Microbial electrolysis cells as innovative technology for hydrogen production

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Abstract: *Hydrogen production is becoming increasingly important in view of using hydrogen in fuel cells. However, most of the production of hydrogen so far comes from the combustion of fossil fuels and water electrolysis. Microbial Electrolysis Cell (MEC), also known as Bioelectrochemically Assisted Microbial Reactor, is an ecologically clean, renewable and innovative technology for hydrogen production. Microbial electrolysis cells produce hydrogen mainly from waste biomass assisted by various bacteria strains. The principle of MECs and their constructional elements are reviewed and discussed.*

Keywords: *microbial Electrolysis Cells, hydrogen production, waste biomass purification*

1. INTRODUCTION

One of the major global problems nowadays is to satisfy the rapidly rising energy demands. The existing energy system has two main disadvantages: first, the energy is produced mainly from fossil fuels, whose resources are limited and second, the use of hydrocarbon fuels causes dangerous environmental pollution due to the huge emissions of CO_2. That's why the need of using alternative power sources, which can gradually replace the traditional energy fuels, is widely discussed [1].

The opinion of more scientists is that the hydrogen will be the main power source in the future [2]. The hydrogen has three times more caloricity than petrol and it has not corrosive effect on the metals. The producing of hydrogen is still expensive and that is limiting its wide application [3]. Conventional electrolysis is one of the two most common methods currently used to produce hydrogen. Hydrogen production by electrolysis is not connected with CO_2 emission. The insufficiency of this method is that it needs large quantity of electricity.

Microbial electrolysis cells (MECs) could be a partial solution of the problem. A MEC is an electrolyzer that oxidizes organic matter at the anode, while the cathode carries out the abiotic reduction of water in the usual way [4]. Using microorganisms in electrolysis systems decreases the overpotential, makes easier the electron transfer and reduces the necessary quantity of electricity for the electrolysis. Theoretically, the hydrogen evolution on the cathode needs a potential of E_{CAT} = − 0.41 V (vs.SHE). The anode potential of most MFCs reaches around E_{AN} = − 0.30 V (vs.SHE). Therefore, the minimum overall cell voltage needed is E=-0.11 V [5].

$$E = E_{CAT} - E_{AN} = (-0.41) - (-0.30) = -0.11V \tag{1}$$

The most important thing is that the MECs use substrates from renewable sources and have high conversion efficiency. That’s why MEC is an appropriate technology for potential application in local power plants and also for simultaneously wastewater treatment and hydrogen generation.

The development of microbial electrolysis cells (MECs) represents an exciting new area of environmental biotechnological research, exploiting common wastewater as a fuel source to produce hydrogen. The first demonstration of the renewable method for hydrogen production from wastewater using a microbial electrolysis system is underway at the Napa Wine Company in Oakville [6].

The MEC has been intensively investigated and developed for the last five years. For the progress of this innovative technology the generalization of achievements is of a big importance. In this paper, the principles and construction elements of MEC are reviewed and discussed.

2. MEC

2.1. Structure and operating principle

Microbial electrolysis cell is a technology for hydrogen production closely related to Microbial fuel cells (MFCs). Whilst MFC's produce an electric current from the microbial decomposition of organic compounds, MEC's partially reverse the process to generate hydrogen or methane from organic material by applying an electric current. The anode process of an MEC is the same as that of a MFC and the cathode process is the same as that of a water electrolyzer [7]. In principle, MEC can be divided into three major components: anode chamber, cathode chamber and separator [8] (Fig.1).

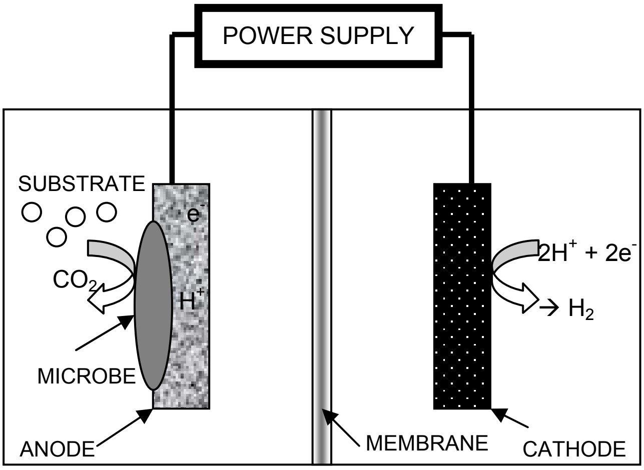

Fig.1: The working principle of a microbial electrolysis cell

In an MEC, electrochemically active microbes growing on the surface of the anode break down organic matter into CO_2, electrons and protons. The electrons and protons pass through the external electric circuit and the electrolyte, respectively, and combine at the cathode to generate hydrogen. The oxidation at the anode is supported by a microbial biofilm on the electrode, which acts as an electrocatalyst. MEC proposes to design specific microbial biofilms for the development of MEC anodes by identifying new sources of inoculum, adapting the microbial population and determining the structural characteristics of biofilm that will optimize its electroactive properties [9].

