

Interplay Between Diffusivity and Surface Barriers on Vanadium Ion Transport in Polymeric Membranes for All-Vanadium Redox Flow Batteries

Yasser Ashraf Gandomi¹, Doug Aaron, 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: yashraf@utk.edu; mmench@utk.edu

Abstract

Enclosed and open batteries have been widely used for electrical energy storage at medium and large scales [1-8]. Redox flow batteries (RFBs) are open batteries, thus scalability is a major advantage of these devices; engineering cell reactors for desired output power can be performed independently, without altering the available capacity and vice versa [8]. All-vanadium redox flow batteries (VRFBs) are a type of RFB with the unique benefit of not suffering from cross contamination and irreversible capacity decay as a function of crossover (both water and vanadium) [9,10].

Crossover of vanadium ions and water through the ion-exchange membrane occurs due to several drivers; of them, concentration gradient and electric field are considered dominating contributors [11-15]. Among various components being used within the VRFB architecture, ion-exchange membranes play a significant role, influencing not only the rate of crossover but also affecting the performance of the cell directly [8]. It is well-known that the ohmic overpotential is dominated by the membrane in VRFBs. Therefore, engineering ion-exchange membranes must improve ionic conductivity while reducing crossover; this optimization effort is the subject of much research in the literature.

One of the major issues to be addressed is the contribution from interfacial phenomena (contact resistance between electrodes and membrane) to the ionic conductivity along with ionic and water transport through the ion-exchange membrane. In this work, we have utilized a novel experimental set-up (capable of measuring the ionic crossover in real-time) to quantify the permeability of ionic species. In addition, we have designed, engineered and prototyped several conductivity cells for measuring the ionic conductivity of the ion-exchange membranes and electrolytes ex-situ. Such a comprehensive experimental diagnostic has enabled us to provide further details regarding the impacts of interfacial phenomena on ionic conductivity and crossover. The results of this study provide deeper insight into the optimization of VRFBs for high-performance and robust applications.

References:

1. J.-D. Xie, H.-Y. Li, T.-Y. Wu, J.-K. Chang, and Y. A. Gandomi, *Electrochimica Acta*, 273 257-263 (2018); <https://doi.org/10.1016/j.electacta.2018.04.007>.
2. S. Gu, C.-T. Hsieh, Y.-M. Chiang, D.-Y. Tzou, Y.-F. Chen, and Y. A. Gandomi, *Materials Chemistry and Physics*, 215, 104-111 (2018); <https://doi.org/10.1016/j.matchemphys.2018.05.016>.
3. M. Zehsaz, F. V. Tahami, and Y. A. Gandomi, *Applied Mechanics and Materials*, 50, p. 93-99. *Trans Tech Publ* (2011).

4. M. Zehsaz, F. V. Tahami, and Y. A. Gandomi, *International Journal of Advances in Engineering & Technology*, 3 (2), 108 (2012).
5. H.-L. Tsai, C.-T. Hsieh, J. Li, and Y. A. Gandomi, *Electrochimica Acta*, 273 200-207 (2018); <https://doi.org/10.1016/j.electacta.2018.03.154>.
6. S.-Y. Gu, C.-T. Hsieh, T.-W. Lin, J.-K. Chang, J. Li, and Y. A. Gandomi, *Carbon*, 137, 234-241 (2018); <https://doi.org/10.1016/j.carbon.2018.05.024>.
7. S.-Y. Gu, C.-T. Hsieh, J.-Y. Yuan, J.-H. Hsueh, and Y. A. Gandomi, *Diamond and Related Materials*, 87, 99-106 (2018); <https://doi.org/10.1016/j.diamond.2018.05.014>.
8. Y. A. Gandomi, D. Aaron, J. Houser, M. Daugherty, J. Clement, A. Pezeshki, T. Ertugrul, D. Moseley, and M. Mench, *Journal of The Electrochemical Society*, 165 (5), A970-A1010 (2018); doi: 10.1149/2.0601805jes.
9. 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>.
10. 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.
11. Y. Ashraf Gandomi, D. S. Aaron, M. M. Mench, *Membranes*, 7(2), 29 (2017); doi:10.3390/membranes7020029.
12. 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>.
13. Y. A. Gandomi, T. A. Zawodzinski, and M. M. Mench, *ECS Transactions*, **61** (13); 23-32 (2014). doi:10.1149/06113.0023ecst.
14. 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.
15. Y. A. Gandomi and M. M. Mench, *ECS Transactions*, **58** (1), 1375-1382 (2013); doi: 10.1149/05801.1375ecst.