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Multi-electrode microbial fuel cell (MEMFC): A close analysis towards large scale system architecture

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ABSTRACT

Microbial fuel cells are capable of producing electricity through the treatment of wastewater, however, the low power density poses main hurdles towards their wide application. In present work, microbial fuel cell based on multiple anodes, acting as baffle is constructed for achieving higher performance which can be scaled up for real life application. It is investigated for continuous sixty two days using distillery wastewater (WW) in three batches under ambient condition. During first batch, the WW is maintained under stagnant condition inside the anode chamber where as in the rest of the two batches WW is recirculated in the chamber. A maximum power density 427 mW m^{-2}, is achieved under stagnant condition which is further enhanced to 597 mW m^{-2} under recirculation mode. Recirculation of WW reduces the internal resistance arising from the mass transfer by 50%. Maximum COD removal and Coulombic efficiency obtained is 43% and 23%. Biofouling on the surface of the membrane facing anode chamber is observed.

1. Introduction

Access to the energy is the prime indicator of the lifestyle of present society, which has led to increase the production of commodities leading to an increase in effluent. A substantial amount of energy is being consumed in recycling them. In many occasions the effluent contains significant amount of organic substances which is considered as significant source of energy. Recovery of the energy through the consumptions of the organic substances present in the effluent facilitates to treat them partially. Microbial fuel cell is a device which is capable of directly converting chemical energy present in the organic materials to electricity using micro-organism as catalyst [1,2]. It also facilitates the treatment of the wastewater (WW) partially while producing the electricity. Low power density and conversion efficiency of MFCs pose the main hurdles towards the wide applications of them.

Recently, major emphasis is paid in MFC research to achieve efficient system architecture [3–6], elucidation electron transfer mechanism at molecular level [7–9], low cost and efficient anode and cathode developed [10]. The performance of the reactor basically depends on intrinsic and extrinsic parameters viz, system architecture, electrode material, bacterial community and extrinsic parameters like operating temperature, pH of the substrate, organic load etc [11]. For the adoption in industrial scale installation of MFCs, extrinsic major parameters plays significant role i.e. material which is needed for fabrication and system architecture.

Several designs have been put forward by researchers to obtain high power density such as Benthic Microbial Fuel

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Nomenclature

b	constant, g A^{-1} d^{-1}%
COD(0)	initial COD, mg L^{-1}
COD(t)	COD at the time t, mg L^{-1}
ΔCOD(t)	total COD removal in t days, mg
$\Delta COD_{cu\%}(t)$	cumulative COD removal efficiency after time t, %
$\Delta COD_{cu}(t)$	cumulative COD removal after time t, mg L^{-1}
F	Faraday's constant, C mol^{-1}
η_{col}	Coulombic efficiency
i_{av}	average current during period t, mA
R_{int}	internal resistance
R_{ex}	external resistance
M	molecular weight of oxygen, g
n	number of electrons exchanged per mole of oxygen reduction
V	volume of the anode chamber, L

Abbreviation

ABR	anaerobic baffled reactor
ARB	anode-respiring bacteria
CE	Coulombic efficiency
COD	chemical oxygen demand
CR	constant resistance mode
HRT	hydraulic retention time
MEMFC	multi-electrode microbial fuel cell
MEA	membrane electrode assembly
MFC	microbial fuel cell
OCV	open circuit voltage
SRT	solid retention time
WW	wastewater

Cell [3], single chamber MFC [4], up flow MFC with an interior cathode [5], flat plate microbial fuel cell [6]. Different substrates are used for electricity generation viz, synthetic WW, industrial WW, domestic WW, etc [11]. The performance of the reactor can be improved by decreasing the internal resistance of the system, using efficient electrode material and fabricating efficient system architecture, which can provide improved environment to bacterial community to work efficiently [10,12,13].

Conventionally, anaerobic WW treatment technology provides potential for reducing treatment costs and anaerobic baffled reactor (ABR) is used worldwide for efficient treatment of wastewater [14]. The WW bends in the reactor along the guiding baffle, followed by each sludge bed in an up and down manner. This allows a longer solid retention time (SRT), thus allowing the organic compounds to be utilized through sufficient contact with the micro-organisms which have been produced on surface of baffle as biofilm [14,15], because of obstruction, degradation taken place faster compared to normal degradation, hydraulic retention time (HRT) is relatively short and varies from only a few hours up to two or three days [16,17].

In this work, a Multi-electrode microbial fuel cell (MEMFC) is fabricated based on ABR, where, anodes are arranged in baffled fashion which can be easily scaled up to industrial scale. Present arrangement offers an enhancement in the retention time for the organic material to interact with the active biomass.

2. Materials and methods

2.1. System architecture

Multi-electrode Microbial Fuel Cell is fabricated using transparent acrylic sheet of thickness 8 mm in the form of hexagonal prism with a height of 15 cm as shown in Fig. 1a. The reactor consists of a pair of concentric hexagonal prism separated by a distance of 7 cm. The side length of the outer and inner hexagon is 9.5 cm and 2.5 cm respectively to provide an empty bed (anode chamber) volume of 3.27 L. On each face of the outer hexagonal prism, a rectangular window of dimensions 8.5 cm × 5 cm is created for placing cathode electrode for free air breathing. The windows on the reactor can accommodate a total cathode surface area of 255 cm^2. Total twelve vertical slots are created inside the anode chamber for placing baffle plate to improve the mixing of the organic materials. One of the twelve slots is reserved for placing separator to ensure unidirectional flow of WW from the inlet to the outlet inside the anode chamber. Effluent is fed in the anode chamber from the ceiling of the reactor and discharged from the bottom of the reactor. The outlet of the anode chamber is connected to the inlet through a mini fountain pump, to maintain continuous circulation of WW. In order to achieve scaled up design, the hexagonal prism can be replaced with polygonal prism to achieve larger footprint area. The volume can be further increased by increasing the height of the reactor. Each side of the polygonal prism can have several openings aligned vertically for accommodating the cathode electrodes.

2.2. Anode configuration

Expanded graphite sheet of thickness 1 mm is used to fabricate the anode electrode of dimension 7 cm × 11 cm. These sheets are further roughened to enhance the microbial adhesion, which results in well-established biofilm. These sheets are inserted in the eleven slots inside the anode chamber to act as baffle plate. A set of anode plates are fasten alternatively with one side attached to the floor of the reactors and leaving a gap of 4 cm between the ceiling and the plates. Another set of plates are alternatively attached to the ceiling of the reactor leaving a gap of 4 cm at the bottom of the reactor as shown in Fig. 1a. Each of the anode plates are connected to the external load through copper wire.

2.3. Cathode configuration

Fine platinized carbon powder (Pt content 20%; Vulcan) is coated on flexible carbon paper (Toray Carbon Paper TGP-H-060) to fabricate the cathode electrode. The platinum loading