Application Note: Measuring In-Plane Membrane Conductivity as a Function of Relative Humidity and Temperature Using a Scribner 850e, 885 PSTAT and BekkTech Conductivity Cell

Introduction

This application note provides instructions for the setup and operation of a Scribner Associates 850e Fuel Cell Test System, 885 Fuel Cell Potentiostat and BekkTech BT-112 Conductivity Cell for in-plane measurement of polymer electrolyte membrane (PEM) resistance and conductivity as a function of Relative Humidity (RH) and temperature. Example results are presented for Nafion® NR-212 membrane material at 80 °C.

NOTE: This test can be performed either by: (1) stepping the humidifier temperature, and therefore dew point, to the dew point required to achieve the desired RH scan (this is referred to as the Humidifier Set-Point method); or (2) by fixing the humidifier temperature and changing the proportion of a wet and dry gas stream to achieve the desired dew point and RH. This method is referred to as the “Wet-Dry Gas Mixing” method.

Advantages of the Humidifier Set-Point method:

- Requires less equipment
- Does require mixing a wet and dry gas stream so there is no need to heat a T-fitting
- Uses simpler setup

Disadvantages of Humidifier Set-Point method:

- Cannot test at low humidity at low membrane temperature
- Cannot cycle through different RH (must go from low to high RH to conduct experiment in reasonable amount of time). The humidifiers are not equipped with a cooling system and therefore take a long time to cool down.
- Takes a longer amount of time because the humidifiers must heat up to the desired temperature for each test.

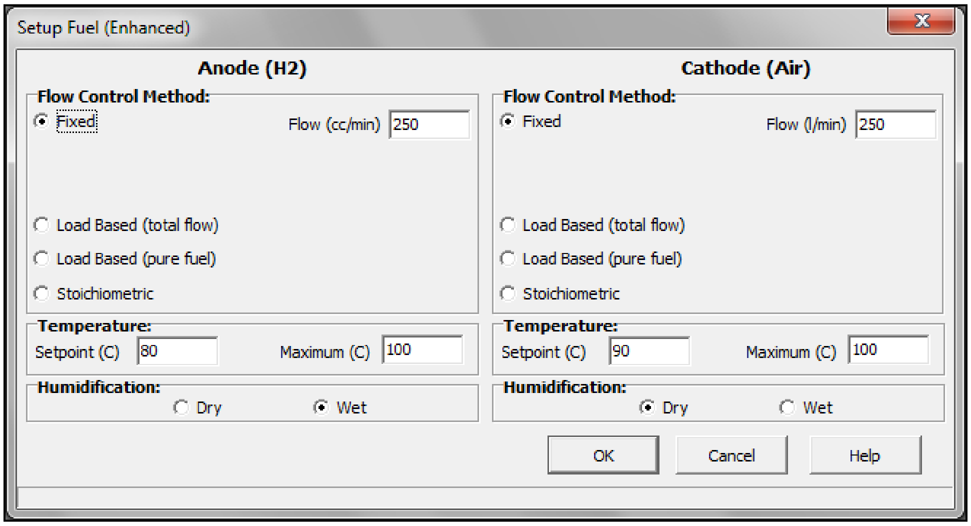
The following instructions are for using the Wet-Dry Gas Mixing method.

Setup of the 850e Fuel Cell Test System for Wet-Dry Gas Mixing Method

The 850e Fuel Cell Test System is operated in a wet gas-dry gas mixing mode for control of the humidity of the gas stream delivered to the conductivity cell and membrane. Here, the Anode Humidifier provides the “wet” stream and Cathode Humidifier provides the “dry” stream. The wet and dry streams combine and mix prior to entering the conductivity cell. By changing the proportion of wet gas and dry gas, the absolute humidity of the mixed gas stream is controlled and can be rapidly changed.

Wet-Dry Set-up with an 850e Equipped with Wet-Dry By-Pass Option

If the 850e is equipped with the factory installed Wet-Dry By-pass option, then the wet gas-dry gas mixing is easily facilitated by operating the cathode in the “dry” configuration such that the cathode gas by-passes the cathode humidifier and the anode humidifier is operated in the “wet” configuration so that the anode gas passes through the heated anode humidifier as during normal fuel cell operation. This is shown in Figure 1.



Setup Fuel (Enhanced)

Anode (H2)

Flow Control Method:
● Fixed
Flow (cc/min) 250
○ Load Based (total flow)
○ Load Based (pure fuel)
○ Stoichiometric

Temperature:
Setpoint (C) 80
Maximum (C) 100

Humidification:
○ Dry
● Wet

Cathode (Air)

Flow Control Method:
● Fixed
Flow (l/min) 250
○ Load Based (total flow)
○ Load Based (pure fuel)
○ Stoichiometric

Temperature:
Setpoint (C) 90
Maximum (C) 100

Humidification:
● Dry
○ Wet

Figure 1. Fuel configuration for Wet-Dry Gas Mixing method when using an 850e with Wet-Dry Gas By-Pass Option. In this configuration, the anode side provides a "wet" stream with 80 °C dew point the cathode provides the "dry" stream. The absolute humidity and therefore RH in the conductivity cell is controlled by selecting the appropriate proportion of wet and dry gas flows.

