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Simultaneous organic matter removal and disinfection of wastewater with enhanced power generation in microbial fuel cell

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HIGHLIGHTS

- Major breakthrough in MFC research is disinfection with hypochlorite catholyte.
- Simultaneous secondary treatment and disinfection can be achieved in MFCs.
- Power generation increases by increasing available chlorine dose from 0.67 to 3 g/L.
- At Cl_2 dose of 3 g/L Coulombic efficiency of 26% and 6 fold more power is produced.
- Both the chambers of MFC were effectively used for pollutant removal.

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ABSTRACT

Presence of pathogenic microorganism in anodic effluent of microbial fuel cell (MFC) makes it unfit for reuse. In this study, performance of dual chamber MFC was evaluated in terms of organic matter removal, power generation and disinfection in cathodic chamber. Anodic effluent was treated further in cathodic chamber for achieving disinfection with different doses of sodium hypochlorite (NaOCl) with available chlorine varying from 0.67, 1.32, 2, 3 and 4 g/L. Addition of different doses of NaOCl resulted in satisfactory disinfection along with removal of nitrogenous compounds. Power output of MFC improved up to 3 g/L of available chlorine (6.5 W/m^3); however, further increase in chlorine concentration decreased the power. Voltammetric and impedance analysis showed higher and faster electron reduction and decrease in polarization resistance at 3 g/L dose. Higher organic matter removal from wastewater and complete elimination of microorganism, along with improved power output, demonstrates effectiveness of hypochlorite as catholyte.

1. Introduction

Adequate supply of water, food, and energy are three major issues facing the world today. In order to address these issues, wastewater is now being looked as a resource rather than a waste, a resource for water, for energy, and for the plant fertilizing nutrients, nitrogen (N) and phosphorus (P) (Asano et al., 2007). Accomplishment of wastewater reuse often increases the energy required for treatment because of increased water quality necessary for reuse. A lot of advancements are going on to meliorate the quality of wastewater treatment, but miserably the more advanced the treatment more energy is required in order to produce better quality effluent.

Microbial fuel cell (MFC) uses electrochemically active bacteria as catalysts to oxidize organic and inorganic matter and generate current. The electrons produced by the bacteria are transported from anode to the cathode through an external circuit and protons are transferred through proton exchange membrane (Du et al., 2007). The effluent treated in anodic chamber of MFC requires further treatment, such as disinfection, ion removal, color removal, etc. for safe disposal into water bodies or to make it suitable for possible reuse. To make MFC as more complete and sustainable solution for wastewater treatment, research needs to be devoted on enhancing the efficiency and quality of treated effluent for possible reuse of treated water.

Increase in power output of MFCs has been reported previously using different chemical catholytes with high redox potentials such as bleaching powder (Momoh and Naeyor, 2010), potassium ferricyanide, dichromate, oxygen (Wei et al., 2012; Guerrero-Rangel et al., 2010), persulfate, permanganate, etc. (You et al.,

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2006; Behera, 2011). The utilization of cathodic chamber for metal recovery along with secondary treatment has been reported (Choi and Cui, 2012). Use of calcium hypochlorite (Momoh and Naeyor, 2010) and sodium hypochlorite (Jadhav et al., 2014) as catholyte in MFC has been reported for enhancing power output of MFC, but this study has not considered disinfection potential of these catholytes. Recently, Arends et al. (2014) explored the disinfection potential of H_2O_2 in constructed wetland bioelectrochemical system (BES) using imposed potential. The reduction of oxygen to hydrogen peroxide in cathodic chamber and complete disinfection at 0.1% H_2O_2 concentration within 1 h of contact time was achieved. To achieve higher power output, this study did not consider optimum dosing of H_2O_2 in BES and also performed disinfection in separate chamber.

After secondary treatment of sewage or other industrial wastewaters in MFC, inoculated with mixed anaerobic sewage sludge, the effluent contains pathogens and other microbes due to which it is not advisable to reuse the treated effluent for human contact reuse or dispose it in water bodies unless it is disinfected. Most of researchers achieved up to 97% chemical oxygen demand (COD) removal in MFC. In order to make anodic effluent suitable for unrestricted and contact reuse purposes, there is need of 99.99% COD removal (AWWA, 1999) and complete disinfection of water. When raw water is heavily contaminated with microorganisms, general practice is to follow pre-chlorination at initial stage apart from post chlorination in water treatment system (AWWA, 1999); which increases cost of water treatment system. Utilization of cathodic chamber of MFC for disinfection can minimize this cost. Also, use of hypochlorite as cathodic electron acceptor in MFC increased power production of this device by 9 times as compared to oxygen as an electron acceptor (Jadhav et al., 2014). However this study has not explored the possibility of disinfection in cathodic chamber. Moreover, it is worth pointing out that use of hypochlorite can eliminate the need of expensive catalyst, required for oxygen reduction on cathode, which makes this process simple and economical.

