eLatrine: Lessons Learned from the Development of a Low-Tech MFC Based on Cardboard Electrodes for the Treatment of Human Feces

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The aim of the study was to provide experimental proof-of-concept that stand-alone power generation based on microbial fuel cells (MFCs) operated using human feces as the substrate can be achieved. A pit latrine that is typically employed for decentralized treatment of human feces e.g. in regions without access to centralized wastewater infrastructures was installed as sampling site. It was the philosophy that the components, i.e. anodes and cathodes, used in the MFCs had to be based on low-cost precursors. This was achieved by recycling common household materials or waste products and a low-tech/cost production method was developed to convert them into usable electrodes. It is demonstrated that i) pre-tests on using an equivalent to vent-air from ovens or fire-places allowed a low-tech carbonization of e.g. corrugated cardboard to electrode materials; ii) that anodes based on corrugated cardboard can be operated using real human feces as substrate, nevertheless, providing only low current densities (15.09 ± 5.18 μA cm−2) and iii) cathodes – with nitrogen functionalities derived from (artificial) urine – based on corrugated cardboard or as an alternative jeans cloth show a good oxygen reduction reaction (ORR) activity. Introducing nitrogen containing surface moieties to the cathode surface increased the ORR up to factor 5 (chronoamperometry at 0 V vs. Ag/AgCl sat. KCl) compared to the untreated reference. Most importantly, highly valuable lessons for exploiting real and highly heterogeneous and dense substrates like human feces in microbial electrochemical technologies were learned.

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In 2015 the United Nations proposed the 17 Sustainable Development Goals to be achieved by 2030.1 Among these are for instance “Good health and well-being”, “Clean water and sanitation”, “Affordable and clean energy” as well as “Sustainable cities and communities”. Hence, sanitation and concurrently treat of waste is a key challenge, as it covers technical as well as socio-economic and health related issues.2,3 Wastewater treatment facilities and related infrastructure, e.g. as typically installed in the USA or Europe, can be a significant sink for energy and resources,4–6 which are needed for construction, maintenance, especially of the sewer system, and operation.7 At the same time an estimated 2.4 billion people, or approx. 33 % of the world population, do not have access to such infrastructure. For this share of the world’s population using simple solutions such as pit latrines can already be advantageous in terms of hygiene and security when compared to open defecation.2,3 Therefore decentralized sanitation systems seem advantageous in developing regions with no or only very little existing infrastructure.

Waste and wastewaters have gradually become perceived not as sinks of chemicals and energy but as re-sources thereof. In this light microbial electrochemical technologies (MET)8 and especially microbial fuel cells (MFCs) are considered to be a highly promising solution.8 MFCs are primary microbial electrochemical technologies based on a microbial anode at which the oxidation of the substrate, i.e. the waste, takes place. Thus, the removal of the organic load, usually under anaerobic conditions, is directly connected to its energetic exploitation. So far, numerous wastes and wastewaters have been investigated in MFCs for organic removal efficiency and electric current production (see e.g.5). However, almost exclusively the integration of MET-technologies in existing wastewater treatment lines is under consideration in recent research.10–12 Studies focusing on the treatment of human feces in MFCs always used artificial or diluted substrates.13,14 For decentralized systems, not only the load of waste will be increased, but also other parameters such as inhomogeneity or temporal fluctuations will be more challenging, as would be the case when treating human feces directly without any form of pretreatment.

The decentralized utilization of human urine was first considered by NASA15 and recently successfully revisited in several projects.16–21 MFC electrodes and especially the cathodes have been developed using similar high-cost approaches, being derived from chemical fuel cell development.22 The development of low-cost and high performance electrode materials has only gradually taken place, e.g.23,24 This study continues this research direction: In order to create a MFC which is viable for use in developing regions it must be as cheap as possible. To this end MFCs were produced using mainly materials and methods available in any household.

Corrugated cardboard is a cheap and widely available material, which is ideally suited as a scaffold for MFC anodes, e.g.25,26 A fully cardboard based microbial fuel cell for pit latrines was developed as a form of decentralized treatment for human feces. To realize a form of low-tech electrode manufacturing, the carbonization process, typically done in expensive ovens under a pure nitrogen atmosphere, was tested in household setting. In parallel cardboard based electrodes were modified for improved oxygen reduction reaction (ORR) by adding catalytically active N-containing surface moieties from artificial urine during carbonization.

