Rainwater-driven microbial fuel cells for power generation in remote areas

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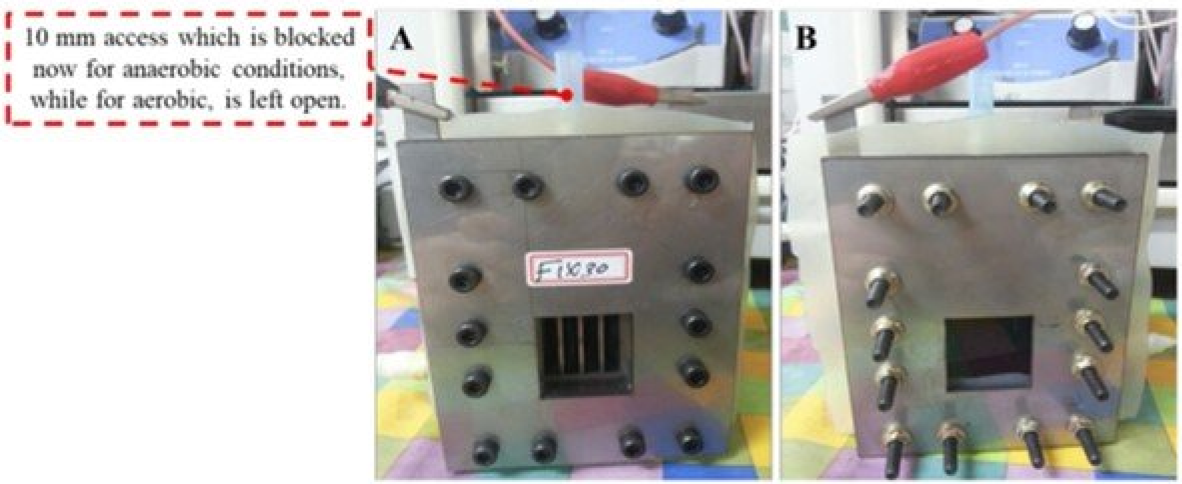


MFC that was used on the study: a) cathode side, and b) anode side. Credit: *Royal Society Open Science*, doi: 10.1098/rsos.210996

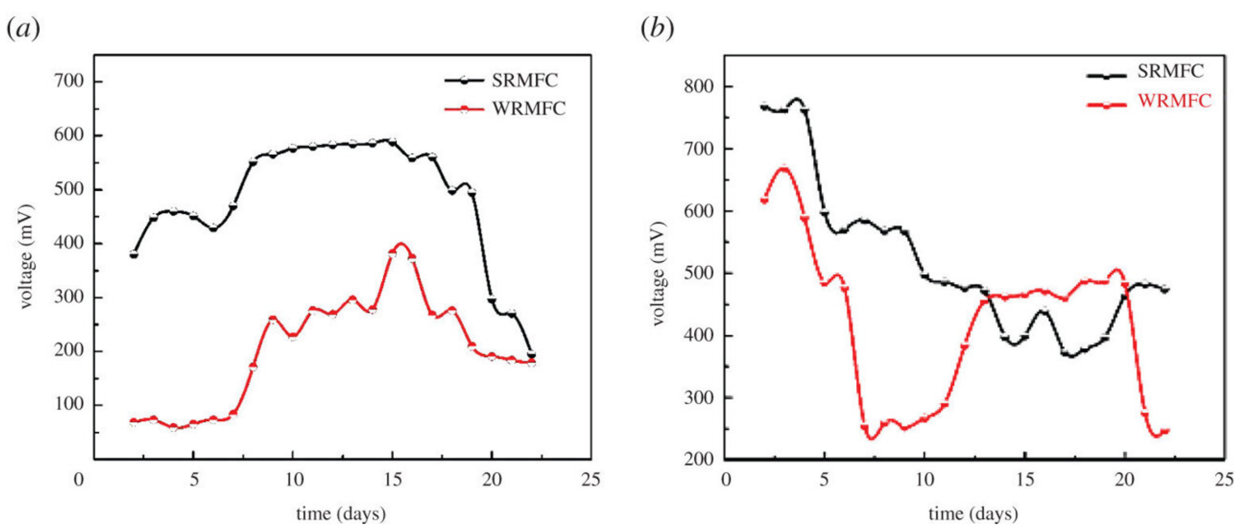
In a new report now published on *Royal Society Open Science*, Mohammed Taha Amen and a team of scientists in bio-nanosystem engineering, chemical engineering and microbiology at the Chonbuk National University of South Korea, and the Zagazig University, Egypt, showed the possibility of using rainwater as a sustainable analyte in an air-cathode microbial fuel cell (MFC). The results showed how the constructs could work within a specific temperature range, under aerobic and anaerobic environments.

