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Modification of activated sludge properties caused by application of continuous and intermittent current

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ARTICLE INFO

Article history:
Received 25 July 2012
Received in revised form
11 November 2012
Accepted 13 November 2012
Available online 23 November 2012

Keywords:
Electrocoagulation
Floc size
Sludge filterability
Zeta potential
Soluble microbial products (SMP)
Humic substances
Microbial activity
Activated sludge properties
Submerged membrane electro-bioreactor (SMEBR)

ABSTRACT

This study investigated the impact of direct current (DC) field on the activated sludge properties for potential improvement of the biological as well as membrane treatment processes. Three mixed-liquor suspended solids (MLSS) concentrations (5,000, 10,000 and 15,000 mg/l) were subjected to current densities (CD) ranging from 5 to 50 A/m^2 at five electrical exposure modes (time-ON/time-OFF). The results showed that CD between 15 and 35 A/m^2 increased the filterability of the sludge more than 200 times when compared with the untreated reference sludge. The average removals of protein, polysaccharides and organic colloids from the sludge supernatant at this range of CD were 43%, 73% and 91%, respectively, while the average reduction of the specific resistance to filtration (SRF) was 4.8 times higher. The changes of sludge properties depended on the current density, electrical exposure mode and the MLSS concentration. At CD of 25 A/m^2 and MLSS below 10,000 mg/l, shorter time-OFF was needed in each electrical cycle, while more time-OFF was needed at higher MLSS concentrations. It was concluded that proper application of the DC field could improve biomass in terms of its dewaterability and the removal of SMP, which are highly correlated to membrane fouling in the submerged membrane electro-bioreactor (SMEBR).

1. Introduction

In an electrocoagulation (EC) process, the release of Al^{3+} from anode dissolution causes the flocculation of colloidal organics by reducing the absolute value of zeta potential to a level where the Van der Waal forces are greater than the repulsive forces between the negatively charged colloids (Ni'am et al., 2007; Larue et al., 2003). The Al^{3+} ions produced react with the free OH^- in water to initially form monomers, mostly $Al(OH)^{+2}$, $Al(OH)_2^{+1}$ and $Al(OH)_4^-$. Afterwards, these species are converted into polymers species such as $Al_8(OH)_{20}^{+4}$, $Al_{13}(OH)_{34}^{+5}$, which eventually can be transformed into long chains of $Al(OH)_{(s)}$. These cationic hydroxide complexes can effectively remove the negatively charged organic materials through various phenomena including electrostatic forces (Chen, 2004). These complexes have a large surface area with a diameter up to 1 μm (Balkan and Kolesnikova, 1996) capable of adsorbing and trapping the soluble and colloidal particles, which are eventually separated from the liquid medium by sedimentation or hydrogen flotation (Can et al., 2003; Bayramoglu et al., 2004; Kobya et al., 2006). Simultaneously, hydroxides and hydrogen gas ($3H_2O + 3e^- \rightarrow 3/2H_{2(g)} + 3OH^-$) are produced in the cathode zone. The effectiveness of EC depends primarily on the current density (CD = current [A]/

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0043-1354/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.watres.2012.11.020

electrode area [m^2]), which controls the dosing rate of metal ions into the liquid medium and the gas bubble density (Ni'am et al., 2007). The values of CD cited in the literature generally range between 10 and 150 A/m^2. Higher current density is required when flotation is the mechanism of separation of the coagulated particles. Lower CD are suitable for EC processes combined with other separation facilities such as sedimentation tanks, sand and coal filters or membrane filtration (Holt et al., 1999).

EC demands professional qualified staff capable of operating and controling the system. On the other hand, EC requires lower retention time and no chemical coagulants than conventional coagulation with metal salts (Kobya et al., 2006). EC also decreases the salt and ion content in solids and the supernatant (Mollah et al., 2001; Chen, 2004) while generating flocs of bigger size and density (Larue et al., 2003) than during a chemical coagulation. These advantages of EC led to its application to treatment of wastewaters containing dyes (Daneshvar et al., 2004), oil (Canizares et al., 2008), textile industry by-products (Bayramoglu et al., 2007), and slaughterhouse by-products (Bayramoglu et al., 2006). Although, the application of DC has been proven to be effective in electrocoagulation of wastewater, its entire impact on biomass characteristics has not fully explored, particularly, regarding the interactions within a conventional membrane bioreactor (Watanable and Kimura, 2006; Wang et al., 2008) and the submerged membrane electro-bioreactor (Bani-Melhem and Elektorowicz, 2011, 2010; Wei et al., 2011; Elektorowicz et al., 2009).

