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Improving current production of *Shewanella oneidensis* MR-1 with electrospun anode materials

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Summary of key findings

We present a comparison of two electrospun anode materials characterized with *Shewanella oneidensis* MR-1 under steady state conditions. The achievable anodic current densities of microbial fuel cells in a half-cell setup operated with *S. oneidensis* are very responsive to the anode morphology. Two electrospun anode materials were investigated which mainly differ in fiber diameter resulting in an approximately four-fold fiber surface area difference. The electrospun material with 126 nm fibers yields current density of (56 ± 14) µA cm^{-2} (normalized to the projected anode area) at -0.2 V vs. SCE and performs more than a factor of three better than the material with 848 nm fibers with a current density of (16 ± 14) µA cm^{-2}. The volumetric current density of the 126 nm fiber material (3378 ± 830) µA cm^{-3} is more than a factor of three higher than the carbon nanotube based material investigated previously by Kipf et al. (2013).

Background and relevance

Even though other organisms such as *Geobacter sulfurreducens* show higher current densities, *S. oneidensis* may be relevant for microbial fuel cell applications where a high tolerance towards oxygen is required. As demonstrated by Patil et al. (2013) and Kipf et al. (2013) materials with high specific surface areas yield high current densities of microbial fuel cell anodes operated with *S. oneidensis*. Electrospinning enables the fabrication of high surface area carbon fiber mats with fiber diameters ranging from the nanometer to the micrometer scale. Therefore, two materials of different fiber diameters and a fiber surface area differing by a factor approximately four were characterized. The quasi-steady state measuring technique ensures results comparable to a systematic material screening conducted by Kipf et al. (2013). Aiming at higher anode current densities, the suitability of electrospun materials for anode applications with *S. oneidensis* was investigated.

Results

Anode carbon materials with fiber diameters of (126 ± 43) nm (EFM126nm) and (858 ± 107) nm (EFM848nm) and a porosity of 92% to 93% were fabricated by electrospinning of Polyacrylonitrile precursor in Dimethylacetamide with polymer concentrations of 6 wt% and 14 wt%, respectively. The fibers were collected on aluminium foil and peeled off prior to the carbonization with a maximum temperature of 1180 °C. The fiber mats have a thickness of 133 µm (EFM126nm) and 165 µm (EFM848nm). For the fabrication of EFM848nm a custom hot-air assisted electrospinning technique was used. A hot-air jet is blown along the needle heating the polymer solution within the needle and leading to a lower viscosity of the polymer solution and faster a drying of the fibers. Both materials were tested in duplicates according to Kipf et al. (2013) under anoxic quasi-steady state conditions with a stepwise increase of the current density of 11.1 µA cm^{-2} every 48 hours. The resulting polarization curves are shown in Figure 1.1.

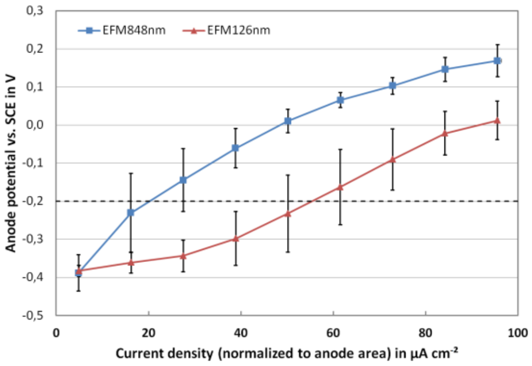

Figure 1.1 Polarization curves of electrospun carbon anodes with fiber diameters of 126 nm and 848 nm. The fiber surface area of the 126 nm fiber material is approximately 4-fold larger than that of the 848nm fiber material.

The achieved current densities given in Table 1.1 were evaluated at -0.2 V vs. SCE. This value allows benchmarking of the anode materials since the potential of air operated cathodes lies seldom above 0.2 V vs. SCE, yielding a cell voltage of 0.4 V. Values for C-Tex 13, an activated carbon material, with the highest area based current density and a carbon nanotube material with the highest volumetric current density reported by Kipf et al. (2013) are given for comparison.

Table 1.1 Comparison of current densities obtained at -0.2 V vs. SCE by quasi-steady state characterization with *S. oneidensis* of two different electrospun fiber materials (EFM), activated carbon cloth (C-Tex 13) and carbon nanotube based anode. The values were evaluated by linear interpolation and represent mean values ± the difference to minimal and maximal values. The fiber surface area based current density and the roughness factor were calculated using the fiber diameter, the area density of the anode material, and the density of turbostratic carbon (Zou et al., 2003).

Anode material	Area based current density µA cm^{-2}	Volumetric current density µA cm^{-3}	Roughness factor	Fiber surface based current density µA cm^{-2}
EFM126nm	56 ± 14	3378 ± 830	250	0.50 ± 0.12
EFM848nm	16 ± 14	1218 ± 1026	66	0.55 ± 0.46
C-Tex 13 (Kipf et al., 2013)	24 ± 0.4	482 ± 7	-	-
Bucky paper (Kipf et al., 2013)	4.00 ± 0.05	1049 ± 13	-	-

Discussion

The investigated electrospun material with 126 nm fiber material yields a current density of (56 ± 14) μAcm^{-2} at -0.2 V vs. SCE which is more than 2-fold higher than the best material reported by Kipf et al. (2013). The current densities normalized to the fiber surface area are almost identical suggesting that *S. oneidensis* can make use of the whole surface area provided by the anodes. Also mass transfer of nutrients and electron shuttles does not limit the performance of the relatively thin anodes. Therefore, thicker anode materials with optimized fiber surface area might deliver an even higher area based current density.

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