Energy-efficient treatment of organic wastewater streams using a rotatable bioelectrochemical contactor (RBEC)

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A B S T R A C T

A membraneless bioelectrochemical system – rotatable bio-electrochemical contactor (RBEC) consists of an array of rotatable electrode disks was developed to convert the chemical energy from wastewater organics (acetate) directly into electricity. Each rotatable electrode disk had an upper-air exposing and a lower-water submerging halves. Intermittent rotation (180°) enabled each halve to alternately serve as anode and cathode. Removal of chemical oxygen demand (COD) was increased by 15% (from 0.79 to 0.91 kg COD m⁻³ d⁻¹) by allowing electron flow from the lower to the upper disk halves. Coupling with an acidified anodic effluent of a microbial fuel cell (Harnisch and Schroder, 2009; Rozendal et al., 2006). Such pH splitting phenomena could lead to as high as a 6 pH units difference between the two electrodes (Claauwaert et al., 2008), hence severely stifling the driving force of the system (i.e., potential difference between anode and cathode) as each unit of pH gradient represents an overpotential (potential loss) of 59 mV (Nernst equation). Correcting the pH by acid/base dosing or addition of a concentrated buffer (e.g. phosphate buffer) is not feasible for large-scale application, although these methods are effective in laboratory trials (Cheng et al., 2010). A loop-concept has been described as a mitigation strategy for the aforementioned pH limitation during MFC operation, where the acidified anodic effluent of a MFC served as the influent for the cathode in a two-compartment configuration (Freguia et al., 2007). However, the obligatory requirement of mechanical recirculation of wastewater throughout the system against gravity may limit process scale-up (Claauwaert et al., 2009; Freguia et al., 2007).

Here, a new BES configuration, rotatable bioelectrochemical contactor (RBEC) is described and evaluated for its capacity to convert soluble organics directly into electrical current without using conventional pH control methods or the need of energy consuming wastewater re-circulation. While similar to the well-known rotating biological contactor (RBC), the RBEC has several distinctive fea-

1. Introduction

Bioelectrochemical systems (BES) such as microbial fuel cells (MFC) and microbial electrolysis cells (MEC) have emerged as a new environmental technology for recovering valuables such as energy from organic waste streams (Rabaey et al., 2007; Rozendal et al., 2008). These systems involve microorganisms to convert the chemical energy of the organic pollutants in wastewater directly into electricity or other energetic products such as hydrogen gas (Logan et al., 2008; Rozendal et al., 2008). However, up-scaling BES to an industrial scale still remains as a challenge. To generate electron flow, a BES should have several generic features. Firstly, an electron donor (e.g. organics present in a wastewater) is oxidized by an electrochemically active biofilm which can subsequently transfer the liberated electrons to an electrode (here anode). Secondly, the electrons at the anode are driven by a potential gradient to flow toward a cathode via an external electrical circuit. Electrical energy is generated if a suitable resistive load is located between the two electrodes. Thirdly, the electrons at the cathode react with a soluble electron accepting species (e.g. oxygen, nitrate) which becomes reduced. Similar to a hydrogen fuel cell (e.g. proton exchange membrane fuel cell), electricity generation in a BES is sustained only when the ionic charges between the anode and cathode is balanced. For each electron flowing across the external circuit, a positively/negatively charged ionic species must be transferred from the anode/cathode. The buildup of a proton gradient (pH splitting) is recognized as the key obstacle for efficient current generation in MFC (Harnisch and Schroder, 2009; Rozendal et al., 2006). Such pH splitting phenomena could lead to as high as a 6 pH units difference between the two electrodes (Claauwaert et al., 2008), hence severely stifling the driving force of the system (i.e., potential difference between anode and cathode) as each unit of pH gradient represents an overpotential (potential loss) of 59 mV (Nernst equation). Correcting the pH by acid/base dosing or addition of a concentrated buffer (e.g. phosphate buffer) is not feasible for large-scale application, although these methods are effective in laboratory trials (Cheng et al., 2010). A loop-concept has been described as a mitigation strategy for the aforementioned pH limitation during MFC operation, where the acidified anodic effluent of a MFC served as the influent for the cathode in a two-compartment configuration (Freguia et al., 2007). However, the obligatory requirement of mechanical recirculation of wastewater throughout the system against gravity may limit process scale-up (Claauwaert et al., 2009; Freguia et al., 2007).

Here, a new BES configuration, rotatable bioelectrochemical contactor (RBEC) is described and evaluated for its capacity to convert soluble organics directly into electrical current without using conventional pH control methods or the need of energy consuming wastewater re-circulation. While similar to the well-known rotating biological contactor (RBC), the RBEC has several distinctive fea-