Development of a continuously operated Microbial Fuel Cell (MFC)

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3.2 Development of a continuously operated Microbial Fuel Cell (MFC)

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Abstract
In contrast to a conventional fuel cell the electrons in a microbial fuel cell (MFC) originate from the metabolic conversion of organic substrates by special bacteria instead of using molecular hydrogen. Recent research in our group has shown that the maximum electrical power density in a MFC correlates with the biomass concentration in batch MFC experiments [1].

In continuous MFC systems additionally the dilution rate D could have an effect on the specific power density. Therefore two steady state conditions are adjusted and the resulting specific power densities, and the biomass and substrate concentrations were measured.
These results were implemented in a mathematical description of the continuous MFC-process and the visualization of the model is presented.

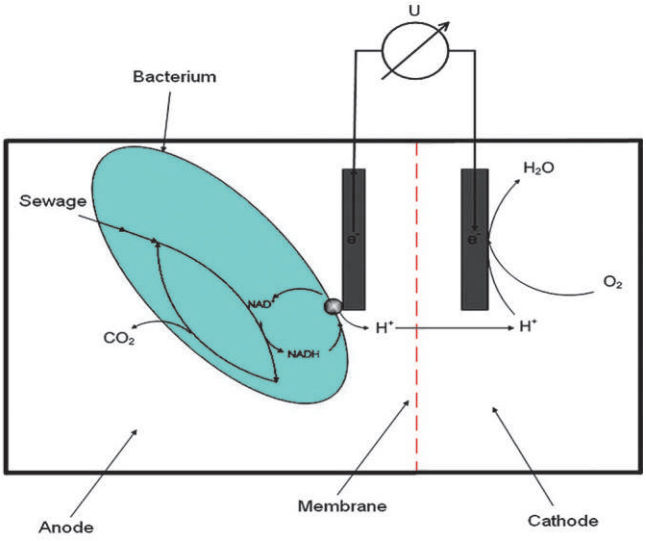

Fig. 3.2-1: *Principle of a microbial fuel cell. The bacteria in the anode is able to use the reduction equivalent from the sewage degradation to generate electrons*

Introduction
A microbial fuel cell (MFC) has some advantages compared to a conventional fuel cell. Beside the mild operation conditions (pH around 7.0, room temperature) the MFC produces electricity while degrading a waste water effluent at the same time. In contrast to a conventional fuel cell, where hydrogen is oxidized in the anode compartment, the electrons in the MFC derive from bacteria. The microorganisms regenerate their redox-equivalents (NADH) by transferring the electrons on the surface of the anode. The complete mechanism is demonstrated in Figure 3.2-1.

Scope of the project
In recent publications we have demonstrated the effective electricity generation by microorganisms using a MFC [1]. All results are derived from unsteady batch operation mode. The unsteady conditions (increasing biomass concentration, decreasing COD of the wastewater and increasing/decreasing power production) are disadvantageous regarding an application in a technical process.

A continuous operation of a MFC is limited by the maximum specific growth rate μ_{max} of the bacteria, which relates to the critical dilution rate $D_{crit.}$ Higher dilution rates than D_{crit} cause a washout of the biomass out of the anode compartment. On the other hand high dilution rates are desirable, because they correspond to an increase of the maximum power density in a MFC [2].

Hence a continuously operated microbial fuel cell with a constant power production on high level and a constant wastewater degradation is the main goal of this project. With the help of a mathematic description of the overall process, it is possible to scale up and simulate the process for optimization purpose.

Material and Methods
For this work the bacterial strain *Shewanella putrefaciens* is used, which was obtained from the German Collection of

Microorganisms and Cell Cultures (DSM 6067). A sodium phosphate buffer (0.1 M) with NaCl (0.1 M) solution at pH 7.0 was used during the experiments as electrolyte. In the anode compartment glucose (0.1 M) was added. Potassium hexacyanoferrate (III) (0.1 M) was added in the cathode compartment as reducing agent.

Carbon felt was used as electrode material in the anode and cathode compartment. This material has high specific surface compared to graphite plates. Therefore it is easy for the bacteria to regenerate their redox equivalents.

