Membraneless microbial biofuel cell for municipal waste water treatment

M Vishnevskaya1*, D Gazizova1,2, A Victorenko1,2 and I Konova1

1National Research Centre “Kurchatov Institute”, Biotechnology and Bioenergy Department, 123182 Moscow, Russia
2Moscow Physical Technical Institute, 117303 Moscow, Russia

* Corresponding author: Vishnevskaya_MV@nrcki.ru

Abstract. Microbial biofuel cell is the promising technology that gives possibilities to generate electricity by degradation of organic contaminations. Thus, this technology became very perspective for municipal waste water treatment to minimize energy consumption of waste water treatment plants. The main limitations of microbial biofuel cell application are related with high cost of membranes and electrodes materials. Absence of membrane and application of cheap materials with low conductivity and low surface area usually leads to decreasing of power output. In this paper we present membraneless microbial fuel cell (MFC) with cheap conductive electrodes that can be applied in future for waste water treatment. Gluconobacter Oxydans VKM V-1280 strain from All-Russian Collection of Microorganisms was used as biocatalyzer for anode. Graphite was applied as electrode material. Immobilization was provided by using mixture of poly (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) and poly (ethyleneglycol) diglycidyl ether (PEGDE). Experiments were provided by using synthetic analog of municipal waste water. No additional chemical mediator was applied. Power output was 1.43 mcW/sm2. Electrodes were stable during biofuel cell (BFC) operation. Thus, it was demonstrated that it is possible to apply membraneless MFC for municipal waste water treatment.

1. Introduction

Today, the energy industry is divided into three categories by fuels types: renewable sources, fossil fuels and nuclear sources [1]. The last two are the most popular, however the applying of fossil fuels can harm the human being and environment of the planet generally [2]. For example, greenhouse gases are produced as a result of fossil fuels burning leading to climate changes as well as environmental deterioration [3]. Therefore, the search for new sources of energy now is ongoing.

One of the latest developments in this area is the MFC, which produce energy by oxidizing organic compounds from waste water. Due to this oxidation electrons are emitted and then received on anode, what causes the produced electrical current to be sent to cathode. The anode compartment contains a biocatalyst (microbial cells or enzymes), a mediator and a substrate (oxidizable organics – alcohols, sugars, etc.). Oxidation of the substrate leads to the appearance of a charged state of the anode and the generation of a potential difference between the anode and the cathode. On the external circuit, the electrons are transferred to the cathode by the action of electromotive force. All the described processes occur in the water phase – in the anode compartment there is a physiological buffer that provides the vital activity of microbial cells, in the cathode compartment there is a buffer stabilizing the pH index [4].
Scientists observed the current created by bacteria as early as 10s of the 19th century [5]. But it was only in the 1990s that the MFC began to be considered a promising technology [6]. After the discovery of the fact that the mediator is not a binding part of the MFC, developments in this area have expanded [7].

Research is underway on detection of bacteria strain, which will allow MFC to work with highest efficiency. The selection criteria in this case are bacteria’s ability to decompose organic substances and transmit electrons from intracellular space to anode. The most commonly used bacteria for creating of BFC are *Shewanella oneidensis*. However, despite the fact that in the MFC other bacteria are used more often, *Gluconobacter oxydans* that is a promising type of bacteria with which for creation of BFC [8]. It was shown that application of these bacteria can help to increase power output and exclude mediator from anode chamber [9].

The topical issue in new MFC development is search of more cheap material for electrodes. They should provide sufficient conductivity, chemical stability, biocompatibility and high specific surface area [10]. The most common and suitable by electrochemical properties material is graphite. Graphite rods are cheaper than most alternative electrodes. And yet they have acceptable properties for use in microbial biofuel cells [11, 12]. Graphite rods are biocompatible to living organisms and have the ability to transfer electrons. So those cheap materials are still interesting for such applications as a MFC for waste water treatment.

MFC can be used for variety of purposes. For example, it can be used as a biosensor: the MFC with *Gluconobacter oxydans* is capable of providing low-power Internet of Things devices with on board processing, wireless communication and reading functions [13]. MFCs are also used in the field of bioenergy based energy sources for the autonomous mobile robots [14]. Frequently, the MFCs are used to improve the environment, including water treatment [15].

In presented paper we demonstrate possibility of creation of the membranless MFC based on graphite electrodes for waste water treatment with electrical power generation.