The work highlighted the significant influence of the rainwater season under anaerobic conditions, where summer rainwater achieved an open circuit potential (OCP) of 553 ± 2 mV, without the addition of nutrients at ambient temperature. Addition of nutrients further increased the cell voltage. The team obtained the maximum open circuit potential for winter rainwater by exposing the reactor to air (aerobic conditions) at ambient temperature.

The resulting rainwater microbial fuel cell (RMFC) generated a maximum power output of 7 ± 0.1 mWm^{-2} at a corresponding current density value of 44 ± 0.7 mAm^{-2} at 30 degrees Celsius. The scientists obtained the maximum output power at ambient temperature with summer rainwater. During summer, Lactobacillus spp. formed the dominant electroactive genus, while Staphylococcus spp. dominated the winter rainwater. The cyclic voltammetry analysis confirmed how electrons could be delivered directly from the bacterial biofilm to the anode surface, without any mediators to open a new avenue for sustainable rainwater-based microbial fuel cells (RMFCs).

Converting chemical energy into electricity in a microbial fuel cell (MFC)

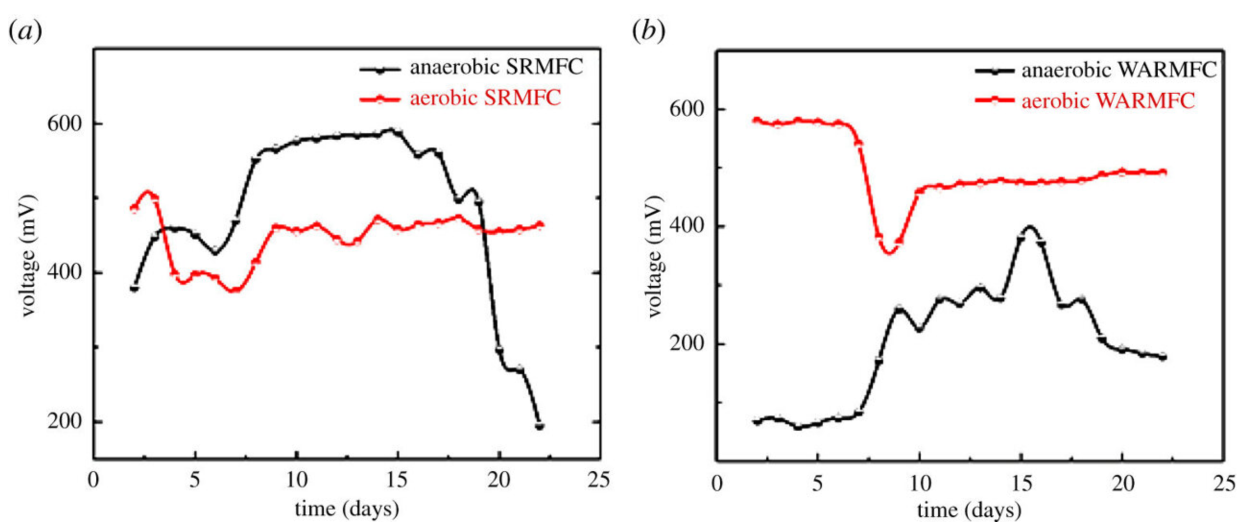
A microbial fuel cell system provides a setup for microorganisms to convert chemical energy embedded in some organic compounds to electricity by oxidizing these compounds into ATPs (adenosine triphosphate) through sequential reactions. The MFCs differed from other types of fuel cells since living organisms can act as a catalyst to organize organic materials present at the anode chamber. The process of MFC development provides a clean, reliable and efficient process, without any toxic byproducts. While the energy produced by MFCs is relatively low, it could gain energy from several types of wastes naturally present in diverse environments for direct conversion into electricity. In remote areas, MFCs are therefore considered a convenient power-generating device for wireless sensors. Rainwater contains a variety of microorganisms collected from the atmosphere, with ample evidence for microbial activity in the air. Fresh rainwater samples contain a wide phylogenetic variety including genomic sequences such as Alphaproteobacteria, Actinobacteria, Bacteriodetes and Lentisphaerae. The presence of diverse microorganisms motivated the scientist to study the possibility of generating electricity using rainwater microbial fuel cells (RMFC) due to their ability to metabolize organic and inorganic components. In this work, Amen et al. investigated two different rainwater samples based on sample collecting season to generate electricity through a single chamber air-cathode MFC. The results surprisingly provided a promising power output from a relatively high-quality atmosphere.



