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Electro-conditioning of activated sludge in a membrane electro-bioreactor for improved dewatering and reduced membrane fouling

Sharif Ibeid [a,*], Maria Elektorowicz [a], Jan A. Oleszkiewicz [b]

[a] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada
[b] Department of Civil Engineering, University of Manitoba, Winnipeg, Canada MB R3T 5V6

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ABSTRACT

The impact of applying a direct current (DC) field on the morphology and structural composition of municipal wastewater flocs and their bound water content was investigated. The effects on sludge dewaterability and membrane fouling were assessed using batch electro-bioreactors and continuous flow submerged membrane electro-bioreactor (SMEBR). Series of batch electro-bioreactors were tested at current densities (CD) ranging between 5 and 35 A/m^2 for three concentrations of mixed liquor suspended solids (from 3000 to 15,000 mg/l) and five electrical exposure modes (time-ON/time-OFF). Results of batch tests showed that CD of 15 to 35 A/m^2 enhanced sludge filterability, represented as specific resistance to filtration (SRF), up to 200 times compared to sludge in the control reactor. Electrically enhanced sludge under continuous flow (SMEBR) exhibited a reduction of SRF over the conventional activated sludge from 8 to 86 times, while membrane fouling rate decreased by 6 times. It was assumed that the removal of organic materials and soluble microbial products (SMP) through electro-coagulation (up to 90% for polysaccharides and up to 50% for protein), reduction of bound water by electroosmosis, increasing floc size through electro-bio-flocculation and the reduction of sludge organic/inorganic ratio were the major mechanisms contributed to SRF and membrane fouling reduction.

1. Introduction

In municipal wastewater treatment plants, sludge dewaterability can be described through either the rate of filtration or the achievable percentage of bound water content in sludge after the dewatering process [1]. Effective sludge dewatering is critical to cost-effectiveness of downstream processes such as drying or thermal oxidation. Different definitions of water distribution within the sludge exist in literature [2], the most widely used is the one proposed by Vesilind and coworkers [3–6] where water within sludge comprises four different pools: bulk water (free water), interstitial water, vicinal water and chemically bound water. Chemically bound water is strongly attracted to the flocs and can be removed at 105 °C [7,8]. Bulk water represents the fraction of water that is not associated with the solid surface and can be found in the voids; the interstitial water represents the part held by capillary forces; the latter two pools of water can be removed by physical means; e.g. pressure filtration, open air drying and centrifugation. Vicinal water represents the fraction that might be attracted to organic solid surfaces within the microbial flocs through the H-bonds between the polar water molecules and the flocs' polar active groups such as hydroxyl and amine groups. Christensen and Characklis [9] described the extra polymeric substances (EPS) as a hydrated matrix with 98% water content. EPS represents the pool of organic fractions produced by microorganisms that are located at the surfaces or outside of the microbial cell surfaces that help the aggregation of cells into flocs [10]. Polysaccharides and protein are the major constituents of EPS in any biomass solid surface. Nielsen et al. [11] reported that protein is the predominant fraction of EPS formed in biofilters and trickling filters. Dignac et al. [12] illustrated that protein is the predominant fraction of EPS found in the activated sludge. Protein has a high density of negatively charged amino groups that act electrostatically with cations and other active groups to form stable flocs, yet protein is the structural unit of enzymes involved in biochemical reactions [13]. Thus, the existence of various types of organic materials in forms of soluble and bound EPS as major constituents of the activated sludge liquors allows for stronger water–biomass bonding that makes its dewatering difficult.

* Corresponding author.
E-mail address: s_ibeid@encs.concordia.ca (S. Ibeid).

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Simultaneously, they contribute to a rapid membrane fouling [14]. Most mechanical dewatering processes cannot decrease water content of biological sludge below 65% (total solids=35%) even with the addition of thickening amendments [15]. Several works showed a successful reduction of sludge water content by applying electrokinetics [14,16–18]. DC field assisted dewatering systems, combinations of conventional dewatering methods and electrokinetics, reduced water content to 53% by weight [19], to 35% [16] and to less than 10% [17]. Such electro-dewatering systems applied in previous works depended primarily on electroosmotic flow of water and the process was initiated with high solids content of waste activated sludge (WAS) after thickening (e.g. 4% TS).

The primary objective of this research was to apply DC field to change activated sludge structure and morphology in order to reduce membrane fouling rate and to improve WAS properties before any mechanical dewatering takes place. The secondary objective was to define the electrical operating parameters such as voltage gradient, current density (CD) and exposure mode for different mixed liquor suspended solids (MLSS) concentrations that enhance WAS dewaterability. Membrane fouling rate reduction was discussed in details in a previous publication [20]. This paper focuses on the outcomes that demonstrated the enhancement of sludge dewaterability, while fouling was simultaneously reduced by applying electro-bioreactors.