**Materials and Methods**

If not stated otherwise, all potentials provided in this article refer to the Ag/AgCl reference electrode (sat. KCl, 0.197 V vs. standard hydrogen electrode (SHE)). All chemicals were of analytical or biochemical grade and purchased from Sigma Aldrich or Roth (Germany). Nitrogen gas was used for preparation of electrodes (5.0, Westfalen Gas

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AG, Germany) and for anode characterization (5.0, Fa. Linde AG, Germany).

Sample collection.—Mixtures of human feces and urine were collected in a pit latrine (Okolocus GmbH, Leipzig, Germany) over the whole time of the project. Sample substrates for anode characterization experiments (~1.5 L each) were taken with a ladle and mixed thoroughly, no extra liquid was added. For each sample the pH (pH 3310, WTW, Germany) and the conductivity (Cond 3110, WTW, Germany) was measured.

Preparation of electrode materials.—All electrodes used in the experiments described below were prepared by a common carbonization procedure. The carbonization was performed in a soldering furnace (P3000, Nabertherm, Germany). The electrode preparation using modern carbonization equipment is adapted from previous work using established conditions and parameters (800 °C, 2 h, pure nitrogen atmosphere). Corrugated cardboard (packaging material) was cut into single, double or triple layered sections and connected to titanium wires (current collectors) using a simple weaving / knitting method. Titanium was chosen as the only “high-tech” electrode component as pre-tests with stainless steel current collectors showed localized corrosion caused by the high chloride content of the substrate (human feces) of up to 4.9 g Cl− kg fresh matter−1.

In order to transition towards a low-tech carbonization method, cardboard was carbonized in a batch furnace (TC 504, Rohde, Germany) at temperatures between 500 °C and 300 °C in the presence of air (~20% O2) as found e.g. in a household oven or for charcoal production.

Cathode modification.—To enhance the oxygen reduction reaction at the cathode, N-containing surface moieties were introduced to the cathode material surface by dipping the electrode material into artificial urine for 30 seconds. Artificial urine was chosen as a placeholder for real urine or yellow water both being available in households. Afterwards the material was dried overnight under ambient conditions and carbonized as described above. This procedure was applied to corrugated cardboard and later jeans cloth. The influence of the number of layers of cardboard structure was evaluated to gain insight into the effect of the electrode architecture. Cardboard without any flute layers (0 layers) was too brittle for effective wiring. An alternative was to use jeans cloth as the precursor. This material has a planar structure, i.e. structurally equivalent to cardboard based electrodes with 0 layers. Also the dipping time was increased to 60 seconds for testing this cathode material.

The concentration of N sources in the artificial urine solution was increased 10 fold in comparison to the original recipe: urea (100 g L−1, i.e. 3.33 mol N L−1), creatinine (8 g L−1, i.e. 0.21 mol N L−1) or uric acid (0.7 g L−1, i.e. 0.02 mol N L−1). A solution containing all three N-Sources, i.e. with a total of 3.56 mol N L−1, and solutions containing only a single N source were prepared by dissolving the respective substance in aqueous iron(II)sulfate heptahydrate solution (0.012 g L−1) whose concentration was also increased. In an anticipated transfer to practice the same concentration effect can be achieved by soaking the precursor multiple times in real urine until all the water evaporates or evaporating the water from the urine before dipping.

Anode characterization.—All experiments were performed in a single chamber electrochemical cell (see Figure 1) consisting of a 600 mL glass beaker. The anode was placed at the bottom of the cell followed by filling the cell with 500 mL of human feces. Finally, the cathode was placed at the top. To avoid contact between anode and cathode the titanium wires (current collectors) were insulated with 1 mm (inner diameter) silicon tubes. In all experiments surface modified cathodes (see section Preparation of electrode materials) were used. The substrate: fresh human feces, was derived from a pit latrine. No additional inoculum was used. To provide stable temperature the electrochemical cells were incubated at 37 °C (Incubator Hood TH 15, Edmund Bühler GmbH, Germany). The temperature was chosen to mimic body temperature. To minimize water evaporation the cells were closed with a lid that was airtight (printed from poly lactic acid (Innofil3D, Netherlands) with a 3D printer (Ultimaker 2, Ultimaker, Netherlands)).