OCP for (a) SRMFC and WRMFC at ambient temperature; and (b) at 30°C. Credit: *Royal Society Open Science*, doi: 10.1098/rsos.210996

The experiments and seasonal effects

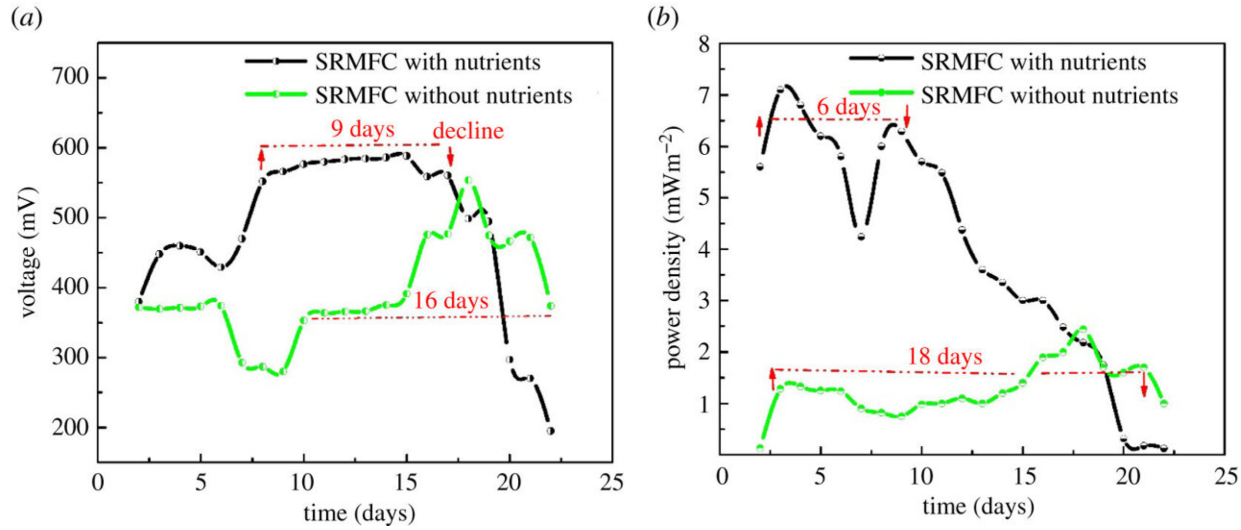
The team collected rainwater in April and December for summer and winter rainwater, respectively, and used the samples either without additives or with Nutrient Broth media. Amen et al. next constructed an MFC for function as a single chamber air-cathode made of transparent polyacrylic between the anode and cathode. The team placed a silver/silver chloride (Ag/AgCl) reference electrode in the anode compartment to measure the potential of the electrodes. They assembled the MFC and sterilized it using UV, then tested its performance with pure rainwater as an anolyte (electrolyte on the anode side), alongside rainwater with nutrient broth media. To examine aerobic/anaerobic conditions, the team next provided direct contact of ambient air to the MFCs and in another instance blocked access to oxygen to create anaerobic conditions. Amen et al. expected the types of microorganisms and their quantities in rainwater to vary according to the season. The summer rainwater provided a maximum open circuit potential than in winter at an ambient temperature after 15 days of function. The results indicated how the proposed rainwater microbial fuel cells could create a very acceptable potential regardless of the collecting season, although summer rainwater produced a more favorable anolyte.



The OCP for (a) both anaerobic and aerobic reactors in the case of SRMFC, and (b) WRMFC. Credit: *Royal Society Open Science*, doi: 10.1098/rsos.210996

