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Effects of pressure differences between flow battery half-cells

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BACKROUND & MOTIVATION

The dynamic viscosity determines the flowability of electrolytes used in flow batteries and is thus a key impact on the hydraulic resistance caused at the throughflow of flow cells per se and especially porous graphite felt electrodes. Assuming a laminar flow, the directly proportional relationship of fluid viscosity η and pressure loss Δp in a porous medium with a defined permeability κ can be expressed using Darcy's law:

$$-\nabla p = \eta \times \frac{u}{\kappa}$$

The dynamic viscosity of electrolytes (assumed as Newtonian fluid) depends on:
- Electrolytic mixture and ion concentration
- Operating temperature
- State of charge

In flow batteries the dynamic viscosity of the electrolyte species can vary considerably, thus creating a cyclically varying impact at successive charging and discharging (Figure 1).

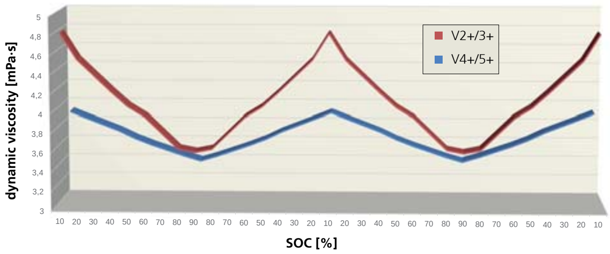

Figure 1. *Cyclically varying dynamic viscosity of $V^{2+/3+}$ and $V^{4+/5+}$ electrolyte depending on SOC 1.6 mol/L V, 2.6 mol/L H_2SO_4, 30 °C [2]*

In previous studies, the dynamic viscosity has mostly been treated as a constant value. Fewer studies have investigated the impact on cell performance (by required pumping power and diffusion of ions) while the engineering point of view, regarding the impact on pressure within the cells, has received no consideration yet [1,2,3].

The viscosity differences of the electrolyte species can cause significant pressure differences between battery half-cells of equal design and operating parameters.

Especially large-scale battery cells without electrode flow fields can be subject to high stress by differential hydraulic pressure (Figure 2).

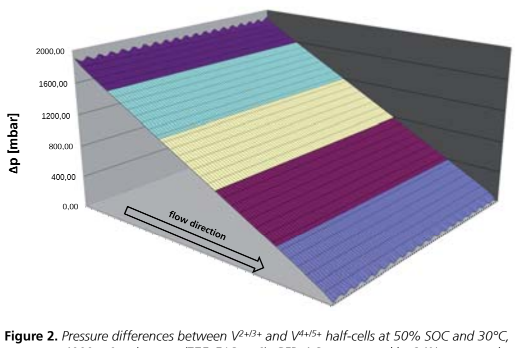

Figure 2. *Pressure differences between $V^{2+/3+}$ and $V^{4+/5+}$ half-cells at 50% SOC and 30°C, 4000cm² active area (775x516mm²), GFD 4.6 compressed by 24% compression, $\dot{V} = 4.7E^{-5}$ m³/s [4], $\eta_{V^{2+|3+}} = 2.7$mPa·s, $\eta_{V^{4+|5+}} = 1.25$mPa·s, 1.6 mol/L V, 2 mol/L H_2SO_4*

EFFECTS OF PRESSURE DIFFERENCES

The mechanical effects of pressure differences between the half-cells of a single cell flow battery can be described using membrane theory and constrained modulus method assuming membrane and graphite felt as a spring assembly connected in series while the graphite felt can be approximated as a system of homogeneously distributed, but dependent, linear-elastic springs connected in parallel (Figure 3).

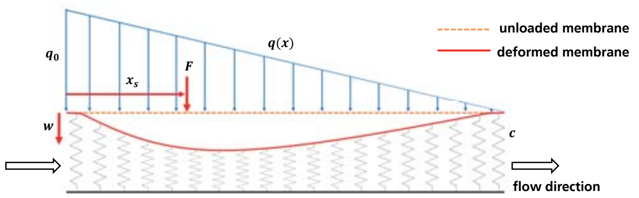

Figure 3. *Force-deflection schema of the membrane-graphite felt-system*

Besides the variation of diffusion processes because of the actual pressure regime, a unilateral deformed membrane will lead to deviations from the intended compression of graphite felt electrodes. This effect will increase even further with the use of flexible bipolar plates in flow battery stacks (Figure 4).

The consequences are:
- Yet undefined changes of internal electrical and hydraulic resistances
- Reduction of service life due to a higher material stress

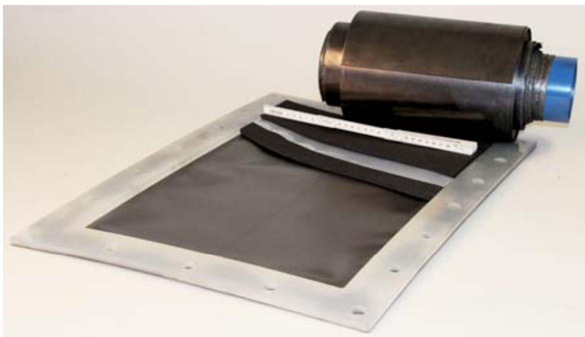

Figure 4. *Sectional view of a 2500 cm² flow battery cell with highly-flexible bipolar plates*

FURTHER STEPS

- Comprehensive characterizations of vanadium electrolyte species
- Determination of relevant mechanical properties of membranes and graphite felts as well as force distributions and membrane deflections
- The mentioned constrained modulus method will be adapted to the requirements and boundary conditions and shall be implemented into FEM
- Additional methods for deformation analysis will be examined and further developed

References
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