Two experiments were performed with each three replicates, i.e. n = 3. In the first experiment the anode characterization was carried out with two different electrochemical setups, a microbial electrolysis cell (MEC) setup with the anode poised at a constant potential of 0.2 V and a microbial fuel cell (MFC) setup with a 100 Ω or 1 kΩ resistor between anode and cathode. In the MEC setup the electrodes were connected in a three electrode arrangement using an Ag/AgCl (sat. KCl) reference electrode (SE 11 Sensortechnik Meinsberg, Germany) and a potentiostat (PGSTAT 10 MULTISTAT Autolab, Netherlands). For data analysis the projected current density, i.e., the current normalized to the projected surface area (footprint area) of the used anodes was used. For all experiments only modified cardboard cathodes (see section “Cathode modification”) with ~1.2 fold larger projected surface area compared to the anodes were used. The use of such activated carbon and catalyst type electrodes have been shown to be effective in MFCs. For the MFC setup, the cell voltage was measured with a digital multimeter (Keithley 2701 equipped with a Keithley 7700 20 channel multiplexer module, Keithley, USA). The anodes were examined for 4 days in the MEC setup. Afterwards, the mode of operation was switched to the MFC setup and the cell voltage was measured over a period of 4 days. Internal resistance was measured with a PARSTAT MC (Ametek Inc., USA).

In the second experiment only the MEC setup was used. The lower anodic part of the electrochemical cells was purged with N2 gas via a cannula to avoid O2 induced inhibition of microbial activity. For this experiment the electrodes were allowed to equilibrate at open cell potential (OCP) in the substrate solution for 18 h. After the equilibration phase, chronoamperometric measurements were conducted at an applied potential of 0.2 V with constant N2 purging.

Cathode characterization.—To compare the influence of the introduction of N-surface group modifications on the catalytic activity for the oxygen reduction reaction (ORR) both modified and unmodified electrodes were tested with three independent electrochemical measurements: Galvanodynamic linear sweep voltammetry (GDLSV), cyclic voltammetry (CV) and chronoamperometry (CA). All experiments were carried out using a conventional three electrode arrangement connected to a potentiostat-galvanostat (SP-200 BioLogic, France) or an Autolab PGSTAT 20 (Ecochemie, Netherlands)) with an Ag/AgCl reference electrode and a platinum sheet as the counter electrode. All measurements were performed in a carbonate buffer solution (10 mM, pH 7.5, conductivity 1 mS cm−1, which is in the range of municipal wastewater) at room temperature while air purging.

Cyclic voltammetric measurements were performed in the potential range of 0.4 V and −0.6 V with a scan rate of 1 mV s−1. The respective projected current density data (j) of cyclic voltammograms were extracted as average values of several forward and reversed scans at potentials of 0 V and −0.2 V, respectively, i.e. j0.4V and j−0.2V. Chronoamperometric measurements were performed for potentials of 0 V and −0.2 V until a constant current flow (for at least 10 min) was
reached. For galvanodynamic linear sweep voltammetry open circuit voltage (OCV) was measured till a constant value was reached (which took between 30 min to several hours), then the reduction current was increased with a scan rate of $-10 \, \mu A \, s^{-1}$.

The influence of each N source in the artificial urine for cathode surface modification was tested at jeans cloth electrodes using GDLSV to equilibrate at OCP in human feces for 18 h before starting the chronoamperometric measurement. The OCPs were constant over time for all three MECs. MEC 1 and MEC 2 showed an OCP between 0.1 and 0.2 V while MEC 3’s OCP was 0.4 V. After the equilibration phase, chronoamperometric measurement at 0.2 V with active N2 provision (anode) was conducted for 4 days (Figure 4). N2 provision did not change the anode performance. After an initial current drop the anodic current density stabilized at 11.90 ± 1.62 μA cm$^{-2}$ after 50 h of operation (Figure 4). The low observed performance could be due to limiting mass transfer or low bioavailability of the dense substrate as well as low activity of the electroactive microorganisms.

Anode characterization.—Figure 3A shows the results of chronoamperometric measurement of cardboard anodes using human feces as substrate for 4 days with the MEC setup directly followed by cell voltage measurement in MFC mode (Figure 3B). An initial current production followed by decrease and stabilization at lower current levels at average 15.09 ± 5.18 μA cm$^{-2}$ after 60 h of operation was observed in all three cells (Figure 3A) with MEC 3 showing lower current than MEC 1 and MEC 2.

