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Urine transduction to usable energy: A modular MFC approach for smartphone and remote system charging

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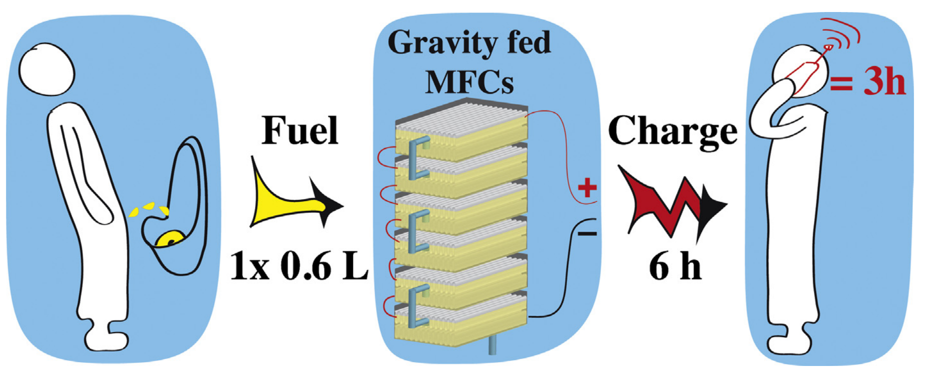
HIGHLIGHTS

- 1st application of a MFC design that can be scaled-up without power-density losses.
- 1st full charge of a basic phone within 42 and 68 h employing neat urine as MFC-fuel.
- 1st full charge of smartphone within 68 and 82 h employing neat urine as MFC-fuel.
- 1st charging system allowing 1 h 45 min phone call per 3 h of charge.

GRAPHICAL ABSTRACT



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ABSTRACT

This study reports for the first time the full charging of a state-of-the-art mobile smartphone, using Microbial Fuel Cells fed with urine. This was possible by employing a new design of MFC that allowed scaling-up without power density losses. Although it was demonstrated in the past that a basic mobile phone could be charged by MFCs, the present study goes beyond this to show how, simply using urine, an MFC system successfully charges a modern-day smartphone. Several energy-harvesting systems have been tested and results have demonstrated that the charging circuitry of commercially available phones may consume up to 38% of energy on top of the battery capacity. The study concludes by developing a mobile phone charger based on urine, which results in 3 h of phone operation (outgoing call) for every 6 h of charge time, with as little as 600 mL (per charge) of real neat urine.

1. Introduction

Microbial Fuel Cells (MFCs) are a bio-electrochemical technology converting organic waste into electricity [1]. An MFC comprises two electrodes, a cathode and an anode, and relies on the capacity of certain microorganisms to use the anode as their end-terminal electron acceptor in their anaerobic respiration. The technology's intrinsic characteristics are, low power – compared to established technologies, wide range of organic matter (otherwise considered as waste) can be used as fuel, low fiscal and maintenance costs, stacking of MFC collectives required for exploitable power levels and durability with robustness. Over the last three decades, research in the field has focused on (i) improving the power density of individual units [2,3], (ii) reducing the cost of each unit [4–6], (iii) assembling units into stacks to reach

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exploitable power [7,8], (iv) widening the range of potential fuels [9–11], and (v) demonstrating the implementation of this biotechnology into practical applications [12–18]. The results we present here focus on the latter aspect.

Previous research demonstrated the possibility of charging a basic mobile phone with urine as the fuel for MFCs (battery partially charged up to 3.7 V in 24 h) [17]. This previous study opened up the possibility of employing urine in remote locations for telecommunication purposes as well as demonstrated that the simplicity of the MFC design – i.e. ceramic membranes – was conducive to mass production. In the present study, the focus is also on the implementation of the MFC technology as a power supply for telecommunication purposes, however with significant advances, bringing the application closer to potential deployment. The aims of the study were therefore: (i) to fully charge the battery of both a basic and a smart phone, up to 4.2 V (full charge), (ii) to have a system independent of any external electrically powered peripherals (i.e. pump), (iii) to fuel the MFC system with the amount of urine of a single individual and (iv) to have minimal footprint and maintenance requirements.

To reach useful levels of power, pluralities of small MFCs need to be assembled into stacks or cascades. By assembling fluidically isolated small MFCs and electrically connecting them into parallel/series configurations, both the voltage and current can be increased [8]. The size of individual MFCs plays an important role in the performance of the collective, and although units can be enlarged, this is often at the detriment of power density [8,19]. This is primarily due to diffusion limitations and sub-optimal volume-to-surface-area (SAV) ratios, which can be improved by decreasing the size of the MFC reactor and thus maximally exploiting the (inter)active surfaces, where the microbial biofilms transfer electrons [8,19,20]. Provided that these parameters are respected in the re-design of a MFC architecture, then it should be possible to achieve equal power densities with both unit enlargement (to a certain extent) and miniaturisation [21]. This could be achieved by employing a medium size chassis, housing anode and cathode electrodes without a membrane, exposed to the same electrolyte [21]; in this setup, the anode is fully submerged to the fuel, whereas the cathode is only partially exposed to the bulk urine. Such MFC "module" can be considered as a collective of 20 MFCs connected in parallel, and in the present study, 6 such modules were used and connected in series. Such scaling up refers to the individual MFC elements within each box, which have been put together in a collective manner as a modular stack, indicating how they can be multiplied to produce higher power and treat higher feedstock volumes. The results demonstrate for the first time that this design can be employed to power practical applications by charging various types of cell phones. This system was recently shown to be robust and stable over 6 months, in a series electrical configuration – without any cell reversal [21].

