Comprehensive Analysis of Water and Solute Transport in the Ion-Exchange Membranes of All-Vanadium Redox Flow Batteries

Yasser Ashraf Gandomi[1], Matthew M. Mench[1, 2]

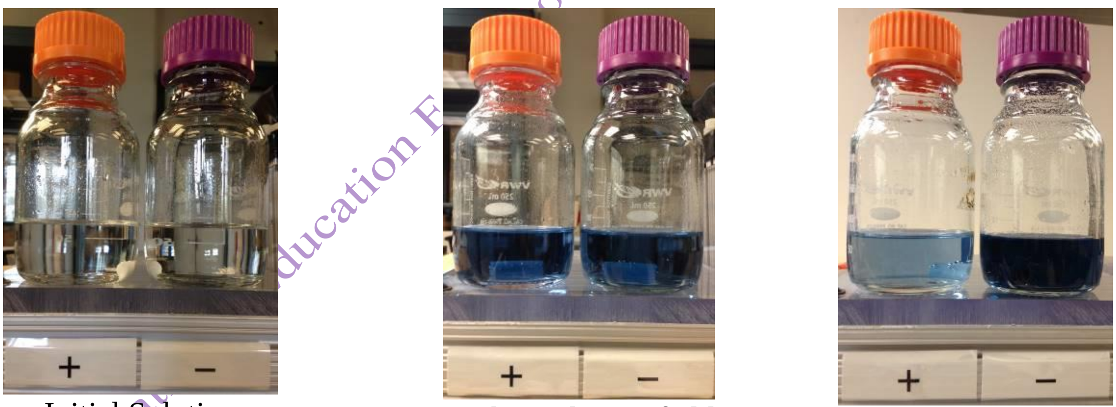
[1] The Electrochemical Energy Storage and Conversion Laboratory, Department of Mechanical, Aerospace and Biomedical Engineering, University of Tennessee, Knoxville, Tennessee 37996, USA
[2] Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

Corresponding e-mail: mmench@utk.edu

Abstract

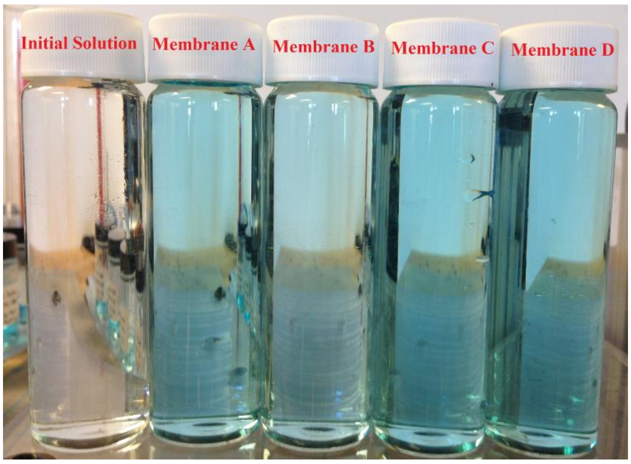
One of the major sources of capacity loss in all-vanadium redox flow batteries (VRFBs) is the undesired transport of active vanadium species across the ion-exchange membrane, generically termed crossover [1]. Different parameters affect the transport of solutes (vanadium ions) and solvent (water) through the ion-exchange membrane [2-4].

The ion-exchange membrane properties (type, thickness, equivalent weight, and reinforcement), the battery configuration (electrode morphology, flow filed design) and operating conditions (flow rate, temperature, vanadium concentration, and charge/discharge current) are among the important parameters [5]. Figure 1 visually demonstrates some examples of the effect of these parameters on the crossover, as the concentration of ions affects the colour of solution [5].

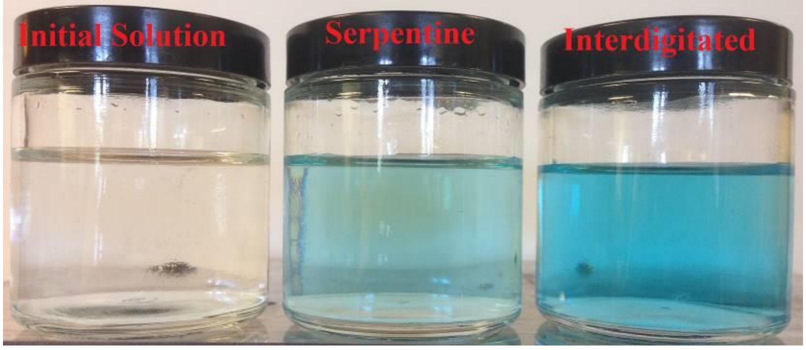


Initial Solution — With no electric field — With electric field

(a) The effect of electric field on the crossover behaviour of vanadium species



(b) The effect of membrane characteristics on the crossover behaviour of vanadium species



(c) The effect of flow field design on the crossover behaviour of vanadium species

Fig1. The qualitative demonstration of the effect of different parameters on the crossover behaviour of vanadium species

The concentration gradient and the electric field (via migration and electro-osmosis) are the main driving forces for vanadium ions transport across the membrane [5]. Water transport across the ion-exchange membrane is due to multiple driving forces including the electro-osmotic drag, thermo-osmosis, osmotic and hydraulic pressure gradient [6, 7].

In this work, a novel system including multiple cells has been designed and built to precisely investigate the crossover of vanadium species and water transport through the membrane in real-time. The test system utilizes ultraviolet/visible (UV/Vis) spectroscopy and is capable of separating contributions to crossover stemming from electrostatic potential gradient, concentration gradient, cell architecture and operating conditions.

In this study, the permeability of vanadium species and water across the membrane has been quantified for a wide range of operating conditions and by varying the affective parameters outlined earlier.

References:

1. D. S. Aaron, S. Yeom, K. Kihm, Y. Ashraf Gandomi, T. Ertugrul, M. M. Mench, Journal of Power Sources, 366, 241-248 (2017); https://doi.org/10.1016/j.jpowsour.2017.08.108.

2. Y. A. Gandomi, D. Aaron, T. Zawodzinski, and M. Mench, *Journal of The Electrochemical Society,* **163** (1), A5188-A5201 (2016); doi: 10.1149/2.0211601jes.

3. Y. Ashraf Gandomi, D. S. Aaron, M. M. Mench, Membranes, 7(2), 29 (2017); doi:10.3390/membranes7020029.

4. Y. A. Gandomi, D. Aaron, and M. Mench, *Electrochimica Acta,* **218**, 174-190 (2016); http://dx.doi.org/10.1016/j.electacta.2016.09.087.

5. Y. A. Gandomi, T. A. Zawodzinski, and M. M. Mench, *ECS Transactions,* **61** (13); 23-32 (2014). doi:10.1149/06113.0023ecst.

6. Y. A. Gandomi, M. Edmundson, F. Busby, and M. M. Mench, *Journal of The Electrochemical Society,* **163** (8), F933-F944 (2016); doi: 10.1149/2.1331608jes.

7. Y. A. Gandomi and M. M. Mench, *ECS Transactions,* **58** (1), 1375-1382 (2013); doi: 10.1149/05801.1375ecst.