After 96 h in MEC mode the electrochemical cells were connected to 100 Ω resistors (MFC setup) and the cell voltage was measured (Figure 3B). The cell voltage decreased within 20 h from 0.200 V to below 0.025 V in all MFCs (Figure 3B). The strong decrease at 20 h (MFC 2 and 3), 64 h (MFC 2) and 70 h (MFC 1 and 2) was due to evaporation of water which was compensated with tap water to a level of 500 mL.

After 96 h of MFC operation the external resistors were increased to 1 kΩ following an alternative approach of MFC conditioning to improve the power output. However, the application of a higher resistance did not lead to higher cell voltages (not shown). In summary, irrespective of the external resistance, the MFCs did not generate a satisfying cell voltage over time. This may have several reasons, the most probable are: 1) The external resistance (100 Ω and 1 kΩ) was too high compared to the internal resistance of the cells (~30 Ω), 2) The cathodes did not work properly due to limited O2 availability respectively high inner electrode resistance due to insulation by substrate components, or 3) The activity of the electroactive microorganisms at the anode was reduced because of residual O2.

In the second set of experiments the electrodes were allowed to equilibrate at OCP in human feces for 18 h before starting the chronoamperometric measurement. The OCPs were constant over time for all three MECs. MEC 1 and MEC 2 showed an OCP between 0.1 and 0.2 V while MEC 3’s OCP was 0.4 V. After the equilibration phase, chronoamperometric measurement at 0.2 V with active N2 provision (anode) was conducted for 4 days (Figure 4). N2 provision did not change the anode performance. After an initial current drop the anodic current density stabilized at 11.90 ± 1.62 μA cm$^{-2}$ after 50 h of operation (Figure 4). The low observed performance could be due to limiting mass transfer or low bioavailability of the dense substrate as well as low activity of the electroactive microorganisms.
Figure 4. Current density at 0.2 V vs. Ag/AgCl in a single chamber electrochemical cell operated on human feces. N2 was provided to the anode to avoid O2 inhibition. The inset shows the current density over the complete experiment.

The pH of 6.84 in the anodic part, maybe also affecting the microbial electroactivity, did not change over the time of the test run, while the pH in the cathodic part increased to 8.49.

Taking into account, that all described experiments were performed only for a limited period of time, an additional long term experiment (CA, 0.2 V vs. Ag/AgCl) using cardboard electrodes was performed for 26 days. No noteworthy current generation could be observed during this experiment. The data are not shown because the Experimental setup differed from the described setup in the Materials and methods section (other current collector material, no PLA lid). Furthermore, an additional experiment, using the setup described in the Materials and methods section, but using carbon plate electrodes instead of cardboard electrodes, was performed for 6 days. An improved current generation was also not observed for this experiment, as these cells showed a current output of only 4.74 ± 0.19 μA cm⁻². The current densities when using human feces and urine as substrate are well below these found for corrugated cardboard based biofilm anodes fed with acetate, which clearly shows that not the low-cost electrode material itself is the bottleneck.

In conclusion, the tests highlighted different challenges and possible reasons for low anode performance, which have to be tackled for further development (see Table III in the Conclusions and outlook section).

Cathode characterization.—Oxygen reduction reaction catalysts are produced using high-cost approaches and materials with ideally assembled alloys, composites or nanoparticles as catalysts. Thus, their application seems too expensive and technically demanding for developing countries. Therefore here low-cost as well as ubiquitous materials were investigated.

Based on previous research on the use and introduction of FePc, containing a R₈N₄Fe(II) center complex, onto a carbonaceous backbone material, urine as the nitrogen source of catalyst precursors was investigated. Urine is available as a household waste product, which contains both R₈N and iron. Through carbonization with the material these substances should lead to the desired surface functionalities. To the best of the author’s knowledge this is the first attempt at using (artificial) urine to modify carbon based electrodes for forming active sites for the ORR.

A considerable difference in catalytic activity for the oxygen reduction reaction between the urine modified and unmodified electrodes has been achieved with three independent electrochemical measurements as shown in Figure 5.

