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Numerical Modeling of Capillary-Driven, Paper-Based, Flow-Through, Microfluidic Redox Flow-Batteries

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During the last couple of decades, interest in small-sized, single-use, disposable devices such as rapid diagnostic kits (RDK's) has dramatically soared [1]. Currently, such portable electronic devices rely heavily on conventional coin/button cell batteries for their operation. Although such batteries are very reliable and efficient, they become troublesome when such single-use kits have to be disposed of. The problem is that the kits are usually discarded when the battery is not fully discharged. Evidently, this means a huge waste of energy, but, more importantly, it poses severe environmental hazards when the chemicals stored inside the battery diffuse into aquifers. In a world re-imagined with bio-degradable materials, it is of no surprise that in recent years we are witnessing a growing interest in cellulosic materials for the construction of such kits. Paper is cheap, recyclable, and bio-degradable. An extra feature of cellulosic paper is that they can be used in the context of a flow battery to energize the printed circuitry of such kits [2]. That is to say that, while test fluid such as urine or blood is laterally spreading through the paper, they can serve as the fuel to energize the kit. As a matter of fact, the electrodes can be as simple as two parallel lines sketched by just a pencil on the two edges of the cellulosic paper. Fortunately, in recent years, novel paper-based, all-quinone, flow-through, microfluidic flow batteries such as PowerPAD have been developed for single-use applications [3]. The cellulosic absorbent pad incorporated in the design of this flow battery establishes flow through its porous carbon electrodes via capillary action thereby eliminating the need for any type of micropump. The device is inherently transient as it relies on passive, dynamic wicking of electrolytes through the porous electrodes where electrochemical reactions occur. But, the power output of this promising flow battery should further be enhanced before it can be considered as a true contender to conventional batteries. And this requires that a mathematical model is available which can be used for its design. In this work, a general theoretical framework has been developed for designing such flow batteries. The proposed two-step methodology can be used for determining the polarization curves of such electrochemical cells at discrete times. Results obtained this way can then be used to investigate the effect of different parameters on the maximum power output of the cell and its efficiency as functions of time. In our two-step methodology, imbibition of electrolytes by electrode/pad is computed first using Richards equation combined with the Brooks-Corey correlations. In the second stage, the saturation field so obtained is used to obtain the time-dependent velocity field from which polarization curves can be obtained at discrete times. Using a two-dimensional finite-element analysis, we have been able to qualitatively predict the time-dependent behavior of the PowerPAD battery [3]. The methodology developed in this work has also enabled us to qualitatively investigate the effect of pad's thickness, pore size, pore-size distribution, and contact angle on the power output of this battery.

Time Block Preference

Time Block A (09:00-12:00 CET)

References

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