Alternative Designs to Harness Natural Convection in Flow Batteries

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Abstract

Introduction:
Harvesting of intermittently renewable energy sources requires corresponding progress in energy storage systems. Rechargeable redox flow batteries offer advantages [1, 2] over the other storage forms such as lifting of water, compression of air, flywheel, etc.[3] Rechargeable vanadium flow battery has been taken up to tens of MWh scale. A soluble lead redox flow battery (SLRFB) [4] does not use expensive vanadium proton exchange membranes. The challenge lies in increasing cycle life and energy efficiency of SLRFB.
The work carried out in our group has established the presence of natural convection loops, caused by lead concentration difference driven density gradient. The present poster submission reports our findings on electrode configurations that promote the role of natural convection. A gap was introduced between electrode and the wall on which it would have been mounted flush otherwise.
Use of COMSOL Multiphysics® Software:
COMSOL Multiphysics® software was used to solve coupled fluid flow, electrochemical reactions, and species transport equations. The predicted results have been tested and validated experimentally.
Results:
Current modeling was inspired by initial work on SLRFB [5, 6, 7] that ignored the any possible role of natural convection. To establish the extent of its contribution, a mixed convection system with forced velocity being ten times larger than the velocity induced by natural convection was also simulated for the same cell.
Figure 1 compares time variation of voltage for two types of flow fields in the battery. The strong effect of natural convection is brought out clearly during charging. Although not shown, if no flow is permitted, the charging voltage rapidly increases with time due to increasing diffusion length (proportional to square root of time). The time variation of discharge potential is however quite different for two flows due to the induced and the forced flow being in opposite directions. Figure 2 compares cell potential vs. time for the standard design (wall mounted electrodes) and the new design. The charge efficiency for the new design is larger than that for the standard design.
To validate the predictions, experiments have been performed in both types of cells, and the results are presented in Figure 3. The broad features predicted by the model are validated by the measurements. A number of other experimental measurements, not shown here, are compared with model predictions and the two are found to be in good agreement. The ability of the model to quantitatively capture the experimental

observations raises the hope that simulations can be used to probe more complex configurations before fabricating and testing them.

Conclusions

We are able to verify, through simulation and experiments, that a change in electrode configurations while keeping the electrode area and the electrode spacing the same, impacts battery characteristics significantly. Measurements also showed that the induced natural convection is dominated by concentration difference driven density difference. The density difference due to temperature difference on account of ohmic heating of the electrolyte solution is two orders of magnitude smaller.

Reference

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Figures used in the abstract

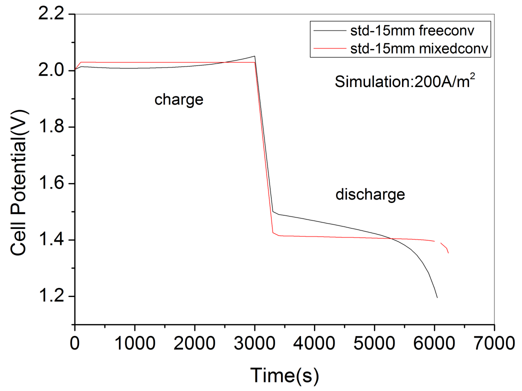

Figure 1: Comparison of cell potential for free convection and mixed convection in standard SLRFB: Charging: 3000 s, relaxation (open circuit or zero current): 300 s (which is not plotted) discharge cut-off voltage: 1.2 V.

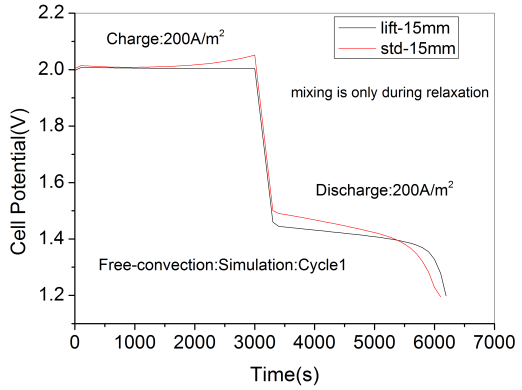

Figure 2: Comparison of cell potential for Natural convection in standard and lift SLRFB.

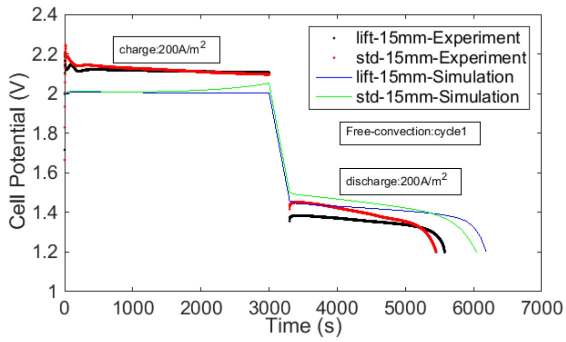

Figure 3: Experimental verification of cell potential for free: charge/discharge potential in first cycle for standard and lift design cells design of SLRFB from simulation as well as experiment for natural convection.