GDLVS of urine modified cathodes show a higher ORR activity, i.e. more negative j₀ V and j₋₀.2 V, than the unmodified material.
Table I. Overview of projected current densities of carbonized three layered cardboard electrodes at 0 V and −0.2 V resulting from three different electrochemical methods.

| Method                      | j_{0 V} mA cm\(^{-2}\) | j_{−0.2 V} mA cm\(^{-2}\) |
|-----------------------------|--------------------------|-----------------------------|
| Galvanodynamic linear sweep voltammetry |                          |                            |
| Urine modified              | −0.37 ± 0.08             | −0.82 ± 0.18                |
| Unmodified                  | −0.27 ± 0.03             | −0.62 ± 0.05                |
| j_{(urine modified)}/j_{(unmodified)} | 1.37                     | 1.32                        |
| Cyclic voltammetry          |                          |                            |
| Urine modified              | −0.22 ± 0.04             | −1.07 ± 0.17                |
| Unmodified                  | −0.12 ± 0.05             | −0.88 ± 0.12                |
| Chronoamperometry           |                          |                            |
| Urine modified              | −0.09 ± 0.01             | −0.51 ± 0.07                |
| Unmodified                  | −0.07 ± 0.01             | −0.34 ± 0.07                |

Further insight into the ORR activity of modified electrodes:—

Due to the multilayered structure (and its inherent capacitor-like properties) of the corrugated cardboard electrodes, the current densities vary for each electrochemical method. GDLSV and CV methods yield factor two to three higher current densities than the CA method (see Table I). However a combination of all three methods clearly shows the positive impact of the modification procedure on ORR performance. For a more precise insight into the effect of the electrode architecture the influence of several layers of the cardboard structure was evaluated. As can be seen in Figures 6A and 6B with decreasing number of layers the inherent capacitor-like properties decrease, as well as the projected current density.

To evaluate the contribution of each N-containing substance to the catalytic activity for the oxygen reduction reaction additional tests were performed with jeans cloth based cathodes, another household waste product. These electrodes also show an
electrocatalytic improvement on the ORR by urine treatment, but at a reduced impact of inherent capacitor-like properties compared to the multilayered corrugated cardboard electrodes, as shown in Figure 6C.

The jeans cloth based electrodes were carbonized with different N-containing compounds at higher concentrations to evaluate if the modification process could be further improved. All N-containing substances inherent in artificial urine (urea, creatinine and uric acid) were tested individually and as mixture to determine, if a single compound in natural urine could be associated with improved ORR performance.

Figure 7 and Table II provide an insight into the contribution of each N-containing substance to the catalytic activity for the oxygen reduction reaction. The improvement of the modification procedure is clearly visible but not explicitly correlated to the modification media. The GDLSV data of the highest catalytic activity of each differently modified electrode (Figure 7A) as well as chronoamperometric measurements (Figure 7B) signify a difference between the mixture with all compounds and single substances. Interestingly both electrode modifications with the highest N-amount, all components (3.56 mol N L⁻¹) and urea (3.33 mol N L⁻¹), indicate the best obtainable performance at applied potentials below −0.1 V, however showing the highest deviation during CA measurements (see Table II), respectively.

Table II provides a summary of the adjusted cathode modification. The “concentrated” urine modification improves ORR-catalytic activity of jeans cloth electrodes by at least factor 2 compared to the base material. The urine-modified electrodes show sufficient electrocatalytic ORR activity compared to previous experiments with Vulcan/FePc modified electrodes with 10 fold higher supporting electrolyte concentration. For future applications (which include the usage of real urine as a modification media) the main N-containing compounds should be enriched by a partial drying process, i.e. by allowing the material to soak while drying in the sun, which should mean a marginal increase in the effort and no increased cost for production of the cathodes.

**Conclusions and Outlook**

Within the study a clear progress was made in the development of low-cost and low-tech production procedures for materials for microbial fuel cells. Low-cost electrodes can be gained from house-hold wastes using low-tech thermal treatment, i.e. household ovens and open fires, although further research is still required to establish a full production chain for both anode and cathode materials. Especially the introduction of nitrogen functionalities, catalyzing the oxygen reduction reaction on cathodes, showed promising results. Significant progress was made on the development of the components. Neither an integration of the components into a pit-latrine based MFC nor a complete functionality of the components was achieved. The exploitation of human feces in METs seems significantly more challenging than of domestic wastewater from a wastewater treatment plant or even urine, which we assign to the complex biological as well as chemical-physical properties of this substrate. Table III summarizes the challenges faced in this study that have to be tackled in order to improve the system performance. Especially long term experiments as well as lower anodic potentials could help to enrich electroactive microorganisms and therefore, to improve the applicability of human feces as MFC substrate.

