

Project Title: Enhancement in Spontaneous Electrokinetic Energy Generation through Hydrophobic Patterning of the Evaporation Surface

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Funding Amount Requested: \$25,000

Research Problem: Increasing industrialization and population growth is expected to drive a significant rise in electricity consumption over the coming decades. As a result, there has been a concerted effort towards exploiting renewable energy resources and technologies owing to concerns over global warming and dwindling fossil fuel supplies. This project will contribute towards that effort by advancing electrokinetic energy conversion technology capable of generating electrical power using waste heat and solar radiation. It is well known that electrolyte flow through a conduit/pore with a net surface charge generates an electrical current upon migrating the counter-ions in the Debye layer using a pressure-gradient [1]. This phenomenon causes a charge separation across the channel/pore terminals yielding a voltage difference that can be utilized to perform electrical work. Remarkably, significant open circuit potentials (OCP) can be generated in electrokinetic energy conversion devices (EECD) using water as the electrolyte which is both non-hazardous and abundant. Nevertheless, the external work required to drive liquid flow through EECDs diminishes their practical utility.

Interestingly, the requirement of an external pump or pressurized vessel in EECDs can be eliminated by driving the electrolyte using spontaneous capillary flow [2]. Such a flow does not rely on external work but is rather sustained by solvent evaporation at a channel/pore terminal extracting heat from the environment. Several hundred millivolts of OCP have been reported for open (no solvent recycling) and closed (with solvent recycling) SEECDs employing porous films as the evaporating surface. While these studies have examined the use of different film materials for enhancing voltage generation, other opportunities for improving the performance of SEECDs remain unexplored. In this project, we propose the use of a hydrophobically patterned evaporation surface to boost spontaneous capillary flow in SEECDs. Such patterning is known to promote evaporation of polar solvents from membrane surfaces [3], and can therefore be expected to increase the voltage/current produced by SEECDs. In recent works, the PI's laboratory has characterized liquid flow in glass channel-based open SEECDs relating the liquid velocity to the voltage/current generated by the device (Figure 1) [4, 5]. Building on those results, we propose experimental characterization of liquid transport and solvent evaporation rates in open and closed Nafion membrane based SEECDs with a hydrophobically patterned evaporation surface for developing the scaling principles relevant to their design and operation. The noted research goal will be accomplished through completion of the following two scientific tasks.

Task 1: *Flow Visualization and Solvent Evaporation Rate Measurements:* The hydrophobically patterned Nafion membranes will be realized by electro spraying aliphatic compounds with a primary amine group on the evaporation surface using an aerosol generator available in the PI's laboratory. Specifically, solutions of hexylamine, dodecylamine and octadecylamine prepared in water containing 25% (v/v) methanol will be aerosolized and deposited. We expect the aliphatic compounds to localize themselves around their point of deposition through electrostatic interactions with the sulfonate groups in the membrane. In addition, covalent attachment of these compounds to the membrane surface will be pursued following sulfonamide chemistry [6]. Liquid transport will be visualized by flowing a tracer dye (e.g., rhodamine B) through the membrane and imaging it with a fluorescence microscope. The evaporation rate across the membrane will be mapped by recording the accumulation of this dye in the membrane as the solvent vaporizes. The electric voltage distribution across the membrane will be measured by placing electrodes at chosen locations. The SEECD unit will be created by sandwiching a commercial Nafion membrane between two polycarbonate plates with gold layers vapor deposited on them to make electrical contacts. The experiments will be performed with membranes of various sizes and thicknesses exposing them to different environmental conditions, e.g., sunlight, wind, humidity and temperature. Additionally, the influence of electrolyte properties, e.g., surface tension, viscosity, etc., will be characterized using water-methanol mixtures. The fluorescence measurements described above will be supplemented with OCP and short circuit current (SSC) data recorded using an electrochemical analyzer.