Wet-Dry Gas Mixing Method with an 850e Not Equipped with Wet-Dry By-Pass

If the 850e test system is not equipped with the Wet-Dry By-Pass option, the wet-dry gas mixing configuration can still be achieved. In this case, the cathode humidifier is drained of water to provide the “dry” gas stream. See the 850e manual for instructions on draining the humidifier tank.

> **NOTE: The Low Water Alarm on the Cathode must be turned off. It should be turned on when testing is complete. Follow the instructions below for turning off the Low Water Alarm**
>
> 1. In the Fuel Cell Software go to File, Instrument Configuration.
> 2. Enter the Serial Number of the 850e Unit
> 3. Uncheck the box beside Low Water Cathode Alarm.

CAUTION: ***It is very important that heat not be applied to the empty cathode humidifier. Serious equipment damage and a safety hazard can be caused by trying to heat to an empty humidifier tank.***

If the 850e is equipped with the Automatic Water Fill (AWF) option, than follow this procedure for draining Cathode tank:

1. Start with the 850e powered OFF.
2. Connect a pressurized water source.
3. Power ON the 850e and allow the system to fill the Anode and Cathode humidifier tanks as normal.
4. Disconnect the pressurized water source.
5. Drain the Cathode humidifier tank. The 850e will try to fill the Cathode humidifier but will not be able to.
6. Turn the 850e power OFF and then back ON.
7. The 850e will perform the programmed start-up humidifier fill cycle. The Cathode humidifier will not fill because there is no water source, and will eventually "time-out".
8. The 850e will disable the Cathode humidifier fill routine until the unit is power cycled, but the Anode humidifier will fill as required.

Warnings

- Do not apply heat to an empty humidifier. ***Serious equipment damage and a safety hazard can be caused by trying to heat to an empty humidifier tank.***
- The test gas (*e.g.,* hydrogen) is plumbed to both the Anode and Cathode inlets so that the same gas is delivered when the fuel is turned on. When using hydrogen as the test gas, it is imperative to purge the system with an inert gas (*e.g.,* N_2) prior to turning on the fuel. Inadequate purging of the test system and cell pose significant hazard due to spontaneous combustion of hydrogen and oxygen in the presence of the platinum electrodes in the Bekktech BT-112/115 Conductivity Cell. The system must be fully purged of hydrogen post-test as well.
- **Hot components! Burn hazard! Use insulation and avoid contact with heated components.**
- It is **imperative** to prevent water condensation at "cold spots" that may exist in the humidified gas flow path. All components in the humidified gas stream must be heated to above the maximum anticipated dew point. The maximum dew point is usually the humidifier temperature of the wet gas stream. Cold spots in the flow path result in condensation leading to water droplet formation, large transients in dew point and overall loss of humidity control.
- The system should be checked thoroughly for leaks before proceeding with testing.

Materials

The following items are required:

- High-purity water (ASTM Type 1 or equivalent, 18 MΩ-cm)
- UHP 99.99% Hydrogen
- UHP 99.99% Nitrogen
- 850e Fuel Cell Test System and *FuelCell®* software
- 885 Fuel Cell Potentiostat
- BekkTech BT-112 Conductivity Cell with Conductivity Clamp
- Scribner Associates or Fuel Cell Technologies Single Cell Hardware – 5 to 25 cm^2
- Polymer electrolyte membrane, *e.g.* Nafion®
- Swagelok ¼" stainless steel T-fittings, ¼'' 90° Elbows
- Flexible heat tape and/or string
- Variable autotransformer(s) (Variac) or other AC voltage controller
- Thermocouples and thermocouple meter or other temperature sensor
- S-tube
- Copper clam shell and insulation
- Dew point chamber

Optional:

- Humidity measurement device for real-time humidity measurement. The device used for the following experiment is a Vaisala HTM 337 Dew Point Probe, inserted in a heated chamber downstream from the conductivity cell (see Figure 4). Real-time humidity data and sample temperature are used to calculate the actual RH to which the membrane is exposed.
- The dew point data, relative humidity and temperature of the endplates can be recorded in the Fuel Cell software using the 892 Data Expansion Module. To do this, connect the endplate thermocouple and Vaisala dew point transmitter to the 892 and enable modules 1-3 under Instrument Configuration, Data Expansion in the Fuel Cell software.

