Estimating Air Flow Rates in a Fuel Cell System using Electrochemical Impedance

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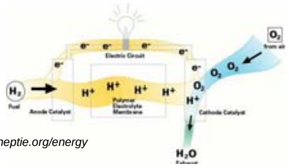

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This work proposes a method to estimate the air flow rate in a fuel cell system from electrochemical impedance spectroscopy (EIS).

Advantages of air flow estimation:

1) Eliminate flow meters thus reducing system cost and the need for frequent calibration.

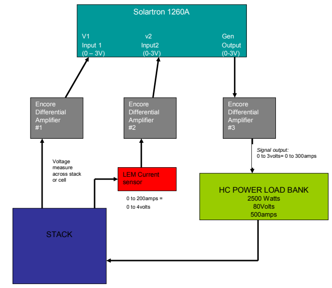
2) Run the system at lower air flows, thus reducing power loss to the compressor/blower.

Electrochemical Impedance Spectroscopy

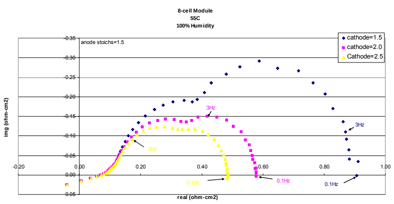
A small ac perturbation is imposed on a dc bias. The frequency of the ac perturbation is varied from 15,000Hz to 0.1Hz. The impedance is measured across either individual cells or the entire stack.

Impedance is the ratio of the element's complex voltage phasor divided by its corresponding complex current phasor.

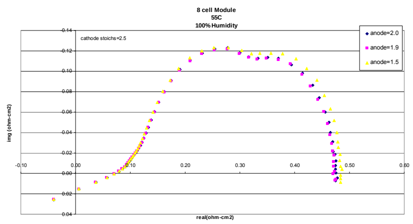
("An Introduction to Circuit Analysis" Scott, Donald)



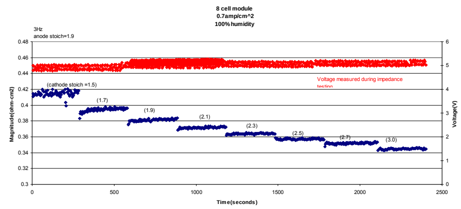
Testing is performed in a laboratory at Plug Power Inc. in Latham, New York. The impedance experiments involve an eight cell stack with a 3M commercially available membrane electrode assembly. The membrane thickness is 1.1 mils and the active area of the cell is 262cm2. The reactant flows to the stack are hydrogen and air. The anode and cathode gas streams are 100% humidified with external humidifiers.



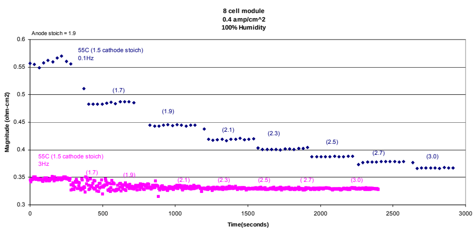
Impedance Sweeps 0.1Hz to 15,000Hz, current density at 0.7amp/cm2 hydrogen is held at a constant flow rate of 15.4slm and as the air flow decreases from 60.9 to 48.7 and to 36.5slm both the real and imaginary parts of impedance increase at lower frequencies.



Air is held at a constant flow rate of 60.9slm and the hydrogen flow decreases from 20.5 to 19.4 to 15.4slm. No change in impedance measurements.



Impedance Magnitude and Phase measured at 3Hz. Different air flows have distinguishable impedance magnitude and phase values at operating conditions for a current density of 0.7amp/cm2, while measured voltage shows little change.



Impedance Magnitude and Phase measured at 3Hz and 0.1Hz, different air flows have distinguishable impedance magnitude values at 0.1Hz but not at 3Hz.

Operating voltage for a fuel cell that accounts for ohmic losses, activation losses and concentration losses (*J. St-Pierre, B. Wetton, G. –S. Kim, and K. Promislow J electrochem. Soc. 154 (2007) B186-B193.)*

$$V = E_o - R_\Omega i - \frac{RT}{\alpha_c F}\ln\left(\frac{C_o}{i_o}\right) - \frac{RT}{\alpha_c F}\ln\left(\frac{i}{\delta(i_l - i)}\right)$$

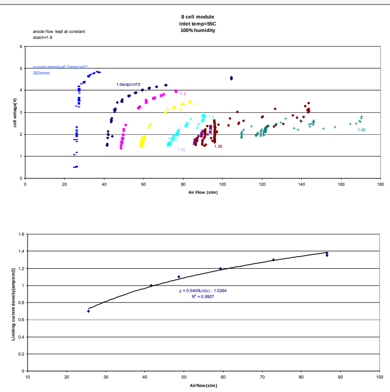
E_o=open circuit potential (volts)
R_Ω= ohmic resistance (ohm-cm^2)
i = current density (amp/cm^2)
R = gas constant = 8.3145 (J/mol K)
F= Faraday's constant = 96485 (c/mol)
T= temperature (K)
α_c = oxygen reduction charge transfer factor
C_o = reference oxygen concentration (mol/cm^3)
i_o = exchange current density (amp/cm^2)
C_c = oxygen concentration in the dry inlet oxidant (mol/cm^3)
δ = oxygen mass transfer coefficient (mol/A cm)
i_l = limiting current density (amp/cm^2).

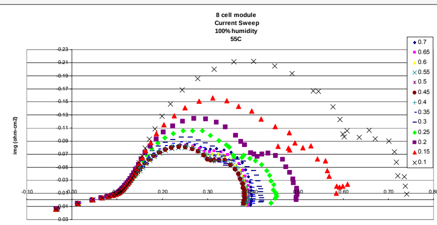
We focus on impedance measurements taken at the low frequency of 0.1Hz, the absolute value of the derivative of the DC voltage will be a reasonable approximation for the impedance.

$$Z = R_\Omega + \frac{A}{i} + \frac{A}{(i_l - i)}$$

$$A = \frac{RT}{\alpha_c F}$$

The dependence of the impedance Z on the air flow rate is through the limiting current density i_l.





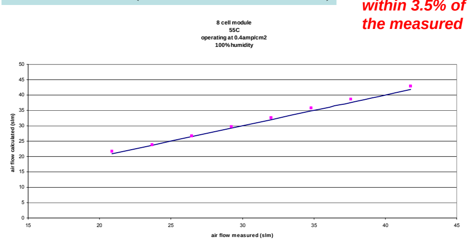
Parameter R_Ω, can be experimentally measured and read from a Nyquist plot. It is the impedance measurement at the high frequency where the curve crosses the real axis. R_Ω=0.10 ohm-cm2.

A (the Tafel slope) - determine the magnitude of the impedance at the lowest frequency for the lowest current density curve where mass transport losses are negligible. subtract R_Ω from this value and obtain the activation resistance which is equal to A divided by the current density A=0.064V.

Estimated vs. Measured Air flow Rates

$$airflow(slm) = \exp\left(1.85\left(\frac{Zi - R_\Omega i}{Z - R_\Omega - \frac{A}{i}} + 1.0264\right)\right)$$

Estimated flow rates are within 3.5% of the measured



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