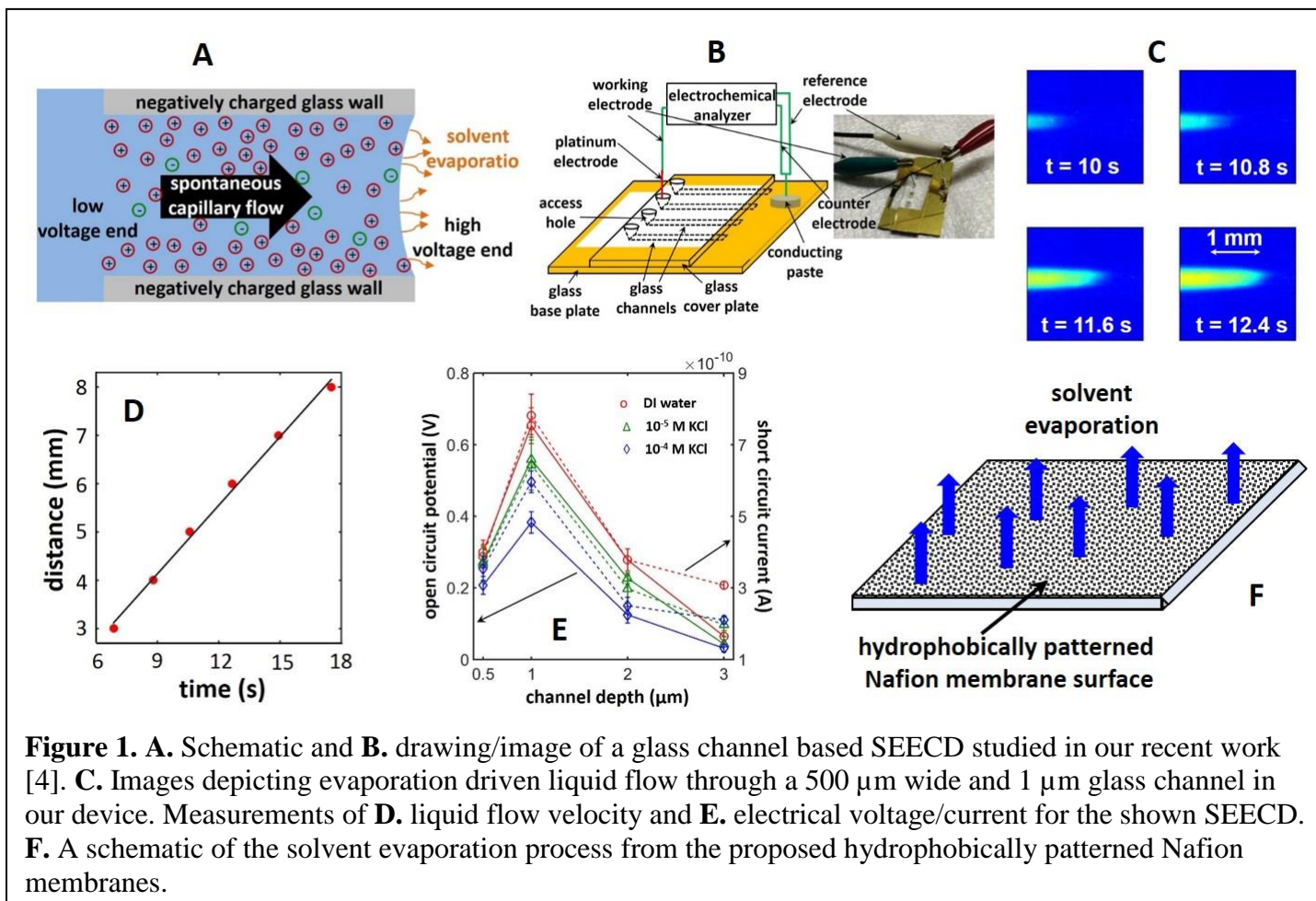


Figure 1. **A.** Schematic and **B.** drawing/image of a glass channel based SEECD studied in our recent work [4]. **C.** Images depicting evaporation driven liquid flow through a 500 μm wide and 1 μm glass channel in our device. Measurements of **D.** liquid flow velocity and **E.** electrical voltage/current for the shown SEECD. **F.** A schematic of the solvent evaporation process from the proposed hydrophobically patterned Nafion membranes.

Task 2: Heat and Mass Transport Measurements: In this task, co-PI Dejam will employ the Differential Scanning Calorimeter (DSC) and Intelligent Gravimetric Analyzer (IGA) systems housed in his laboratories to measure mass and heat transfer across the hydrophobically patterned Nafion membranes prepared in *Task 1*. While the heat transfer data obtained from this study will be used to estimate the energy conversion efficiency in the proposed SEECDs, the mass transport measurements will be compared to the solvent evaporation rates determined in *Task 1* to assess their validity. Additionally, we will thermally image the hydrophobically patterned Nafion membranes during solvent evaporation from their top surfaces to supplement the DSC data and develop a more comprehensive understanding of the heat transfer process in the system. Membranes of various thicknesses will be cut to a size suitable for measurements using the DSC and IGA systems to complete the above experiments.

Target funding programs: The data generated from this project will be used to develop one grant proposal each for the Fluid Dynamics and Interfacial Engineering programs in the Engineering Division at NSF. Additionally, we are working on starting a UW spin-off to commercialize our technology after having patented it recently [4]. Once the proposed business is legally set up, we will pursue SBIR grants through DOE and NSF to extensively develop our ideas related to SEECDs.

References Cited

1. van der Heyden, F.H.J., et al., *Nano Lett.* **7**: 1022-1025 (2007).
2. Li, C., Liu, K., Liu, H., Yang, B., Hu, X., *Mater. Res. Bull.* **90**: 81-86 (2017).
3. Guo, Y., Zhao, X., Zhao, F., Jiao, Z., Zhou, X., Yu, G., *Energy Environ. Sci.* **13**: 2087-2095 (2020).
4. Dutta, D., *US Patent* 10,944,123 (2021).
5. Yanagisawa, N., Dominguez, V., Mahmud, S., Dutta, D., *Phys. Fluids* **35**: 053604 (2023).
6. Caddick, S., Wilden, J.D., Judd, D.B., *J. Am. Chem. Soc.* **126**: 1024-1025 (2004).

Budget Summary

• Graduate student salary support for the Dutta laboratory	\$7,000
• Fringe benefits for the graduate student working in the Dutta laboratory	\$126
• Reagents and supplies for the Dutta laboratory	\$6,374
• User fees for the Dutta laboratory	\$1,500
• Graduate student support for the Dejam laboratory	\$9,823
• Fringe benefits for the graduate student working in the Dejam laboratory	\$177
Total	\$25,000

Budget Justification

- Laboratory supplies include chemicals, consumables (gloves, pipettes, membranes, vials, etc.), electrode materials, electrochemical cells, other circuit components and filters for a water purification system in the Dutta laboratory.
- User fees are requested for services obtained from the electrical and machine shops and the microscopy facility at UW.
- Graduate student salary support is requested for one student each working in the Dutta and Dejam laboratories.
- Fringe benefits for the supported graduate students are calculated at the rate of 1.8% of the salary amount requested.