The experimental setup to measure the specific power density of a MFC is shown in Figure 3.2-2.

The anode compartment was operated continuously with different dilution rates up to steady state conditions. Therefore every day the power/current-diagram was recorded by measuring the voltage drop with different resistances. The maximum specific power densities in this diagram indicate the power efficiency of a MFC. The mathematical model was developed with the Software "Berkeley Madonna, Modeling and Analysis of Dynamic Systems".

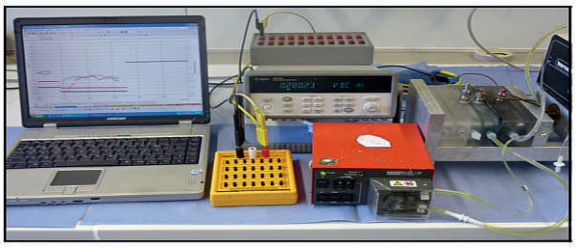

Fig. 3.2-2: *Description of a continuously operation MFC with test devices and test equipment*

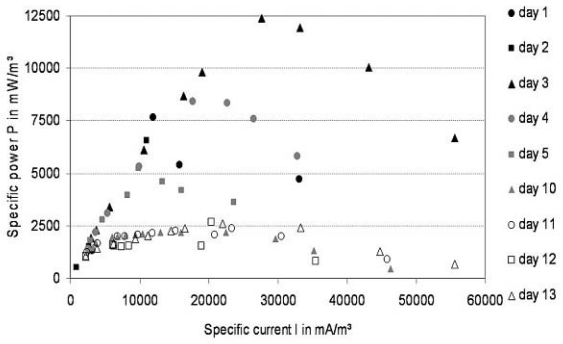

Fig. 3.2-3: *The maximum specific power density in the MFC with a dilution rate D=0.025 h-1 up to steady-state-conditions. In this diagram the maximum power density decreases from 12400 mW/m_ on the first day to 2650 mW/m_ at steady-state-conditions (11th day – 13th day)*

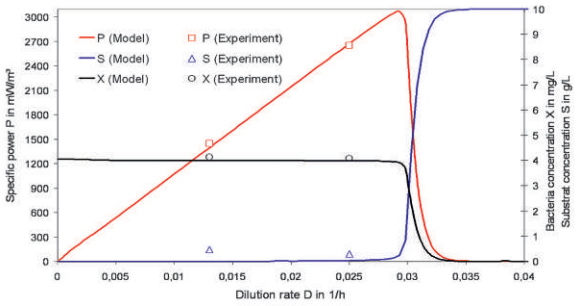

Fig. 3.2-4: *Results of the developed process model (anode compartment) of a continous operated MFC. Process model (lines) and experimental results (symbols) correlate very well*

Results

The specific power density of a continuously operated MFC up to steady-state-conditions is demonstrated in Figure 3.2-3.

Incubated with very high biomass concentration on the first day the number of cells in the anode compartment decrease. With biomass reduction also the maximum specific power density decreases down to steady-state-conditions as shown in Figure 3.2-4.

Assuming that the specific power density correlates with the dilution rate D and the biomass concentration X, a process model was developed. Integrated elements are also the mass balances of the substrate and the biomass in combination with the Monod growth kinetics. The results of this simulation are visualized in Figure 3.2-4. As demonstrated in the graph, the substrate is metabolized completely and the biomass concentration is held on a constant level up to D_{crit}.

The specific power density increases with rising dilution rates. At D_{crit} the washout process of the *Shewanella* cells occurs resulting in a drastically decline of biomass concentration and hence specific power density. The loss of biomass causes an increase of the substrate concentration up to the influent level. The process model and the verification by the experimental results are in a good agreement.

Conclusions

The developed process model could be a helpful tool for further simulations with the MFC to optimize the process parameters without performing time consuming experiments. Further investigations focus on an increase of the maximum specific power density of the MFC. One possibility could be the biomass retention using a cross flow filter module at the effluent of the anode compartment. This method helps to keep the bacteria in the MFC-system. Hence higher dilution rates than D_{crit} are possible and therefore an increase of the maximum specific power density could be expected.

References

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