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Simultaneous electricity generation and microbially-assisted electrosynthesis in ceramic MFCs

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ABSTRACT

To date, the development of microbially assisted synthesis in Bioelectrochemical Systems (BESs) has focused on mechanisms that consume energy in order to drive the electrosynthesis process. This work reports – for the first time – on novel ceramic MFC systems that generate electricity whilst simultaneously driving the electrosynthesis of useful chemical products. A novel, inexpensive and low maintenance MFC demonstrated electrical power production and implementation into a practical application. Terracotta based tubular MFCs were able to produce sufficient power to operate an LED continuously over a 7 day period with a concomitant 92% COD reduction. Whilst the MFCs were generating energy, an alkaline solution was produced on the cathode that was directly related to the amount of power generated. The alkaline catholyte was able to fix CO_2 into carbonate/bicarbonate salts. This approach implies carbon capture and storage (CCS), effectively capturing CO_2 through wet caustic 'scrubbing' on the cathode, which ultimately locks carbon dioxide.

1. Introduction

The cost of energy generation and wastewater treatment is expected to increase in the near future, in order to meet the growing global population and the resultant demand on resources. The treatment of wastewater is typically viewed as an energy intensive burden rather than a resource. The energy value of domestic wastewater can be up to 7.6 kJ per litre (kJ/L) and that of mixed industrial and domestic wastewater as much as 16.8 kJ/L [1]. By harnessing this energy in wastewater, the water industries can become more efficient both financially and environmentally. In addition, wastewater could become a source of energy in parts of the world, which currently lack the essential infrastructure for reliable and affordable energy generation and distribution. Globally, there is an urgent need for low-cost water treatment technologies both in developed and developing countries.

Research in the field of bioelectrochemical systems (BESs) has focused on converting compounds in wastewater to either bioelectricity via microbial fuel cell (MFC), or other energetically valuable products [2]. Properties of the proton selective membrane and its configuration in a dual-chamber MFC offer the opportunity to transfer cations from the anolyte over to the cathode [3]. In this way the cathode can be exploited as a mechanism for removing specific contaminants e.g., heavy metals [4]. This can be taken a step further by supplying an external energy into the BES system, where valuable products such as hydrogen gas [5], hydrogen peroxide [6], methane [7] or caustic soda [8] can be recovered.

The formation of caustic soda for example, is driven by the alkalinisation on the cathode side due to the continuous consumption of protons by the oxygen reduction reaction (ORR) and cationic flux [3]. In general, ORR on the carbon based cathodes proceeds either via the two- or four-electron pathway. The 4-electron pathway appears to be predominant on noble metal catalysts, whilst the 2-electron pathway, known as the peroxide pathway, is more common on carbon based electrodes. In acidic conditions, it will result in the formation of hydrogen peroxide, which is further reduced to water. In an alkaline environment it will result in generation of OH– [9] that leads to a further increase in pH. MFC operation causes not only transport of ions (protons and cations) but also flow of liquid through the membrane, which leads to the so called electroosmotic transport of water [10]. This has resulted in many recent studies moving away from electricity generation and instead focussing on electricity consumption via Microbial Electrolysis Cells, where microbially assisted electrosynthesis can effectively be used for the production of oxidants or disinfectants [11] or even water dissociation via electrodialysis for separating the ionic species. However, it has recently been reported that the same process of microbially driven electrosynthesis can be achieved with both energy production and simultaneous elemental recovery in a simple MFC design [12]. This process generated a highly saline catholyte that additionally acted as a dragging mechanism, similar to the osmotic MFC. The osmotic microbial fuel cell (OsMFC), incorporates forward osmosis membranes, NaCl as the catholyte solution and usually, platinum electrodes. OsMFC represents a water extraction technology, which can recover

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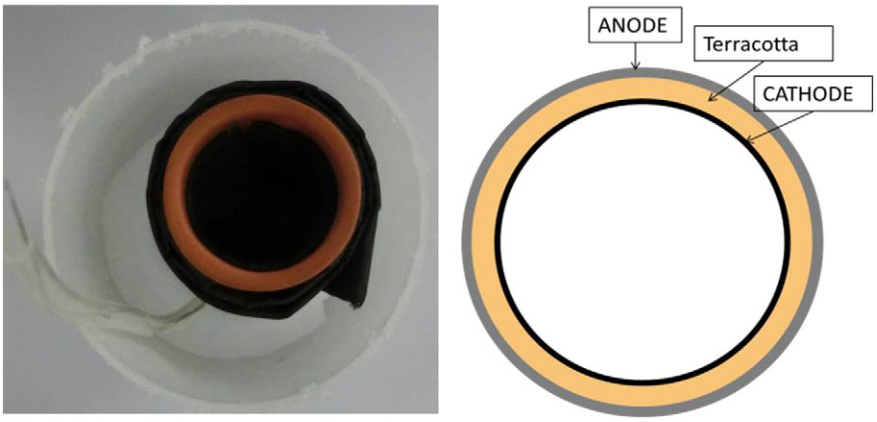

