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# Hydrogen production and ammonium recovery from urine by a Microbial Electrolysis Cell

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## ABSTRACT

We investigated the use of a Microbial Electrolysis Cell (MEC) for the ammonium removal, COD removal and hydrogen production from five times diluted urine. During operation with a batch cathode, a current density of  $23.07 \pm 1.15 \text{ A m}^{-2}$  was achieved corresponding to a hydrogen production rate of  $48.6 \pm 7.47 \text{ m}^3 \text{ H}_2 \text{ m}^{-3} \text{ MEC d}^{-1}$ , an ammonium removal rate of  $173.4 \pm 18.1 \text{ g N m}^{-2} \text{ d}^{-1}$  and a COD removal rate of  $171.0 \pm 16.9 \text{ g COD m}^{-2} \text{ d}^{-1}$ . Ammonia stripping was not possible in the applied MEC and ammonia diffusion from cathode to anode compartment led to a relatively short stable operation period. The stable operation period was prolonged by addition of new cathode media (HRT 6 h), but this resulted in a lower current density ( $14.64 \pm 1.65 \text{ A m}^{-2}$ ), hydrogen production rate ( $32.0 \pm 0.89 \text{ m}^3 \text{ H}_2 \text{ m}^{-3} \text{ MEC d}^{-1}$ ), ammonium removal rate ( $162.18 \pm 10.37 \text{ g N m}^{-2} \text{ d}^{-1}$ ) and COD removal rate ( $130.56 \pm 4.45 \text{ g COD m}^{-2} \text{ d}^{-1}$ ).

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## 1. Introduction

On average one person excretes 1.5 L of urine per day, which corresponds with about 1 volume% of the total produced domestic wastewater. At the same time approximately 80% of the total amount of nitrogen (N) present in this wastewater originates from urine [1,2]. Most nitrogen in urine is found in the form of urea. In the presence of the enzyme urease, urea is hydrolysed to ammonia and carbamate, whereas carbamate further decomposes to bicarbonate and ammonia [3]. As a result of this hydrolysis and subsequent decompositions, ammonia and ammonium account for 90% of the nitrogen in urine [4]. Conventionally, nitrogen compounds are removed from wastewater as they increase the risk of eutrophication of receiving water bodies. At the same time large amounts of

nitrogen fertilizers are produced and applied in agriculture. In 2012 approximately 10.5 Mt N based fertilizers were used in the EU [5].

Removal or recovery of nitrogen from wastewater and urine is energy intensive; conventional nitrification and denitrification requires  $45 \text{ kJ g}^{-1} \text{ N}$  removed, nitrogen removal by the Sharon – Anammox process requires  $16\text{--}19 \text{ kJ g}^{-1} \text{ N}$  removed, while ammonia recovery by  $\text{NH}_3$  stripping requires an even higher  $32.5 \text{ kJ g}^{-1} \text{ N}$  recovered [2].

Recent work has demonstrated that ammonia can be recovered in a bioelectrochemical system (BES), in this case a Microbial Fuel Cell (MFC), in which no power was consumed but a net energy production of  $3.46 \text{ kJ g}^{-1} \text{ N}$  recovered was achieved [6]. BES are an emerging field focussing on various applications, which are ranging from energy [7,8] and

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hydrogen production from wastewater [9] to synthesis of fuels [10] and chemicals [11].

A BES consists of two electrodes; an anode and a cathode which are often separated by an ion selective membrane. At the anode, bacteria catalyse the oxidation of organic matter to electrons, carbon dioxide and protons. In the absence of an electron acceptor (oxygen) at the anode, the electrons are transferred by the bacteria to the electrode and are transported via the electrical circuit to the cathode. At the cathode a reduction reaction takes place. In case of an MFC, oxygen is reduced to water and hydroxyl ions are produced [12]. The electron transport over the electrical circuit induces an ion transport over the ion exchange membrane to compensate for the negative charge transport (electrons) and maintain electro neutrality of the system [13–15]. Due to the hydroxyl ion production the pH in the cathode chamber increases and ammonium ( $\text{NH}_4^+$ ) transforms into volatile ammonia ( $\text{NH}_3$ ), which can be recovered from the cathode compartment by  $\text{NH}_3$  stripping [6,16]. In case of a Microbial Electrolysis Cell (MEC), water is reduced to hydrogen and hydroxyl ions at the cathode [9]. The use of an MEC instead of an MFC for recovery of ammonia from urine can have distinct advantages. The hydrogen gas production eliminates the need of aeration of the cathode, which is necessary in an MFC based ammonium recovery concept, and the produced hydrogen gas has a higher economic value than electricity [17]. Furthermore, the produced hydrogen gas in the cathode can aid in the removal of ammonia from the liquid phase of the cathode and thereby increase the driving force for removal of ammonium from the

