Optimization of microbial fuel-cells start-up behavior for wastewater treatment and electrochemical power evaluation

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INTRODUCTION

Microbial fuel cells (MFC) are an interesting device to gain energy from waste water by simultaneously contributing to water purification. To get electric energy efficiently from MFCs requires a start-up procedure that allows the microorganism to reach full power capability in a short time. Usually a resistive load is used to allow the release of electrons from the microorganism to the external world. In our experiments a constant current source is applied which operates the MFC always at the maximum power point in the current density/power density characteristic. By this approach a fast development of the microorganism population at the electrodes is reached, resulting in a shorter start up than with constant value resistors. In addition each cell always shows the highest possible performance which allows a fair evaluation of the construction materials. As feed a solution with 10% NaAc is used as substrate, while sodium carbonate is used as buffer solution for a constant pH value. Nafion 117 membrane is used for proton exchange. The electrodes have the dimension of 160mm*130mm, which is larger than most laboratory examples in the literatures, approaching industrial cells. A test system to evaluate different materials of construction for MFCs was set up. This system consists of 40 MFCs which operate in parallel. It is automated by Labview-software and allows observation of power production of the single cells over time. Reference cells are applied to determine anode potentials and cathode potentials as well as the corresponding cell voltages. The investigation includes cathodes operated with aerated water and gas diffusion cathodes using oxygen from air. Synthetic waste water as well as industrial waste water were used as feed for the MFCs.

METHODS

The schematic of our planar electrodes with channels (Eisenhuth Corporation, Germany), is shown in Fig.1. As a separator between anode and cathode compartment ion exchange membranes (e.g. Nafion) as well as porous separators (e.g. Cellgard) were evaluated. Several dimensions of the electrodes were used for the material tests, up to 238mm*145mm, which is bigger than most regular laboratory MFCs. Characteristic polarization curves were measured during the start-up time of the MFCs. In addition the anode and cathode potentials can be measured by reference electrodes as described by He and Nguyen[1].

Fig. 1: MFC electrode

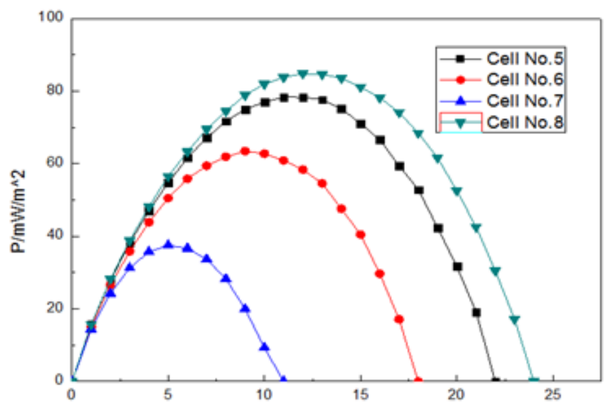

Fig. 2: Curren tdensity/power density characteristic

All the measurements were done by an automated system using the software Labview (National Instruments) and constant current sources to load the MFCs with a desired current. During the start-up period the anode and cathode compartments of the MFCs were operated continuously with aerated water (cathode) and sodium acetate solution (anode). During this time the developed program measures the cell voltage of all cells at different current densities starting at a low current density, which is low enough not to damage the microorganism on the anode. Each cell is treated individually (Fig. 2). Based on the measured values the system stepwise calculates a new load current which corresponds to the maximum in the measured current density/ power density characteristic. The process control system determines whether the cell is operated on the left side of the power density maximum in the current-power density characteristic or on the right side. By this approach the MFCs are always operated at their highest power production capability. Voltage reversal, as described as a problem in MFCs (Kim et al.[2]), can be avoided completely by this approach

RESULTS

In Fig 3. the current density/voltage characteristic and the current density/power density characteristic calculated from these data for a MFC is depicted. These data are not constant over time but change during the operation of a MFC. This is caused by changing supply with nutrition, varying supply with oxygen and individual development of the microbial film on the electrodes. So it is necessary to measure these data several times a day and adjust the applied load current to the maximum power point in the current density/power density characteristic of each MFC. In Fig. 3. four possible situations are depicted. By comparison of voltage and current of the freshest measurement with the stored data from the previous measurement the status of operation is identified. In the next step the load current is adjusted stepwise towards the direction of the power maximum. The time interval for the measurements can be chosen freely as well as the current increments, so this method can be adopted to different sizes of MFCs. By this approach a rapid development of the microorganism could be reached leading to a fast power production. Materials with beneficial properties can be easily detected and be used for the development of industrial MFCs.

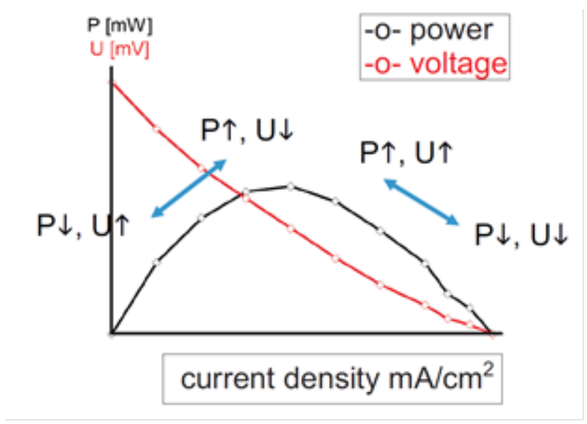

Fig.3.: Strategy for optimization of MFC power output by software controlled load currents.

