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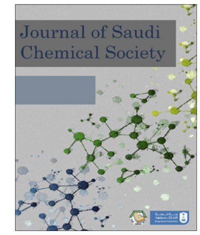

ORIGINAL ARTICLE

Evaluation of dairy industry wastewater treatment and simultaneous bioelectricity generation in a catalyst-less and mediator-less membrane microbial fuel cell

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Abstract Increased human activity and consumption of natural energy resources have led to decline in fossil fuel. These current methods of energy production are not compatible with the environment. In this study catalyst-less and mediator-less membrane microbial fuel cell (CAML-MMFC) represents a new method for simultaneous dairy industry wastewater treatment and bioelectricity generation. The CAML-MMFC used was designed as two chambered that included an anaerobic anode and aerobic cathode compartment and was separated from each other by a proton exchange membrane. The anode and cathode electrodes were made from graphite plate. Current intensity, power density and voltage produced from wastewater as fuel were measured and the effluent from the anode compartment was examined to evaluate pollutant decrease. The maximum current intensity and power density produced were respectively 3.74 mA and 621.13 mW/m^2 on the anode surface, at OLR equal to 53.22 kgCOD/m^3 d and at the external resistance of 1 k Ω. The maximum voltage produced was 0.856 V at OLR equal to 53.22 kgCOD/m^3 d and at temperature 35°C. The maximum coulombic efficiency of 37.16% was achieved at OLR equal to 17.74 kgCOD/m^3 d. The HRT was examined as a factor influencing the power generation and when it was 5 day, maximum voltage and power density were obtained. The maximum removal efficiency of COD,

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BOD_5, NH_3, NH_4^+, dissolved phosphorus, phosphorus in suspended solids, SO_4^{2-}, TSS, and VSS was respectively achieved at 90.46%, 81.72%, 73.22%, 69.43%, 31.18%, 72.45%, 39.43%, 70.17% and 64.6%. The results showed that generating bioelectricity and dairy industry wastewater treatment by CAML-MMFC are a good alternative for producing energy and treating wastewater at the same time.

1. Introduction

Increased human activity and intensive use of natural energy resources, have led to decrease in fossil fuel. The current methods of energy production are not compatible with the environment. Fossil fuels are serious threats to the environment due to the production of greenhouse gases, including carbon dioxide [1,2]. Concerns about climatic change and global warming, increased global demand for oil and the necessity of substituting natural fuel for energy production, require the implementation of new methods for energy production by using natural and renewable carbon resources. In this regard scientists have been through intense efforts in discovering and substituting energy production methods. Many researches have shown that hydrogen and bioelectricity can have an important role as fuel in the future [3]. The technology of Microbial Fuel cells (MFCs) is the latest method for producing electricity from biomaterial by using microorganisms. MFCs are electrochemical converters and convert the chemical energy stored in organic material to current energy by microorganisms which act as biocatalysts in anaerobic conditions [4–6]. Microorganisms in the anode chamber oxidize the substrate added to the system such as wastewater or any other sugary or hydrogenated compound and produce electrons and protons. Free electrons are transferred to the anode electrode and through the external circuit they reach the surface of the electrode cathode. The produced protons pass through the proton exchange membranes or salt bridges and reach the cathode surface and in the presence of oxygen and electrons from water molecules [6,7]. In this process, along with the production of electrical power, the wastewater in the anode chamber is used as a substrate for treatment. Although carbon dioxide is produced during the oxidation process, its dissemination with this technology is low; because the carbon dioxide from renewable substrates originates from photosynthesis in the atmosphere and therefore the amount of carbon dioxide produced is natural [8,9]. The mechanism of electron transfer in MFC is an important topic in their function. Most bacterial species used in MFCs are inactive for electron transfer. Therefore, synthetic and natural compounds such as Thionine, Humic Acid, Neutral Red, Methylene Blue, Methyl viologen, and *Hydroxy naphthoquinone* which are Redox intermediates are used. By adding the mediators the commercial use of MFCs for energy production and wastewater treatment faces trouble, as most of these mediators are expensive and toxic [10,11]. Therefore, nowadays there is a lot of emphasis for improving MFCs without mediators. This method of electricity production leads to improvements in operating costs and increased acceptability of MFCs for wastewater treatment. Recently it has been proved that Iron reducing bacteria such as *Shewanella putrefaciens*, *Shewanella oneidensis*, Geobacteraceae bacteria such as *Geobacter sulfurreducens* and Geobacter metallireducens, Rhodoferax ferrireducens and *Aeromonas hydrophila* which are electrochemically active can transfer electrons to the anode electrode directly, by using Redox enzymes such as cytochrome which are present on the external membrane of bacteria. Soil, marine sediment, fresh water sediment, wastewater and particularly anaerobic and activated sludge are all rich sources for these microorganisms [12,13]. The function of microbial fuel cells is affected by several factors such as the amount of oxidation and electron transfer to the electrodes by microorganisms, loading rate, the nature of the used carbon source, the nature of the proton exchange membrane, proton transfer through the membrane to the cathode chamber, oxygen supply in the cathode, the nature and type of electrodes, circuit resistance, the electrolyte used, operation temperature, pH and sedentary time [14,15]. Among the other uses of this technology is the production of bio- hydrogen and using it as a sensor for pollutant analysis (BOD measurement) [3,10]. MFCs have many advantages, including the cleanliness of the process, efficiency, easy conduct in different circumstances and not producing toxic side by- products; and therefore have shown to be a better option for producing simple and complete renewable energy [13,16]. Industrial dairy wastewater is an important source of organic material for electricity production by using MFCs. In this study for the first time we show electricity production directly from dairy wastewater and its simultaneous treatment by using CAML-MMFC technology.

2. Materials and methods

2.1. Wastewater sample and seeding

Dairy industrial wastewater was collected from Mahtaj Dairy Industry in Zahedan City, Iran and kept in a refrigerator at 4 °C before use. This wastewater is classified as nontoxic due to low hazardous chemicals and high amounts of

Table 1 The characteristic of Mahtaj Dairy factory wastewater in Zahedan.

Number	Parameter	Value
1	COD	3620 mg/l
2	BOD_5	2115 mg/l
3	Total P	187 mg/l
4	NH_3	167 mg/l
5	NH_4^+	174 mg/l
6	TSS	1430 mg/l
7	VSS	647 mg/l
8	SO_4^{2-}	835 mg/l
9	EC	2176 (ms/cm)
10	pH	8.5–10.3