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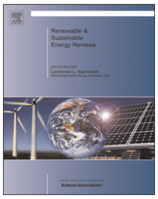

Microbial electrochemical technologies with the perspective of harnessing bioenergy: Maneuvering towards upscaling

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ABSTRACT

Microbial electrochemical technologies have gained much attention in the recent years during which basic research has been carried out to provide proof of concept by utilizing microorganisms for generating bioenergy in an electro redox active environment. However, these bio-electrocatalyzed systems pose significant challenges towards up-scaling and practical applications. Various parameters viz., electrodes, materials, configuration, biocatalyst, reaction kinetics, fabrication and operational costs, resistance for electron transfer etc. will critically govern the performance of microbial catalyzed electrochemical systems. Majorly, the surface area of electrode materials, biofilm coverage on the electrode surface, enrichment of electrochemically active electrode respiring bacteria and reduction reactions at cathode will aid in increasing the reaction kinetics towards the upscaling of microbial electrochemical technologies. Enrichment of electroactive microbial community on anode electrode can be promoted with electrode pretreatment, controlled anode potential or electrical current, external resistance, optimal operation temperature, chemical additions and bioaugmentation . Inhibition of the growth of methanogens also increases the columbic efficiency, an essential parameter that determines the efficacy of bioelectricity generation. Considering the practical implementation of these microbial electrochemical technologies, the current review addresses the challenges and strategies to improve the performance of bio-electrocatalyzed systems with respect to the operational, physico-chemical and biological factors towards scale up. Besides, the feasibility for long term operation, the scope for future research along with the operational and maintenance costs are discussed to provide a broad spectrum on the role of the system components for the implementation of these bio-electrochemical technologies for practical utility.

Contents

Abbreviations: AEM, Anion exchange membranes; Ag/AgCl, Silver/Silver chloride; BES, Bioelectrochemical system; BESA, 2-bromoethanesulfonic acid; BET, Bioelectrochemical treatment system; CE, Coulombic efficiency; CEM, Cation exchange membrane; COD, Chemical oxygen demand; Co-OMS-2, Copper cryptomelane-type octahedral molecular sieve; CoTMPP, Cobalt tetra methyl phenyl porphyrin; DET, Direct electron transfer; $e-$, Electrons; EAB, Electrochemically active bacteria; ED, Electron discharge; EET, Extracellular electron transfer; FePc, Iron phthalocyanine; $H+$, Protons; MEC, Microbial electrolytic cell; MES, Microbial electrochemical systems; MET, Mediated electron transfer; MFC, Microbial fuel cell; MnO_2, Manganese oxides; MWCNT, Carbon based multiwalled nanotubes; PbO_2, Lead oxide; PBS, Phosphate-buffered saline; PD, Power density; PDMS, Poly-dimethylsiloxane; PMS, Power management systems; RBEC, Rotatable bioelectrochemical contractor; SHE, Standard hydrogen electrode; TEA, Terminal electron acceptor; TEAP, Terminal electron accepting process; UFM, Ultrafiltration membrane; VFA, Volatile fatty acids; WWMFC, Overflow-type wetted-wall MFC

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1. Introduction

Microbial electrochemical technology has been emerging as a sustainable biotechnology platform, due to its inherent ability to produce bioenergy and recover value added products. Microbial electrochemical systems (MES) have diverse applications, which include microbial fuel cells (MFC, for harnessing bioelectricity), bioelectrochemical treatment systems (BET, waste remediation), bioelectrochemical systems (BES, bio-electrosynthesis of various value added products) and microbial electrolysis cells (MEC, H_2 production at low applied potential) [1–5]. Microorganisms function as biocatalyst in these systems, advocating the electron flux from metabolic reactions and plays a pivotal role in the bio-electrogenic activity. The research on these microbial catalyzed electrochemical hybrid systems have been intensified for the past 5 years in both basic and applied area [6–8].

So far, MFCs are the most studied type of MES. They function mainly by converting chemical energy to electrical energy through a cascade of redox reactions in the presence of biocatalysts. MFCs use solid electrodes as electron acceptors (anode) and/or electron donors (cathode) to expedite microbial metabolism catalyzing bioelectrochemical redox reactions. The artificial electron acceptor (electrode) induces the development of potential difference, which acts as a net driving force to transfer the electrons from anode to cathode [9–11]. Irrespective of the nature of biocatalyst, both anabolism and catabolism will be involved in the utilization of available substrate for generating reducing equivalents [protons (H^+) and electrons (e^-)] in the form of redox carriers which will help in generating bioenergy [9,12]. MFCs can utilize a wide range of soluble or dissolved complex organic molecules including solid wastes, wastewaters and renewable biomass as substrate (anolyte). Use of mixed consortia as the biocatalyst and wastewater as the feedstock is an economically viable option to upgrade MFCs in the existing effluent treatment units which will have dual benefits viz., treatment of wastewater as well as bioelectricity generation [13,14].

Though MESs are featured to be simple, yet they are governed by various parameters that significantly affect their performance. Fuel cell configuration and design, electrodes and separator materials, pH, concentration of the substrate, anolyte, catholyte, mediators, microbial culture, etc. contribute significantly to the efficiency of an MFC. Two major bottlenecks involved towards practical application of MFCs are low power density and high fabrication and operation costs. Scale-up is an important issue for bringing this technology from lab scale to pilot scale. The main challenges for commercializing a scalable MFC include development of effective and low-cost materials, effective design and increasing power recovery [5]. Simple configuration and low cost are the key factors for the successful application of an MFC at large-scale [15]. MFC research has been extended from reactor ranging from bench scale to semi pilot scale which can provide valuable leads like optimized operational parameters, design configuration etc., to commercialize MFCs in future [16,17]. There are specific limitations for up-scaling this process viz., high internal resistance, pH buffering, low energy gain from the biocatalyst, electrode fouling, etc. Long term stability is important for MFC operation when the economic feasibility and energy balances are considered.

Scaling up of MFCs to production scale is important for real field applications with enhanced bioelectricity generation and concurrent waste treatment. Therefore, this review addresses the contemporary progress and advances made in MES, focusing on some important issues that need to be addressed towards upscaling this technology for efficient waste to energy conversion. These aspects include electrode materials, reduction kinetics at cathode, internal resistance, rate of electron transfer, membrane cost and stacking of MFCs.

- Electrode materials play an important role in the performance of MFCs, especially the effect of surface properties influences