An anaerobic ammonium abstraction, measured in the anaerobic part of the cathode, gave rise to the hypothesis that in such a setup, part of the cathode operation is ultimately in the nitrogen redox cycle [21]. It seems that the anaerobic part of the cathode was functioning as a denitrifying biocathode [22,23]. A similar mechanism has recently been reported by Li et al. (2016) who identified an electroactive ammonium oxidation process [24] and the use of an anaerobic nitrite-reducing cathode that was added to a classical MFC set-up. To achieve our aims, 6 modules were assembled, connected in series and employed to charge a basic mobile phone, a smartphone and in addition be implemented as a bespoke mobile phone charger, which provided ~1 h 45 min of call-time for every ~3 h of charging, only consuming 600 mL of urine as fuel every 6 h. It has to be noted that depending on the type of phone, electronic circuitry was built to manage the charge cycles.

2. Materials and methods

The whole system comprised 3 parts: the feeding mechanism representing the 'urination' of a single individual (Fig. 1a), a cascade of MFCs as the energy transducer and power source (Fig. 1b), and electronic circuitry managing the power produced by the MFCs to charge the cell phones (Fig. 1c).

2.1. Feeding mechanism

For any system and especially for a live biofilm system, the fuel supply rate is a critical factor [21]. As the ultimate aim of this study is the deployment of MFCs in real environments, the feeding mechanism needed to operate without any energy requirement. Hence, the pump was only present to (i) simulate an individual urinating and (ii) to provide a regular feeding pattern. Fuel was pumped into a tube that tilted, when the volume of urine reached 200 mL, into a bigger container, which included a syphon. This combined feeding mechanism was set to distribute 600 mL bursts (≈2.5 L min^{-1}) every 6 h (2.4 L d^{-1}). In field deployment conditions, such gravity feeding mechanism implies that a height of 80 cm below the urinal's floor is required.

Fresh urine was anonymously collected daily from healthy individuals and pooled together (pH ≈ 6.4–7.4). The reservoir tank was filled daily with 2.5 L of urine during weekdays, and with 9 L during weekends. Hence the urine pumped in the feeding mechanism aged consistently between 1 and 3 days (pH ≈ 8.4–9.3).

2.2. Microbial fuel cell cascade

The MFC cascade consisted of 6 modules whereby the outflow of upstream module was the inflow to the module downstream (Fig. 1). The height of the whole setup was 77 cm, including the

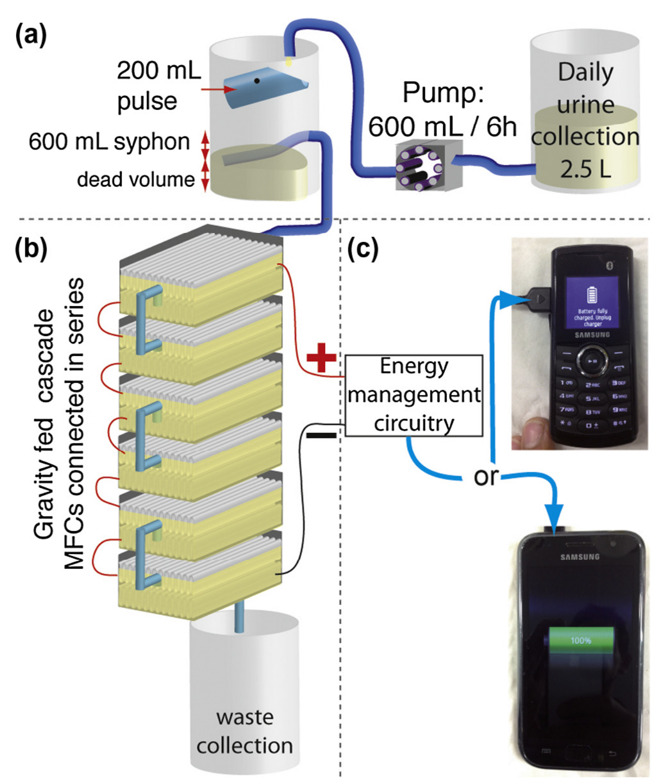

Fig. 1. Illustration of the different sub-systems of the setup employed to charge mobile phones. (a) Feeding mechanism, (b) cascade of MFCs, and (c) various energy harvesting circuitry allowing optimum mobile phone charging.