To further foster the on-site treatment of feces we assume a combination of MET and other physical-chemical methods maybe more promising, possibly as depicted in Figure 8. For instance a physical or chemical pre-treatment step, leading to hydrolysis and hence increased bioavailability, can be followed by a MFC treatment. Alternatively, a full solar driven thermal or a chemical treatment of feces can be followed by nitrogen and energy recovery combined with the process liquidized fecal treatment. However, these approaches could

![Figure 7](image-url)  
**Figure 7.** Electrochemical characterization of urine modified jeans cloth electrodes in 10 mM carbonate buffer solution. A) Galvanodynamic linear sweep voltammograms of the highest catalytic activity (blue: all three N-containing components as modification substance, red: unmodified), scan rate: 10 μA s⁻¹. B) Chronoamperometric measurements at −0.2 V vs. Ag/AgCl, pH 7.5, room temperature, air purging.

| Table II. Overview of projected ORR current densities of carbonized modified jeans cloth electrodes at 0 V and −0.2 V vs. Ag/AgCl resulting from galvanodynamic linear sweep voltammetry and chronoamperometry. |
|-----------------------------------------------|------------------------------|------------------------------|------------------------------|
| Galvanodynamic linear sweep voltammetry | j₀/V / mA cm⁻² | j−0.2V / mA cm⁻² | Chronoamperometry |
| All N-containing compounds | −0.25 ± 0.11 | −0.74 ± 0.29 | j₀/V / mA cm⁻² | j−0.2V / mA cm⁻² |
| Urea | −0.21 ± 0.08 | −0.62 ± 0.35 | −0.05 ± 0.02 | −0.50 ± 0.29 |
| Creatinine | −0.15 ± 0.04 | −0.48 ± 0.29 | −0.06 ± 0.00 | −0.53 ± 0.14 |
| Uric acid | −0.19 ± 0.04 | −0.43 ± 0.13 | −0.06 ± 0.00 | −0.00 ± 0.01 |
| Unmodified | −0.13 ± 0.03 | −0.34 ± 0.13 | −0.01 ± 0.01 | −0.19 ± 0.17 |
| j (all N-containing compounds) / j (unmodified) | 1.9 | 2.2 | 5 | 3.2 |
Table III. Lessons learned – Summary of challenges and assumed system limitations as well as potential solutions to improve a) the applicability of human feces in MFCs and b) the overall system performance.

| Possible Limitations                                                                 | Potential solutions                                                                 |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Substrate (human feces & urine)                                                     | Inoculation, e.g. with sediments from ponds or soils (bio-augmentation) or well-running systems (seeding) including high-tech MFCs/MECs in combination with long term experiments to allow the microorganisms to adapt to the alternative electron acceptor and substrate. Improved tailoring of the electrode architecture, e.g. using bulk carbon granules made of charcoal as anode material. Thermal or chemical pre-treatment, improved integration in the system, see Figure 8. Use of non-corrosive current collectors. Passive mixing via flow through turbulences from the introduction of additional household wastewater streams, e.g. from washing sinks at a height difference, into the MFC or pit latrine or applying manual mixing to establish a semi-continuous mixing. |
| Low intrinsic electroactive microbial activity of human feces                        |                                                                                      |
| Limited bioavailability of the substrate                                            |                                                                                      |
| High salinity (especially Cl\(^{-}\)) causes corrosion                              |                                                                                      |
| Mass transfer limitation                                                              |                                                                                      |
| Anode & Cathode                                                                      | Change current collector material, geometry as well as method used for connection. Improving tailoring of the electrode architecture as well as integration in the system, see Figure 8. Separation of latrine drop and MFC with a baffle and flow channel as shown in Figure 8. |
| High electrode resistance because of insufficient contact to the current collector    |                                                                                      |
| Deposition of substrate components may limit the ORR                                 |                                                                                      |
| Clogging of the electrode pores due to larger organic particles and lipophilic floating scum |                                                                                      |

Figure 8. Possible future implementation based on the findings of this study. Left initial concept and right revised concept based on deploying the electrodes in a separated channel allowing a pre-treatment step in the form of an anaerobic hydrolysis stage, separated by a baffle, in the pit latrine.

only be realized with a higher technical effort as the proposed low tech MFC.

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