DISCUSSION

In the following experimental investigation different separators and cathodes were used as given in Table 1. The developed start-up procedure ensures that each MFC is operated at the point of maximum performance. By this the used materials for construction are always tested under their individual optimum potency. The power development over time allows an evaluation to select the best materials. The data in Fig.4. suggested that the MFCs with gas diffusion electrode (GDE) (Cell No.5 to 7) possessed a relatively higher power density than the MFCs with liquid electrodes at the beginning. It can be observed in Fig.4. that catalyst plays an important role in power density, which is shown in Cell No.7. The best performance of Cell No.7 is achieved at 27th day with the value of more than 190mW/m^2. Furthermore, the MFCs with Cellguard 3501 separator (Cell No.3 and 4) possessed a relatively low power density during the long term performance, showing that Cellguard 3501 separator is not suitable for power density development of MFC. However, the power densities of MFCs with GDE descended rapidly after the 36th day, whose main reason is probably because the GDEs are filled with water during cathodic reaction, which has a negative influence on the cathodic performance. The GDE with Pt catalyst (Cell No.7) can improve power output considerably, but after several weeks of operation the GDE is damaged (Fig.4), probably by catalyst poisoning.

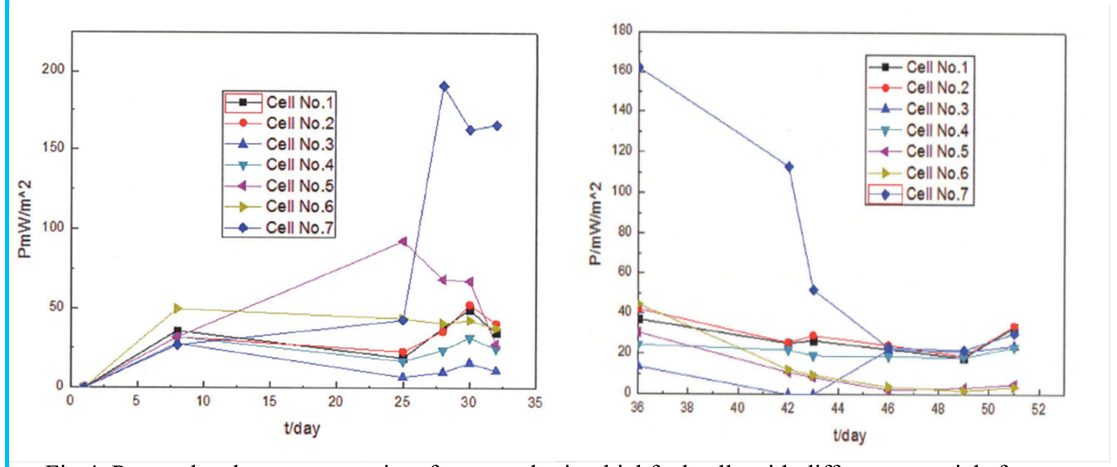

Fig.4. Power development over time for several microbial fuel cells with different materials for construction

Table 1 Examples for investigated MFC materials. PPG86 is a carbon-polymer compound of Eisenhuth company, Germany

	Anode	Cathode	Catalyst	Separator
Cell No.1	PPG86	aerated water	no catalyst	Nafion-117
Cell No.2	PPG86	aerated water	no catalyst	Nafion-117
Cell No.3	PPG86	aerated water	no catalyst	Cellguard 3501
Cell No.4	PPG86	aerated water	no catalyst	Cellguard 3501
Cell No.5	PPG86	gas diff. layer	carbon black	Nafion
Cell No.6	PPG86	gas diff. layer	carbon black	Nafion-117
Cell No.7	PPG86	gas diff. layer	carbon black with Pt 0.5mg/m^2	Nafion-117

CONCLUSIONS

An automated method was developed to reach high power capability of microbial fuel cells in a short time. Performance of the MFCs change with time, but the MFCs are always operated at their optimum power point. By this approach each material which is used for cell construction can demonstrate it´s maximum performance in the cell. A fair evaluation of the materials is possible and the best materials can be selected.
MFCs with GDE possessed a relatively higher power density than the MFCs with liquid electrodes at the beginning. Catalyst plays an important role in power density, which is shown in Cell No.7. Simple separators as Cellguard 350 are not suitable for good power density development of MFC, demonstrated by the low power densities of Cell No.3 and 4. The power densities of MFCs with GDE descended rapidly after the 36th day, whose main reason is probably because the GDEs are flooded with water during cathodic reaction. Performance of cell No.7, which is built with GDE and Pt catalyst, possessed the highest power output at the beginning, but after several weeks of operation the GDE is damaged, probably by catalyst poisoning. As a result cathodes with aerated water are more promising for operation under real waste water conditions. Planar electrodes with channels to conduct the water made of polymer/carbon compounds are well suited materials for MFCs.

[1] He, W., Nguyen, T.V. (2004), Edge Effects on Reference Electrode Measurements in PEM Fuel Cells, Journal of The Electrochemical Society, **151**, A185-A195
[2] Kim, Y., Hatzell, M.; Hutchinson, A.J.; Logan, B.E. (2011), Capturing power at higher voltages from arrays of microbial fuel cells without voltage reversal, Energy Environ. Sci., **4**, 4662

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