Fig. 1. The ceramic MFC assembled and its schematic description.

water molecules from the anolyte through the membrane via osmotic pressure [13]. This relies on forward osmosis (FO), where the osmotic pressure gradient that exists between solutions of two different concentrations is driving the transport of water across the membrane. The driving force is created by high solute concentration solution and water transport occurs naturally via electro passive transport. In OsMFC, externally supplied salt solution is used as catholyte and has been shown to increase current generation [14], however the disadvantage of FO reactors is the salt leakage across the membrane [15].

Wastewater, as an abundant biological resource has an enormous potential for clean energy, and its treatment is an important benefit of this process. In order for the MFC technology to be feasible and implemented in real world conditions, the performance needs to be improved and its design has to be simplified to become cost effective for practical use. To explore this path further it is important to look into cost effective materials, design and methodology to showcase the technology as a serious contender for practical implementation in wastewater treatment plants. For example, ceramic material has been recognised as a low cost alternative to PEM and used as septum/separator [16] or as a whole MFC reactor [17–20]. In addition, the electrode material is another critical factor of the MFC architecture that plays an important role in performance, cost of production and preparation, as well as longevity and maintenance. In this respect, activated carbon based cathodes are inexpensive and useful alternatives to Pt-catalysed electrodes in MFCs [21–24].

The aims of this work were therefore to: i) develop a simple, ceramic based MFC design as an immersed anode in a wastewater tank for both energy recovery and microbially driven electrosynthesis of catholyte; ii) explore simple and cost effective designs based only on carbon electrodes and ceramic materials, and iii) demonstrate the catholyte generation in situ within the catholyte chamber as a means of water recovery and carbon capture.

2. Materials and methods

2.1. MFC design and operation

MFCs were built using terracotta caves (Orwell Aquatics, UK) of 10 cm length, 4.2 cm outside diameter, 3.6 cm inside diameter and wall thickness of 3 mm. They were assembled with carbon veil anode

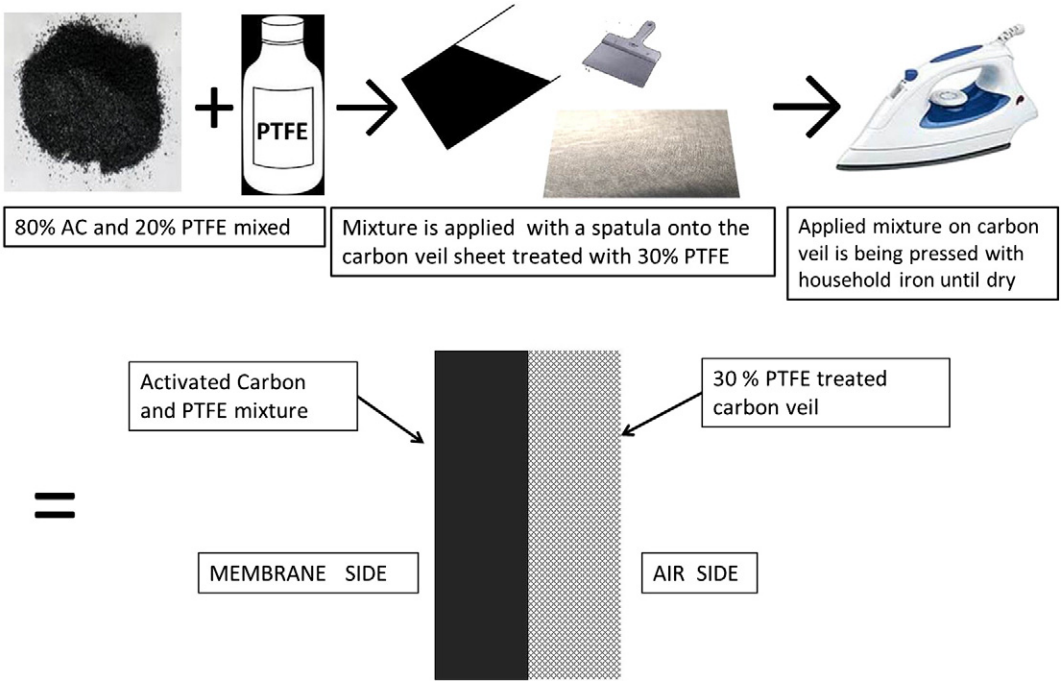

Fig. 2. Cathode electrode preparation procedure.