Bioelectrochemical peroxide production for water disinfection

S. Mosquera[1,2*] , I. Vanwonterghem[1] , J. B. A. Arends[1***], L. Dominguez[2****], D. Rousseau[3*****] , K. Rabaey [1******]**

[1] Center for Microbial Ecology & Technology (CMET), Ghent University, Coupure Links 653, B-9000 Gent, Belgium, Suannysophia.Mosqueraromero@ugent.be*, Inka.Vanwonterghem@UGent.be**, Jan.Arends@UGent.be***, Korneel.Rabaey@UGent.be******

[2] ESPOL Polytechnic University, Escuela Superior Politécnica del Litoral, ESPOL, Facultad de Ciencias Naturales y Matemáticas, Campus Gustavo Galindo Km. 30.5 Vía Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador, suasomos@espol.edu.ec*, ldomingu@espol.edu.ec****

[3] Department of Green Chemistry and Technology, Coupure Links 653, B-9000 Gent, Belgium, Diederik.Rousseau@UGent.be*****

Abstract: Decentralized wastewater treatment systems can offer a long-term solution for sanitation and clean water supply in remote locations. Coupling constructed wetlands for wastewater treatment with electrochemical disinfection opens the opportunity to re-use water within a community. The production of disinfectants, such as hydrogen peroxide, by bio-electrochemical means is feasible. Three independent bio-electrochemical reactors supplied with acetate (0.5 g day^{-1}) in the anode were operated continuously in a 3-chamber system. When a concentrated hydrogen peroxide solution (0.1 %) was recirculated through a middle compartment, current production was maintained at 55.5 ± 9.5 A m^{-2} during 28 days. This demonstrates that hydrogen peroxide, which can be generated at the cathode, is not interfering with bioanode performance. The results are promising and show these innovative technologies as potential solution applicable to areas with water stress.
Keywords: water recovery; hydrogen peroxide; electro-disinfection

Decentralized systems have been proposed for water sanitation in remote areas. Low-investment constructed wetland systems offer a potential solution, especially in (sub)tropical countries [1]. Despite considerable pathogen removal rates (< 4 log removal) by this biological system, fecal indicator standards are not always met for water reuse [2]. Subsequent treatment of the wetland effluent is needed to eliminate the risk of exposure to pathogens in the recovered water. Enhanced disinfection by electrochemical cells coupled to wetland systems has been reported previously [3,4]. Electrochemical systems can produce disinfectants (*e.g.* hydrogen peroxide, H_2O_2), enable enhanced disinfection through the generation of a steep pH gradient [5,6], and offer additional pollution control by oxidative conversion of organic contaminants.

The electrochemical production of H_2O_2 can be applied for local water disinfection and subsequent reuse. Hydrogen peroxide breaks down into harmless water and oxygen, which is more environmental-friendly than chlorine-based disinfectants. Through *in-situ* production of reagents, transportation and safety concerns related to local storage are eliminated, which is especially important for remote areas. Finally, the treatment system can be controlled according to the demand, resulting in reduced costs [7].

A 3 log removal of pathogens can be obtained at low H_2O_2 concentrations (< 0.01 %) with at least 3 hours of contact time [8]. Higher H_2O_2 concentrations (0.1 %) achieved almost complete removal of coliforms in < 1 hour [3]. Electrochemical H_2O_{2-} production in a cathodic compartment should be sufficient to provide an ideal combination between concentration and contact time. A middle compartment between the anode and cathode could allow further concentration of the H_2O_2 (> 0.1 %) by means of electrodialysis, which can be desirable to achieve higher disinfection efficiencies or rates [9].

Coupling electro-disinfection and organics oxidation is possible in a bioelectrochemical system [10,11]. A carbon electrode inoculated with electroactive bacteria in the anode can generate enough power for the reduction of oxygen to hydrogen peroxide at the cathode [11,12]. In this configuration, the challenge is to keep the peroxide from interfering with the desirable microbial community in the anodic compartment. This may lower the efficiency of disinfectant production in the long-term.

