering.

On the other hand, for both modes, at a given initial dry solid content, the decrease of the mass of dry solids introduced into the EDW-cell (or the decrease of the mass of sludge) leads to a significant increase in the EDW kinetics (Olivier et al., 2014).