Best Practices:

- Changing the delay time to 30 minutes after each fuel change step or doubling the flow rate helps to make sure relative humidity and dew point are stable before running the PSTAT Sweep Experiment.
- The copper clam shell produces heat that can cause the temperature of the cell to rise if the experiment is being done at a low temperature. This can be fixed by unplugging the copper clam shell when the cell temperature is set at 30 ^{o}C.
- When heating up the cell, the temperature will overshoot the set temperature. To prevent this, set the cell temperature to 10 ^{o}C below the desired temperature. It should

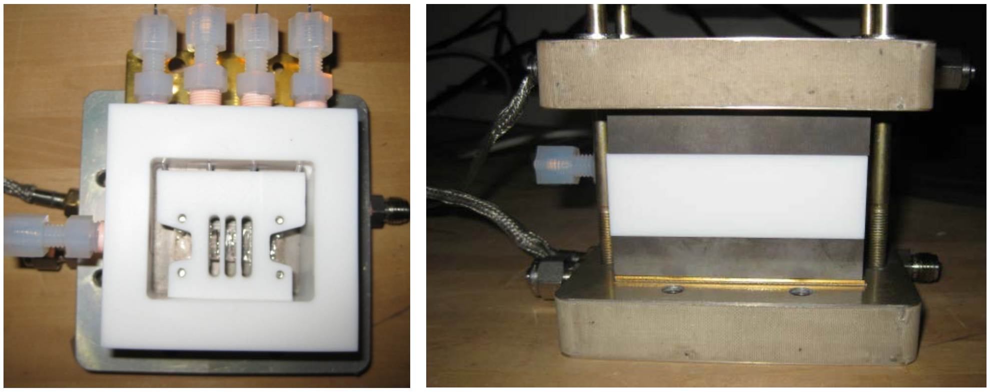
reach close to the desired temperature and when this occurs, set the cell temperature to what it should be.

- Another way to prevent the temperature from overshooting its set point is to switch the endpoint and cell thermocouples so that the endpoint temperature is the one that is being controlled. When the cell reaches the desired temperature, switch the thermocouples back.

Procedure

BT-112 Conductivity Cell Setup - Figure 2

1. Remove bolts from Fuel Cell end-plate. Remove top end-plate and top flow field.
2. Remove screws and clamp top from BT-110 Conductivity Clamp
3. Install membrane as described in the BT-11x manual
4. Place top of clamp back on and replace screws.
5. Reassemble flow field and end-plates, replacing bolts.



(a) (b)

Figure 2. BT-112 Assembly. See the BT-11x manual for additional instructions on sample loading and assembly in the fuel cell hardware.

6. Block off one gas entrance and exit of the cell hardware with a cap. Usually, opposing inlet and exit ports are blocked so that the gas is forced to cross from one side of the cell to the other. *E.g.*, cap the fuel cell cathode inlet and anode outlet, and connect gas to the fuel cell anode inlet and exit line to the cathode outlet port (see Figure 3).

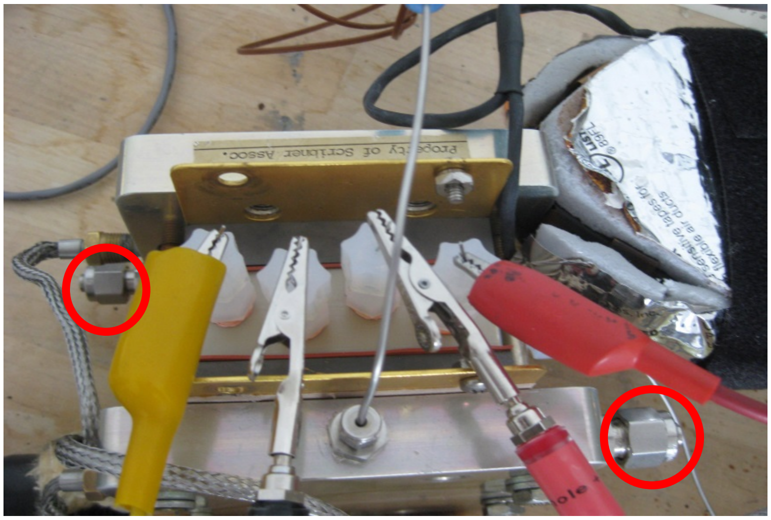


Figure 3. Cell hardware setup. Port caps are highlighted in red circles.

7. Connect fuel cell exit port to a suitable vent or, as shown in Figure 4, a dew point chamber using the S-tube. Connect the thermocouple from the dew point chamber and the connector from the S-tube to the control box (Figure 5).
    - **IMPORTANT!** The dew point chamber temperature should be controlled to 10 ^{o}C above the maximum anticipated dew point, *i.e.,* the dew point of the wet stream.
8. Heated cuffs should be used at the connection points of the S-tube and extra insulation should be used on the top of the dew point probe.