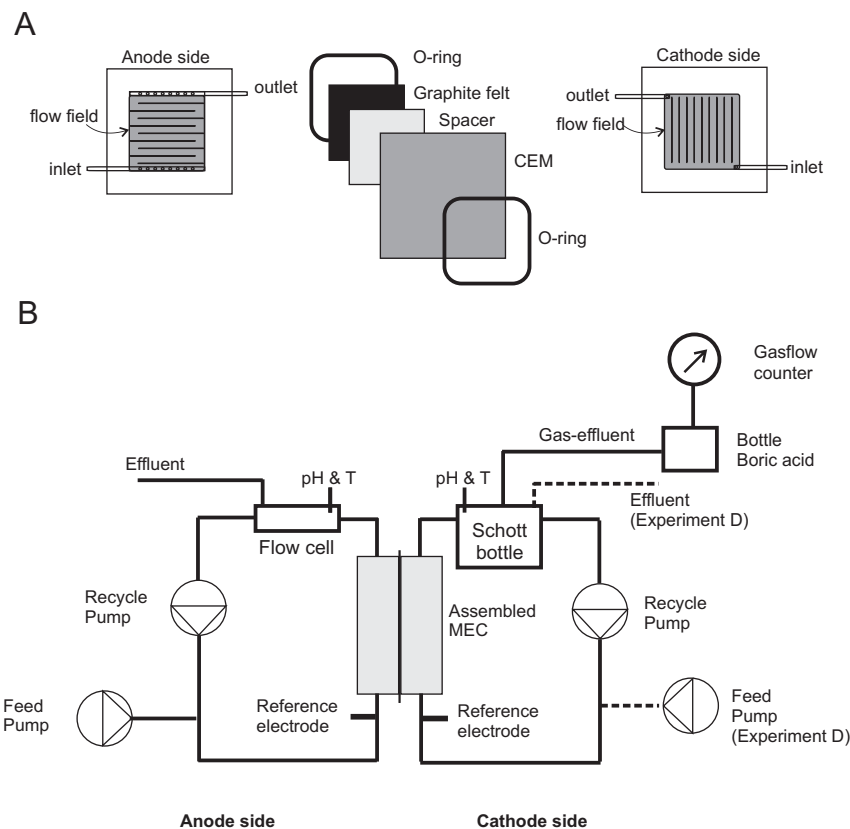
anode compartment [18]. Finally, the applied voltage allows for higher current densities to be gained, which increases the ammonium transport and removal rate [17].

In this work we demonstrate the use of an MEC for the treatment of urine. This manuscript shows that hydrogen can be produced and ammonium can be recovered from urine at the same time. The performance of the MEC was assessed by the current density, the coulombic efficiency, the hydrogen production rate, the cathode efficiency, the ammonium removal rate, ammonium removal efficiency, COD removal rate, COD removal efficiency and the energy requirement of the MEC.

## 2. Material and methods

### 2.1. Setup and experimental procedures

The experimental setup consisted of a 2 chamber MEC (Fig. 1A) made from titanium (Magneto Special Anodes, Schiedam, The Netherlands) with platinum (Pt) coated flow fields using  $2.5 \mu\text{m}$  Pt coating ( $50 \text{ g Pt/m}^2$ ). The flow field of the anode was  $100 \times 100 \times 4 \text{ mm}$  (40 mL), with 8 channels at the inlet and outlets over which the flow was distributed. The cathode flow field was  $100 \times 100 \times 1 \text{ mm}$  (10 mL) with one channel at the inlet and outlet on opposite sides of the flow field. The anode consisted of a graphite felt  $100 \times 100 \times 2.8 \text{ mm}$  (Morgan AM&T Swansea, UK). The graphite felt was compressed with spacer material (thickness 1 mm, 64% open; PETEX 07-4000/64, Sefar



**Fig. 1 – A) schematic representation of the MEC, B) the experimental used during the experiment. The dashed line in indicates the configuration during experiment D, where the cathode media was replenished.**

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