The objective of this study was to investigate the impact of DC field on activated sludge proprieties (the concentration of SMP (protein and polysaccharides), colloidal organics, soluble organics, humic substances, zeta potential, floc size and sludge filterability) without affecting microbial viability. It was anticipated that aluminum anode would release Al^{3+} into the reactor and subsequently, several electrochemical processes were likely to take place in the sludge liquor including electrocoagulation, electrophoresis, electro-osmosis and electromigration of ions, thus shaping sludge characteristics.

2. Material and methods

2.1. Experimental set-up and materials

Experiments were carried out in two stages. In stage 1, a series of 1-L batch electrokinetic bioreactors were set up, equipped with perforated flat (10 cm × 20 cm) aluminum anode and stainless steel cathode, aerated from the bottom to maintain aerobic conditions (Fig. 1). The porous electrodes ensured an adequate mixing of activated sludge in the whole reactor. Three levels of mixed liquor suspended solids (MLSS) were used in a series of tests: low – 3000 to 5000; medium – 8000 to 10,000; high – 13,000 to 16,000 mg/l. A range of current densities between 5 and 60 A/m^2 were tested. Changing of current density was controlled by changing the voltage gradient between 0.5 and 1.5 V/cm. Five exposure modes to DC (5′-ON/5′-OFF, 5′-ON/10′-OFF, 5′-ON/15′-OFF, 5′-ON/20′-OFF and continuous-ON) were selected to run the electro-bioreactors for a minimum of 70 h. Thus, a total of 45

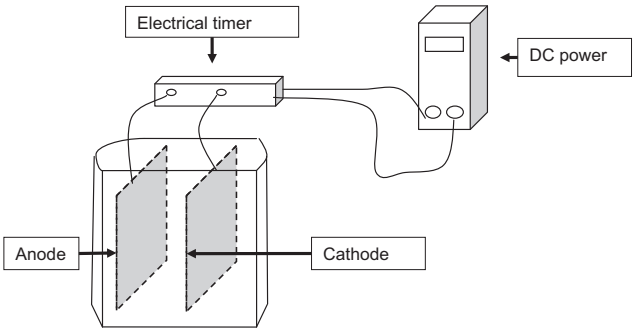

Fig. 1 – Experiment set up of 1-liter batch reactor and electrical connections.

combinations of electrical exposure modes, current densities and MLSS concentrations were conducted in 9 runs. Each run had five electro-bioreactors and one control bioreactor operated simultaneously for comparison purposes.

In stage 2, the same electro-bioreactors were used. In this stage, oxygen uptake rate (OUR) was measured as an indication of microbial activity. Based on the results of stage 1, two current densities (25 and 50 A/m^2) were selected. Two MLSS concentrations of 6000 and 15000 mg/l and the same five electrical exposure modes (5′-ON/5′-OFF, 5′-ON/10′-OFF, 5′-ON/15′-OFF, 5′-ON/20′-OFF and continuous-ON) were applied. A control reactor without electrical current was run in parallel. All combinations were completed in 4 runs, each lasted 48 h. During each run, the current density (CD) was maintained constant by adjusting the voltage. No wastewater was added into the reactors, just biomass freshly delivered as needed from the wastewater treatment plant serving the City of St. Hyacinthe, QC (Canada) and stored in the refrigerator at 4 °C. Because the tests lasted 13 months, the activated sludge characteristics and quality varied throughout the experiment due to the seasonal changing conditions in the wastewater treatment plant, particularly temperature variation.

2.2. Analytical methods and measurements

Electrical conductivity (ECN), pH, and dissolved oxygen (DO) were measured using a HQ30d single-input multi- meter (Hach, USA). Current density was calculated as current (A) passing between the electrodes divided by the anode effective surface area (m^2). Humic acid was measured as a UVA_{254} using Lambda40 UV/VIS spectrometer (Perkin Elmer, USA). The removal efficiency of humic substances (HS) after applying direct current (DC) field was calculated according to the following equation:

$$HS \text{ removal efficiency} = \frac{UVA254(\text{control}) - UVA254(\text{after } DC \text{ field})}{UVA254(\text{control})} 100\% \quad (1)$$

Floc size was measured using a particle size analyzer (Horiba Partica LA-950V2, USA); the refractive index was set to 1.45. To avoid damage to the flocs during sampling, 5–10 ml of the activated sludge were taken with a syringe (2 mm opening) and stirred gently before injecting into the instrument. The accuracy of the floc size measurements was evaluated