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General Information on Membrane Conductivity:

What is Conductivity?
Conductivity is a bulk parameter which represents the ability of a material to conduct electricity. The units of conductivity are siemens per centimeter. A siemen is equal to 1/ohm. Conductivity is represented by the variable "sigma". The relation between conductivity and resistivity is sigma = 1/resistivity.

What is Resistivity?
Resistivity is a bulk parameter which represents a material's tendency to resist the flow of electrical charge. The relation between resisitivity(rho) and resistance(R) is equal to rho*L/A, where L is the length parallel to the moving electrical charge and A is the cross-sectional area through which the charge is flowing.

What are the challenges in measuring membrane conductivity?
The challenge is in separating ionic creation from ionic conduction. When making a measurement of conductivity, if ionic creation is included, the measured value will be much lower than the actual bulk conductivity value. A two electrode measurement (unless performed at exactly the right frequency) will include the effects of ion creation.

Separating ionic conduction from ionic creation
The ideal method is a Direct Current (DC) method which is a four electrode measurement. Two electrodes supply the current to the sample. Two other electrodes, set far from (but in-between) the current generation electrodes, measure a voltage drop which is only due to charge flow (ionic conduction).

Another approach is to use an Alternating Current (AC) method. By oscillating a sufficiently small current, at the correct frequency, ions can be moved back and forth across a sample without creating or destroying any ions. This is done by charging and discharging the double layers associated with the metal-to-ionomer contacts.

BekkTech prefers the DC Conductivity Measurement for measuring ionic conductivity
Fuel cells operate in a Direct Current (DC) mode. We prefer to measure four electrode, in-plane conductivity using an effective current density as near to the current densities we would expect to see in a fuel cell.

By using a linearly ramping voltage, the differences between pure resistance and any unusual features occurring are easier to identify. Another advantage - High quality DC electronic equipment is generally less expensive to purchase.

What is High Frequency Resistance (HFR)?
HFR is ideally the resistance measured when the current is in phase with the voltage (i.e. phase angle equals 0.) It is at this condition that no ions are being created or destroyed. It is generally assumed that the voltages measured are due to ion conduction. Thus, a true HFR value is assumed to be a representation of the membrane resistance.

In practice, many researchers choose a fixed frequency (ie. 1000Hz for smaller cells) for their HFR measurements. In this case, data collected with large phase angles should be ignored. It is a complex correction to find the true membrane resistance from this type of data.

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General Information on Membrane Conductivity (continued):

What causes a high HFR measurement?
The High Frequency Resistance (HFR) measurement measures:

- electronic losses from the point of connection to deep inside each catalyst layer
- some ionic losses within each catalyst layer
- ionic losses through the membrane

The differences between two well-conducted HFR measurements can almost always be attributed to Relative Humidity (RH). The ionic losses in Nafion-like materials vary significantly with RH. High HFR values can indicate an inappropriate HFR frequency, a very dry membrane, or large electronic losses in the system. Varying frequency and RF can help to determine which of these is the issue.