Electrochemical characterization and experimental effects in the setup

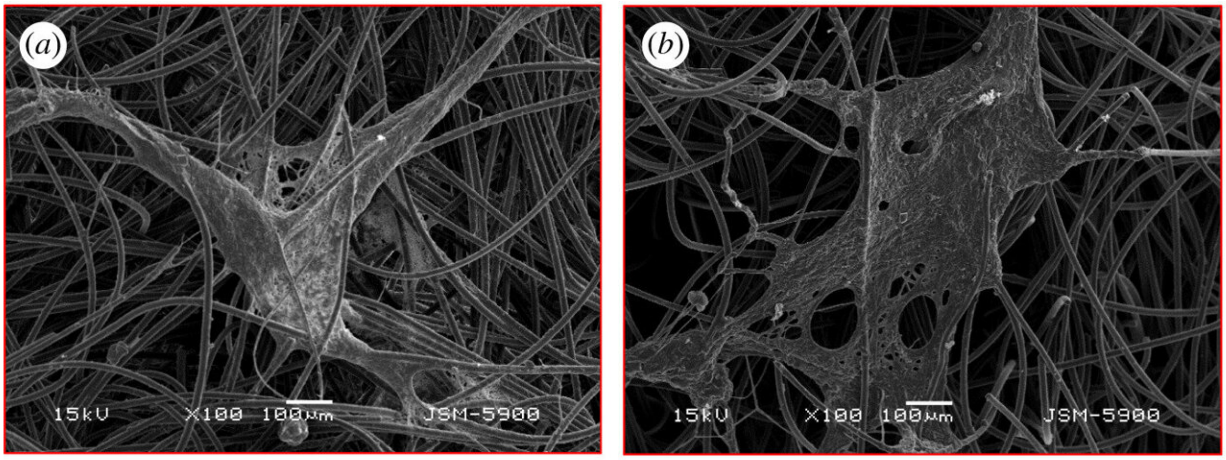
The team also tested the electrochemical performance of microbial fuel cells using a potentiostat and cyclic voltammetry analysis in a three-electrode setup, where they assigned the anode as a working electrode, the cathode and Ag/AgCl as a counter electrode and reference electrode, respectively. After 22 days of function, the team dismantled the apparatus and cultured the biofilm sampled from both the anode surface and anolyte, in Nutrient agar media. After isolating the bacterial growth, Amen et al. extracted the genomic DNA for analysis. The team found the maintenance of anaerobic conditions in MFCs to be quite difficult in practice and therefore investigated cells under aerobic conditions to determine the successful role of rainwater as an anolyte in the setup for electricity generation. They credited the findings to the fast metabolization of nutrients at 30 degrees Celsius. The output values emphasized the applications of RMFCs (rainwater microbial fuel cells) in summer or winter under the appropriate conditions of interest.



The SRMFC with and without nutrients, (a) voltage output, and (b) power density, throughout the operation period. Credit: *Royal Society Open Science*, doi: 10.1098/rsos.210996

Assessing the reliability of the constructs

The summer rainwater alone (labeled SRMFC-A) produced a maximum voltage output of 553 ± 0.6 mV compared to summer rainwater with nutrients (labeled SRMFC-WN). The setup with summer rainwater alone produced a maximum output by 18 days while those with nutrients in the media achieved a maximum power output in three days. Since the addition of nutrients to a fuel cell in a practical setting is tedious, the results indicated how the setup could be used on its own without nutrients to produce a reasonable voltage for applications in real-time. Additional results with cyclic voltammetry showed how electrons were delivered from the bacterial biofilm to the anode surface via direct contact without mediators. Both winter and summer microbial fuel cells also showed a thick, well-structured electroactive film via scanning electron microscopy, making it possible to transfer electrons to the anode.



SEM images for bacterial biofilm for both; (a) SRMFC and (b) and WRMFC. Credit: *Royal Society Open Science*, doi: 10.1098/rsos.210996

Bacterial community analyses and outlook

The scientists examined the microbiological variants to investigate the microbial community in the used rainwater. They noted the presence of synergistic interactions between microorganisms as an important factor to form electroactive biofilms that sustain the bioelectrochemical systems in the long term. While the Lactobacillus spp. formed as the primary electroactive bacteria in the summer microbial fuel cell setup, Staphylococcus spp. were present more dominantly in the winter setup. The proposed microbial fuel cell (MFC) is applicable to regions across the world. in practice the team expect applications of the setup in remote areas where the cell can be filled with rainwater first and left at open circuit mode to form a biofilm at the anode surface and create a stable open circuit potential. In this way, Mohammed Taha Amen and colleagues showed the development of an air-cathode, single-chamber microbial fuel cell that functioned effectively with rainwater as an anolyte. The resulting product is not only useful to power wireless sensors, but can also be effective as a biosensing tool to monitor the microbial community.

More information: Mohamed Taha Amen et al, Rainwater-driven microbial fuel cells for power generation in remote areas, *Royal Society Open Science* (2021). DOI: 10.1098/rsos.210996

Brent C. Christner et al, Ubiquity of Biological Ice Nucleators in Snowfall, *Science* (2008). DOI: 10.1126/science.1149757