

Asymmetric performance testing of carbon felt electrodes to identify the limiting electrode in vanadium redox flow batteries

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In vanadium redox flow batteries (VRFBs), the electrode is a key component affecting the power density in these systems [1-2]. If the porous electrode has a low surface area, it will adversely affect electrolyte utilization and the power output of the system [3]. Similarly, the electrode should be as electrically conductive as possible to minimize resistive (ohmic) losses. Furthermore, if the surface chemistry of the electrode is not favorable toward the desired redox reaction, a greater amount of activation energy will be necessary to initiate the reaction. Therefore there are numerous opportunities to improve system performance by addressing the limitations in electrode materials.

One major problem with the current carbon-based VRFB electrodes is that they possess very poor electrochemical activity, therefore showing poor kinetics for vanadium reactions. Several attempts were made to improve the surface chemistry of the electrodes by introducing various functional groups or noble metal catalysts [4-5]. In these studies, the effect of reaction kinetics on VRFB performance is investigated by symmetric charge/discharge cycling tests, where the same type of electrode is used for both positive and negative half-cells. Due to the difference in the kinetics of reduction and oxidation reactions in positive and negative half-cell, one of them may limit the overall performance of the system, which cannot be captured with symmetric performance testing alone. To the best of our knowledge, no studies have been performed using asymmetric cell configurations to study reaction kinetics and identify the limiting electrode reactions in these systems.

In this study, the reaction kinetics of the reduction and oxidation reactions for carbon felt electrodes are investigated by charge/discharge cycling performance tests using both symmetric and asymmetric electrode configuration. Raw and heat-treated carbon felts were selected as test electrodes. For the first study, the heat-treated carbon felt was used in the negative half-cell while the electrode in the positive half-cell was varied. Voltage efficiencies were found to be 85.13%, and 87.10% for the raw and heat-treated electrodes, respectively (see Fig. 1). Interestingly, the voltage efficiencies change only slightly with respect to each case, indicating that the selected surface functionalization method do not significantly affect the reaction kinetics in the positive half-cell. However, when the heat-treated electrode was used in the positive half-cell as a control case while varying the electrode type used in the negative half-cell (see Fig. 2), a significant change in voltage efficiencies was observed (60.34% for the raw electrode, and 87.10% for the heat-treated electrode).

Results indicate that although the surface functionalization has a minimal impact on the reaction

kinetics at the positive half-cell, it affects the reaction kinetics of the negative half-cell substantially. Therefore, reaction kinetics at the negative half-cell appears to limit the performance of these systems.

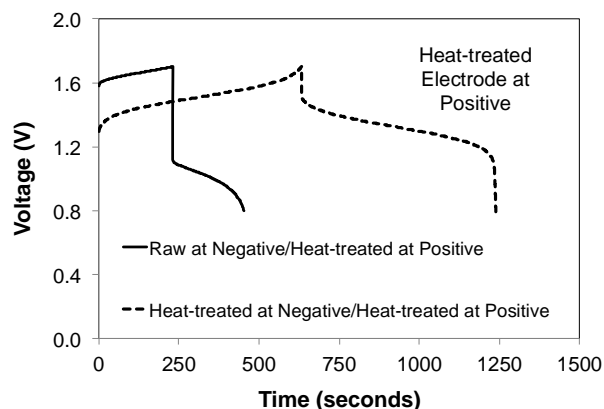


Figure 1. Charge-discharge curves using heat-treated electrode in the positive half-cell while the electrode in the negative half-cell is varied.

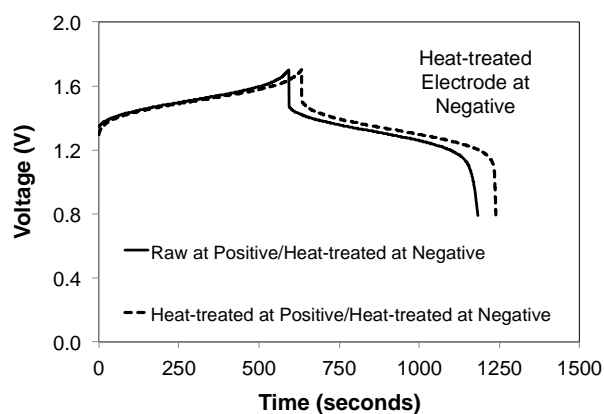


Figure 2. Charge-discharge curves using heat-treated electrode in the negative half-cell while the electrode in the positive half-cell is varied.

Reference:

- [1] Agar, E., Knehr, K. W., Dennison, C. R., and Kumbur, E. C., 2012, *Journal of Power Sources*, in press, DOI: 10.1016/j.jpowsour.2012.10.016.
- [2] A. Z. Weber, M. M. Mench, J. P. Meyers, P. N. Ross, J. T. Gostick, Q. Liu. *J. Appl. Electrochem.* 41, 1137 (2011).
- [3] D. S. Aaron, Q. Lui, Z. Tang, G. M. Grim, A. B. Papandrew, A. Turhan, T. A. Zawodzinski, M. M. Mench. *J. Power Sources* 206, 450 (2012).
- [4] L. Yue, W. Li, F. Sun, L. Zhao, L. Xing. *Carbon* 48, 3079 (2010).
- [5] W. H. Wang, X. D. Wang. *Electrochimica Acta.* 52, 6755 (2007).