Three identical continuous acetate-fed (0.5 g day^{-1}, 6d HRT) bioelectrochemical reactors were tested to corroborate the feasibility of long-term current generation when hydrogen peroxide is concentrated in a middle compartment (Figure 1.1.A). Each reactor consisted of three compartments made of parallel Perspex frames with a working volume of 0.2 L (internal dimensions of 5 cm × 20 cm × 2 cm). The bio-anode was separated from the middle compartment by a cation exchange membrane (CEM-Fumasep f-010120, Fumatech GmbH, Germany). The middle compartment was separated from the cathode compartment by an anion exchange membrane (AEM-Fumasep FAB-PK130, Fumatech GmbH, Germany). The anode was a carbon felt (3.28 mm thick, Alfa Aeasar, Germany) with a projected surface area of 100 cm^2. A stainless steel mesh (inox AISI 304, mesh width: 5.45 mm, wire thickness: 0.8 mm, Omnimesh, Belgium) functioned as anodic current collector. The cathode (stainless steel mesh, AISI 316L mesh size 495 µ, Solana, Belgium) was used as counter electrode without peroxide production.

After an initial start-up phase (33 days), two of the bioelectrochemical reactors were exposed to a concentrated peroxide solution (0.1%), which was recirculated in the middle compartment. Current densities were not affected compared to the control without disinfectant (Figure 1.1.B). Furthermore, all three reactors maintained stable operation for at least 28 days. The current generated (55.5 ± 9.5 mA) could allow production of a 0.07% hydrogen peroxide solution in the cathodic chamber (0.2 L) at 4 h retention time, followed by up-concentration in a middle compartment. However, depending on the organic load and the design of the system, the generated current may vary and the production of peroxide can thus change. A trade-off between organic load for current generation, net peroxide production in the cathode, and up-concentration in a middle compartment should be analysed in more realistic scenarios for water disinfection. These preliminary results reinforce the viability to apply these innovative technologies as a potential solution applicable to areas with water stress

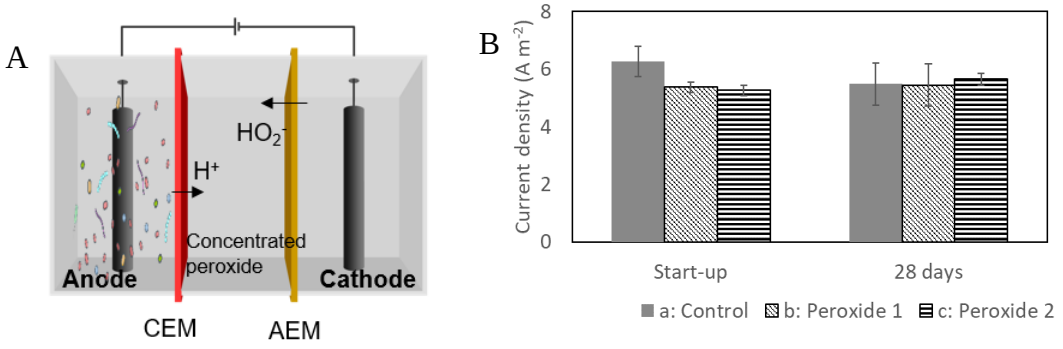

Figure 1.1 A) Scheme of the bioelectrochemical system: anode with electroactive bacteria oxidizing acetate, middle compartment with concentrated H_2O_2 recirculation (0.1%), cathode as counter electrode. CEM: Cation exchange membrane and AEM: Anion exchange membrane. B) Current densities of bioelectrochemical systems at non-limiting acetate fed (0.5 g day^{-1}) during the start-up period (3 days) without H_2O_2 recirculation, and lately during stable operation (26-28 day) for one control (without H_2O_2 recirculation) and two reactors with H_2O_2 recirculation (0.1%). Error bars represent the standard deviation during 3 days of operation.

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