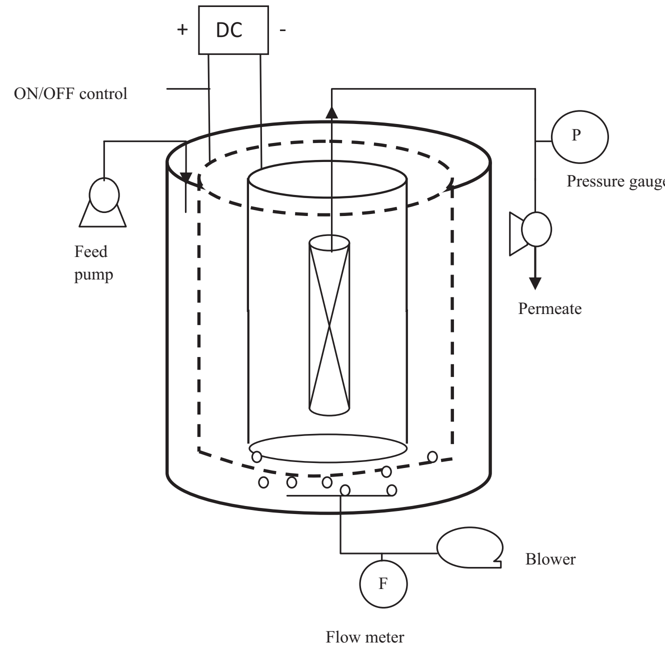

Fig. 1. Experimental setup of SMEBR (Elektorowicz et al. [23]).

2. Material and methods

2.1. Experimental setup

This study consisted of two phases carried out in batch (Phase I) and continuous flow (Phase II) electro-bioreactors. In Phase-I a series of batch 1 L activated sludge electro-bioreactors equipped with aluminum anode and iron cathode were aerated to maintain aerobic conditions. Three MLSS concentration ranges were considered: 3000 to 5000, 9000 to 10,000 and 14,000 to 15,000 mg/l. These ranges represent any likely MLSS concentration produced in treatment plants applying biological treatment, including membrane bioreactors (MBR). Five electrical exposure modes, 5′-ON/5′-OFF, 5′-ON/10′-OFF, 5′-ON/15′-OFF, 5′-ON/20′-OFF and continuous-ON, were tested at current density (CD) ranging between 5 and 35 A/m^2. Each reactor was tested for a minimum of 70 h. A control batch reactor without any electrical field was run to compare the changes of sludge dewaterability. Specific resistance to filtration (SRF) was measured to assess changes of sludge dewaterability. Particle size distribution was measured to evaluate changes of flocs morphology in electro-bioreactor under electrokinetic phenomena. Sludge in batch reactors was mixed using air stones at low air intensity in all runs so that a minimum stirring was produced to prevent flocs mechanical disintegration.

In Phase II, 8 L working volume of a submerged membrane electro-bioreactor (SMEBR) was operated at continuous flow (Fig. 1), while details of SMEBR system are illustrated in previous publications [20,21]. The cylindrical perforated cathode and anode were located around UF hollow fiber, Zeeweed-1 (GE, Canada) membrane module of 0.04 µm pore size and 0.047 m^2 surface area [22]. To ensure reproducibility, three experimental runs were conducted at CD of 15 A/m^2 and 5′-ON/20′-OFF exposure mode. These electrical operating conditions were selected based on the results generated by a series of batch tests of electro-bioreactor. The initial concentration of mixed liquor suspended solids (MLSS) was 4000 mg/l. Hydraulic retention time (HRT) for all runs was 13 h. Solid retention time (SRT) was set to 20 d for Run 1 and Run 2, and 150 d for Run 3. Different SRT were tested to evaluate the enhancement of sludge dewaterability at different operating conditions. Each run was operated for at least 25 d. A conventional membrane bioreactor (MBR) was run side-by side at the same HRT and SRT for comparison. Both reactors were fed with synthetic wastewater composed of glucose (665 mg/l), peptone (85 mg/l), yeast extract (100 mg/l), ammonium sulfate (100 mg/l), potassium phosphate (37 mg/l), magnesium sulfate (40 mg/l),manganese sulfate (4.5 mg/l), iron sulfate (0.4 mg/l), calcium chloride (4 mg/l) potassium chloride (25 mg/l) and sodium bicarbonate (25 mg/l). Sludge in all runs was mixed gently at low air intensity to avoid flocs damage. The reactors were inoculated with samples of return activated sludge reactor brought from the wastewater treatment plant in St Hyacinthe, QC. The same sludge samples were used in batch tests of the electro-bioreactors.

2.2. Analyzes

The changes of sludge dewaterability were assessed based on cake vacuum filtration, total solids (TS) content, specific resistance to filtration (SRF), flocs flocculation (flocs zeta potential and particle size distribution), bound water content, properties of MLSS liquor (organic/inorganic ratio of MLSS and EPS concentration).

2.2.1. Particle size distribution

Flocs particle size distribution was measured using the Partica LA-950V2 laser diffraction particle size analyzer (Horiba, USA). To avoid the damage of the flocs through sampling, 5 to 10 ml of the activated sludge was taken by a syringe with 2 mm opening. The sample was stirred gently in the syringe before injecting in the instrument. The refractive index was set to 1.4.

2.2.2. Zeta potential

A 50 ml sludge sample was centrifuged at 4000 rpm for 20 min. The supernatant was discarded and mixed with a few drops of the activated sludge. This mixture was placed inside the electrophoretic cell of Zeta Meter 3.0$^+$ (Zeta-Meter Inc., USA) for zeta potential measurement of flocs. The final value was given as an average of 10 readings.

2.2.3. Sludge filterability (SRF)

Sample sludge of 50 to 100 ml was filtered in a Buchner funnel under a vacuum of 100 kPa, where Whitman 40 filter paper was