The most investigated microbial cultures for application in MECs are Archaea, the single-celled cyanobacterium Cyanothece 51142 [9], Dechlorinating bacteria (Dehalococcoides spp. and Desulfitobacterium spp.) and also methanogens and homoacetogens microorganisms [10]. Biowaste and wastewater provide immediate profits and the greatest likelihood for success of MEC technology. Abundant and renewable cellulosic biomass can potentially produce enough hydrogen for transportation and industrial use [5]. The identity of the specific microorganisms determines the products and the efficiency of the MEC. Electrogenic microorganisms consuming an energy source (such as acetic acid) release electrons and protons, creating an electrical potential of up to 0,3 V. In a conventional MFC, this voltage is used to generate electrical power. In a MEC, an additional voltage is supplied to the cell from an outside power source. The combined voltage is sufficient to reduce protons, producing hydrogen gas. The efficiency of hydrogen production depends on which organic substances are used. Lactic and acetic acid achieve 82% efficiency, while the values for unpretreated cellulose or glucose are close to 63%. The efficiency of normal water electrolysis is 60 to 70 percent. As MEC’s convert unusable biomass into usable hydrogen, they can produce 144% more usable energy than they consume as electrical energy. Depending on the organisms presented at the anode, MEC’s can also produce methane by a related mechanism [11].

2.2. Electrode catalyst materials

The anode material in a MEC can be the same as in a MFC, such as carbon cloth, carbon paper, graphite felt, graphite granules or graphite brushes. The development of highly efficient anode materials is critical for enhancing the current output of microbial electrochemical cells. Au and Pd nanoparticle decorated graphite anodes were developed and evaluated in a newly designed multi-anode microbial electrolysis cell (MEC). On the contrary, no significant correlation was evident between the current density and the particle density based on area fraction and particle counts. These results demonstrated that nano-decoration can greatly enhance the performance of microbial anodes while the chemical composition, size and shape of the nanoparticles determined the extent of the enhancement [13]. Use of carbon cloth or thin graphite felt as anode materials may provide great advantages over other materials for scale-up.

Platinum is well known as the best cathode catalyst material used in MEC, but it is too expensive [7,14]. The high cost of platinum is driving research into bio-cathodes as an alternative. Extensive studies have been also carried out on precious metal-free catalysts for MEC. Low-cost materials as stainless steal and carbon based NiMo-, NiW-nanocomposites showed good performance as cathode in MEC [15]. Penn State researchers have found a way to replace the platinum catalyst in their hydrogen generating microbial electrolysis cells with stainless steel brushes without losing efficiency. The trapped hydrogen also remains in the reactor longer and is therefore available to microbes that consume hydrogen [12]. The limitation of extending these results to MECs is that they have been only examined under highly acid or alkaline conditions [16,17] Investigation of cathode materials that are efficient catalysts at neutral pH is needed [4].

2.3. General MEC design

MEC can be developed as a single-chamber or a two-chamber system. A MEC lacking a membrane can produce high hydrogen and energy recoveries. Operating without a membrane can allow for more cost effective and simpler designs [5]. Use of a membrane in two-chamber MEC systems can reduce the amount of impurities in the biogas but increase the internal resistance. Removal of the membrane in single-chamber systems simplifies the reactor design but increases the possibility for hydrogen consumption by methanogenic bacteria [4].

3. PERSPECTIVES FOR MEC APPLICATION

Research on the innovative and novel MEC technology is in its infancy. As the bioanode reactions are much more extensively studied in MFC, crucial for the MEC practical application and commercialization is the development of cost-effective cathodes for near-neutral pH and low temperature conditions as well as the minimization of the internal resistance by improvement of the cell design.

MECs can potentially be used for different applications. The main application of MEC is to produce hydrogen, which can be used in different directs. Other application is for effective wastewater treatment. MEC have the potential to convert waste organic matter into a valuable energy source [18].

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