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RESEARCH PAPER

Optimization of double chamber microbial fuel cell for domestic wastewater treatment and electricity production

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Abstract: Microbial fuel cells (MFCs) represent a new approach for treating waste water along with electricity production. The present study addressed electricity production from domestic wastewater using a mediator-less double chamber MFC. The electricity production was monitored under different operational conditions for both summer and winter samples. Optimization of the anodic and cathodic chambers resulted in a maximal current of 0.784 mA and 0.645 mA with the maximal power intensity of 209 and 117 mW/m^2 in power duration of 24 h for the summer and winter samples, respectively. Scanning electron microscopy showed that the bacterial biofilm formation on the anode was denser for the summer sample than that when the winter sample was used, so was the total bacterial count. Therefore, samples taken during summer were considered better in electricity production and waste water treatment than those taken during winter basically because of the high microbial load during the hot season. In parallel, there was a decrease in both biological oxygen demand (BOD_5) and chemical oxygen demand (COD) values which reached 71.8% and 72.85%, respectively at the end of the operation process for the summer sample, while there was no evident decrease for the winter sample. Optimizing the operating conditions not only increased the potential of using domestic waste water in microbial fuel cells to produce electricity, but also improved the quality of the domestic waste water.

Key words: microbial fuel cell; domestic wastewater treatment; operating conditions; electricity production

The sharp rise in the industrialization and motorization urgently demands developing new alternative energy sources because current reliance on petroleum-based fuels is unsustainable due to their limited resources. The development of environmentally friendly alternative technologies is imperative to avoid supply problems and contributions to global warming. Biochemically produced electricity is perceived as a promising alternative sustainable technology. The electricity generated is a result of the oxidation of different organic wastes using degrading bacteria[1] into CO_2 and H_2O. Dual chamber MFC is composed of adjacent anodic and cathodic champers separated by a proton exchange membrane. Electrons produced by bacteria from the organic substrates migrate to the anode and flow to the cathode trough a conductive material producing electricity[2]. Microbial fuel cells (MFCs), upon these bases, represent ideal technology for not only harvesting renewable bioelectricity but also using for treatment of many types of wastewater[3] such as brewery wastewater[4], starch processing wastewater[5], dye wastewater[6], domestic wastewater[7], palm oil mill effluent[8] and landfill leachates[9] or to degrade a single compound[10]. The aspect of simultaneous pollutant treatment and power generation acquires MFCs for their green characteristics. Municipal wastewater contains a massive amount of organic materials that can be used as fuel for MFCs.

Polymers are economical material according to their nature and chemical structure, and possess interesting characteristics, such as high chemical resistance and superior thermal stability, However, they do not have much in the way of functionality, such as electrical conductivity, aqueous swelling and ion-exchange capacity. Various approaches have been made to modify the structure of polymeric backbone in order to impart various desirable properties to employ the modified polymers in advanced practical applications. Among these approaches, grafting is a useful technique for designing new materials that not only retain most of their original characteristics but also

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acquire additional properties of the grafted moieties. The radiation-grafting technique is one of the preferable methods because of the uniform and rapid creation of active radical sites. In addition, it is independent of the chemical nature of the polymer. It can be applied at a wide range of temperatures and easily regulated by controlling the reaction conditions. The produced radiation functionalized polymers can be used in different field, such as proton exchange membranes, chelating polymers, conducting polymers, etc[11,12].

Proton-exchange membrane (PEM) is a key constituent of MFC, which is responsible for proton migration from the anode to the cathode. PEMs exhibit several advantages over liquid or solid inorganic electrolytes, such as high proton conductivity, good chemical, thermal and mechanical properties. Sulfonated aromatic polymer membranes have been given attention owing to their high thermal stability as well as excellent barrier properties against fuels (methanol, H_2) and oxygen[13–15]. On the other hand, the radiation functionalized polymer can be converted into conducting polymer used as electrode, which is another key constituent of the MFC, *via* the deposition of highly conduction metal such as silver within the grafted polymer.

The aim of the present study was to produce electricity during the biochemical treatment of domestic wastewater. To achieve such purpose, a double chamber mediator-less microbial fuel cell was constructed *via* the assembly of two glass bottle and radiation developed proton exchange membrane and polymer electrode. For the maximum electricity production from two different climatic seasons of winter and summer, the anodic and cathodic operation factors, such as temperature, pH value, add carbon source, the presence and amount of ferricyanide as electron acceptor, will be optimized.

1 Experimental

1.1 Domestic wastewater

Two samples of domestic wastewater were collected from Al Gabal Al Asfar stage-2 station wastewater treatment plant (WWTP), Cairo Governorate, Egypt, where wastewater aggregated from inlet working pumping station (IWPS) stage only with mechanical treatment. Two samples were taken, one during September representing the hot season and the other during January representing the winter season in Egypt.

1.2 Chemical characteristics of raw and treated domestic waste water

Chemical tests were carried out for both summer and winter wastewater samples before and after treatment as follows. Biological Oxygen Demands (BOD_5) was determined according to Young and Baumann[16]. Chemical Oxygen Demands (COD) was measured according to Annual Book of Standards[17]. Total suspended solids (TSS), total dissolved solids (TDS), total hardness, Phenol, oil and grease were all performed according to Eaton et al[18]. Heavy metal (Iron, Cobalt, Copper, Zinc and Manganese) concentrations were measured using Perkin-Elmer Model 5000 atomic-absorption spectrometer utilizing air-acetylene flame atomic absorption spectrometry[19].

1.3 Configuration of microbial fuel fell

Double chamber MFC was consisted of two 300 mL bottles (anode and cathode) containing each a silver electrode with a surface area of 10.7 cm × 5.1 cm totally immersed in the anode and cathode solution. The bottles were joined by a glass bridge held by a para film between the flattened ends of the two glass tubes. The glass bridge contained a 3.5 cm diameter hole which was covered with proton exchange membrane (PEM) for proton transport. Electricity production was measured in milliampere (mA) against time (min).

1.4 Preparation of proton exchange membrane using gamma irradiation

Low density polyethylene (LDPE) films were thoroughly washed with methanol and dried in a vacuum oven at 50°C for 24 h. Samples were weighed and then immersed in glass ampoules containing styrene (Sty) solution. Ferric chloride as inhibitor was introduced in the reaction mixtures. The reaction mixtures were deaerated by bubbling of nitrogen gas for 4–7 min, sealed and then subjected to ^{60}Co gamma rays. The obtained grafted samples were removed and washed thoroughly with methanol to get rid of the formed homopolymer. The obtained grafted samples were dried in a vacuum oven at 60–70°C for 24 h and weighed. The graft percentage was determined by the percent increase in weight. The low density polyethylene grafted with polystyrene LDPE-g-P(Sty) films were washed with dichloromethane, soaked for 30 min, removed and dried in an oven for 24 h. The films were sulfonated using chlorosulfonic acid solution in 1, 1, 2, 2-tetrachloroethane at room temperature for 3 h. The sulfonated grafted films were removed and thoroughly rinsed with 1, 1, 2, 2-tetrachloroethane and dichloromethane in order to remove the excess of chlorosulfonic acid. The obtained membranes were neutralized with 0.5 mol/L KOH solution overnight and regenerated by boiling with 1 mol/L hydrochloric acid for 2 h. The membranes were thoroughly washed with deionized water in order to ensure complete removal of acid and finally stored in the sealed bottles at