### 2. Experiments

#### 2.1. Reagents
The bacterial strain *Gluconobacter Oxydans* VKM V-1280 was used in this work. Sorbit-D and yeast extract by Dia-M (Russia) were used for preparation of a nutrient [9]. The composition of synthetic wastewater (SWW) was 1000 mg/L of glucose, 95.5 mg/L NH₄Cl, 56.3 mg/L urea, 22.6 mg/L KH₂PO₄, 12.6 mg/L FeSO₄·7H₂O, 309 mg/L NaHCO₃ and 35 mg/L yeast extract [16]. It was employed as electrolyte. The distilled water was used throughout.

#### 2.2. Test-bed
A chemical chamber (50 ml) with electrodes attached to a 3D printed cap with holes for them was used as membraneless cell for the experiments. Measurements of the current-voltage characteristics (CVC) were carried out on an IPC-Micro potentiostat.

#### 2.3. Obtaining biomass of *Gluconobacter Oxydans*
The biomass of bacteria *Gluconobacter Oxydans* was obtained from the G.K. Scriabin Institute of Biochemistry and Physiology of Microorganisms RAS from All-Russian Collection of Microorganisms. To further maintain the growth of culture, the nutrient medium was used: sorbit-D (10%), yeast extract (1%), distilled water and agar (2.5%) for dense media. Cultivation (100-150 g) for dispersing the culture was carried out for 24 hours at a temperature of 28 °C. Cultivation was carried out for collecting biomass during 20 hours (centrifugation 15 minutes, 10,000 g). After collecting the biomass, it was washed with cold sterile NC solution (0.9% NaCl, 2 mM CaCl₂) [17] and resuspended again in 1 ml of NC solution. The biomass was stored in the refrigerator (+ 4 °C) before using in the experiment.

#### 2.4. Electrode preparation
Graphite rod electrode (diameter 6 mm, length 61 mm) was used as a cathode. Similar electrode with a mixture of *Gluconobacter Oxydans* biomass with high-conducting polymer PEDOT:PSS and PEGDE was used to better fix the biomaterial on the electrode surface in the ratio 4:1:1 as anode. Total mixture (600 μl) was applied to anode and installed to the working area of the electrode equal to 7.3 cm$^2$. The anode was dried at a temperature of +27 °C for 2 days.

### 2.5. CVC measurement

CVC was measured after adding 40 ml of a composition of SWW to the cell. The measurements were carried out on an IPC-Micro potentiostat with a specified voltage from -300 to 300 and back to -300 mV (without interruption) with a step of 50 mV. The time step is about 2 minutes to establish a stable current.

### 3. Results and discussion

The CVC measurement of BFC was provided. For a visual representation of the experimental results graph of the CVC presented at fig. 1.

![Figure 1. Current dependence of voltage in MFC.](image)

Resulting graph at figure 1 showing that there is a capacity in presented MFC cell. Also it is necessary to mentioned that form of CVC is good correlated with the one presented in other paper for *Gluconobacter oxydans* based MFC (see for example [8]).

The next step was to calculate the various characteristics of the cell. For a complete analysis of the results, it was necessary to obtain the values of the capacity and power of the cell. To calculate the average capacity we used the formula: side.

$$C = I/(U/dt)$$

Where ($C$) is the capacitance, ($U$) is the voltage, ($I$) is current and ($dt$) is the measurement time for a particular voltage. The cell capacity made up 5.3 mF average.

The operation process of MFC was provided for consumer and it generated current equal to 0.2 mA and voltage equal to 52.5 mV.

Power generation was calculated by the next formula:

$$P=I*U$$

Where ($P$) is power, ($I$) and ($U$) are current and voltage respectively.

Membraneless microbial biofuel cell showed total power of 10.5 mW. The average value of the specific power is 1.43 mW/cm$^2$. Those results demonstrate that this membranless MFC can operate...
without mediator with respectable power output using waste water as a substrate source. Further research will be focused on optimization of cell itself and optimization of bacterial cell immobilisation method on electrode to obtain higher power output at the same substrate.

4. Conclusion
The obtained results showing that it is possible to develop membranless MFC for municipal waste water treatment applications. Developed cell showing the considerable power output and, it is necessary to mention that there are several ways to enhance efficiency. Further research will be focused to cell design itself and immobilization of bacterial cells efficiency. Also it is necessary to mentioned that this MFC operated without chemical mediator, so makes strong foundation for future practical application.

Finally it is can be mentioned that MFC can be applied in various areas. Its application can enhance municipal waste water and other organics contaminated waters treatment. The development of MFC is an evolving and highly promising direction in nature-like technologies.

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