Use of cathodic chamber for disinfection process in MFC has not been reported so far. Hence, the objective of this study was to explore disinfection of anodic effluent in cathodic chamber of MFC using available chlorine present in hypochlorite solution as catholyte. The aim of this study was to optimize available chlorine dose, for satisfactory disinfection and to increase power output of MFC.

2. Methods

2.1. MFC design and operation

The study was carried out in laboratory scale dual chamber ceramic separator MFC, having stainless steel wire mesh as anode with total surface area of 576 cm^2. The cathode was made up of carbon felt (Panex® 35, Zoltek Corporation) with projected surface area of 1428 cm^2. The MFC had inner cylindrical anodic chamber with working volume of 1.3 L and outer cathodic chamber. The inner cylinder (6 mm thick) was made with baked clayware ceramics and this wall material of the cylinder served as a separator and exchange membrane allowing proton migration from anodic chamber to cathodic chamber. The MFC was operated under batch mode with feeding interval of 5 days. Feed solution with chemical oxygen demand (COD) of 3000 mg/L was prepared by adding sodium acetate (3840 mg/L) as a source of carbon. It also contained (per L) $NaHCO_3$, 4500 mg; NH_4Cl, 954 mg; $CaCl_2{\cdot}2H_2O$, 750 mg; $MgSO_4{\cdot}7H_2O$, 192 mg; K_2HPO_4, 81 mg; and KH_2PO_4, 27 mg. Trace metals were added as $FeSO_4{\cdot}6H_2O$, 30.00 mg/L; $MnSO_4$, 1.58 mg/L; $ZnSO_4{\cdot}7H_2O$, 0.318 mg/L; H_3BO_3, 0.318 mg/L; and $CuSO_4{\cdot}5H_2O$, 13.5 μg/L, $CoCl_2$, 315.6 μg/L, $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$, 315.6 μg/L (Ghangrekar et al., 2005).

This MFC was inoculated initially with anaerobic sludge collected from a septic tank bottom. The inoculum sludge was given a heat pre-treatment (heated at 100 °C for 15 min) for suppressing the activity of methanogens (Jadhav et al., 2014) and 300 ml of sludge was added to the anodic chamber along with synthetic feed. After secondary treatment, effluent from anodic chamber of the MFC was allowed to enter in the cathodic chamber for disinfection (Fig. 1). Disinfection of anodic effluent was tested in cathodic chamber with different sodium hypochlorite (4% w/v available chlorine) dose of 20, 40, 60, 90 and 120 g/L which contains available chlorine doses of 0.67, 1.32, 2, 3 and 4 g/L, respectively. Anode and cathode electrodes were joined with concealed copper wire, connected with 100 Ω external resistance (unless stated otherwise). The connections were made watertight with resin and glue in fixed proportion.

2.2. Chlorine demand for disinfection

The amount of free chlorine present in sample after a given contact time of 1, 5, 10, 15 and 20 min was determined (APHA, 1998). The free chlorine and total chlorine was measured using pocket colorimeter analysis system (HACH test kit, New York). The total chloride content in sample was measured by titrating with $AgNO_3$ (0.141 N) with potassium chromate indicator (APHA, 1998).

2.3. Bacterial count using plating method

The anodic effluent sample was serially diluted and spread on agar plates to count viable cells by plate count method (APHA, 1998). Samples were incubated at 30 °C for 3 days. The colonies were counted with naked eyes. Similar procedure was followed for effluent samples from cathodic chamber after disinfection.

2.4. Water quality analysis

The COD of the anolyte soon after feeding (initial COD) and at the end of feed cycle (final COD) was analyzed by closed reflux colorimetric method as mentioned in Standard Methods (APHA, 1998). Ion chromatography (Metrohm Ion analysis, 761 Compact IC, Switzerland) analysis was performed for measurement of nitrate and nitrite. Other water quality parameters such as dissolved oxygen (DO), conductivity, total dissolved solids (TDS), salinity and pH were measured using a water quality bench meter (Eutech Instruments, Cyber Scan, India). The electrolyte temperature in MFC was monitored regularly using thermometer.

2.5. Electrochemical analysis

2.5.1. Voltage and current

The electrical parameters such as voltage and current were measured using data acquisition unit (34972 A, Agilent Technologies, Malaysia). The voltage was measured in parallel with the external resistance of 100 Ω (unless stated otherwise). Volumetric current density was calculated based on current generated from the MFC per unit volume of effective anodic chamber under different operating conditions. Anodic and cathodic half cell potentials were measured using Ag/AgCl reference electrode (+197 mV vs. SHE, Bioanalytical Systems Inc., USA). Open circuit voltage (OCV) for each MFC was monitored after allowing the circuit to remain in open circuit condition (no current flow and infinite resistance) till the potential value stabilized. The Coulombic efficiency (CE) was calculated as the fraction of total Coulombs actually transferred to the anode against that theoretically present in substrate for current generation (Logan et al., 2006).