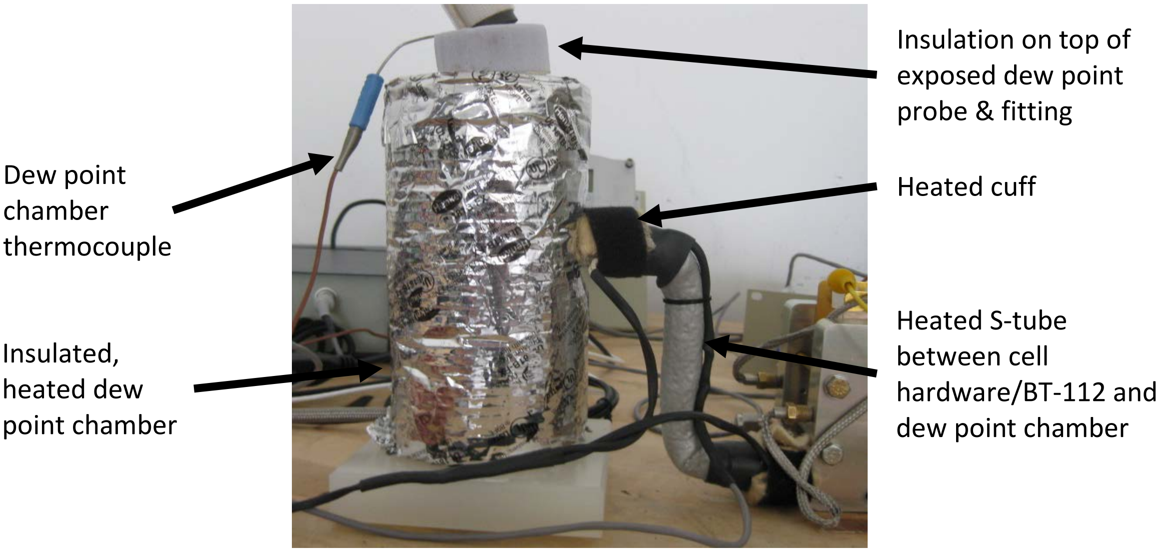


Figure 4. Dew point chamber connected down-stream of the cell hardware via the S-tube. Heated cuffs prevent cold spots and therefore condensation at the exposed stainless steel fittings.

Figure 5. Front panel of the dew point chamber control box. The temperature controller controls the temperature of the dew point chamber. Note: The dew point chamber should be controlled to 10 ^{o}C above the maximum anticipated dew point (*i.e.,* the dew point of the wet stream). The round connectors power the 24 V heaters used in the S-tube and the T-fitting copper clam shell.

850e Fuel Cell Test System

1. Use a T-fitting to connect the Anode and Cathode streams from the 850e (Figure 6).

2. Connect the T-fitting outlet to the inlet port on the fuel cell hardware. All components are ¼” stainless steel Swagelok®.

Figure 6. T-fitting connecting Anode (wet) and Cathode (dry) gas streams.

3. Use the copper clam shell and insulation to heat the T-fitting as shown in Figure 7. Connect the clam shell heater connector to the dew point chamber control box.

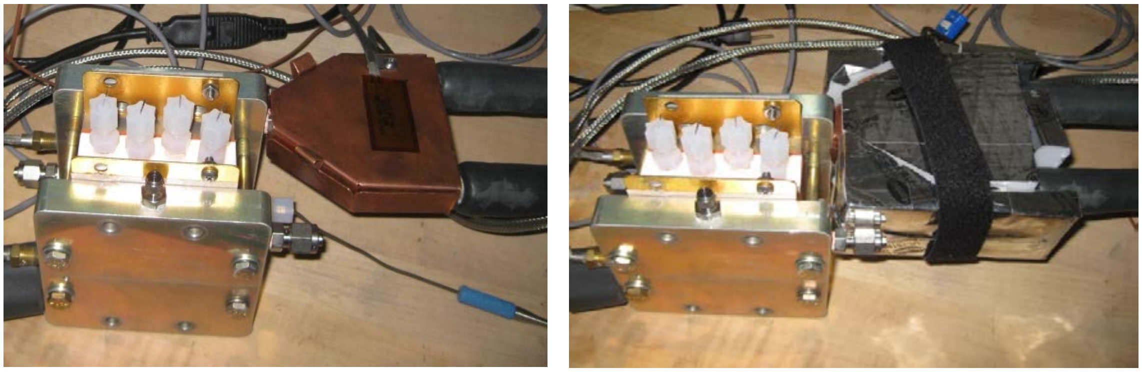


Figure 7. Copper clam shell and insulation installed over the T-fitting connecting Anode and Cathode streams. NOTE: The T-fitting must be heated and insulated to prevent condensation; the copper clam shell is designed to prevent cold spots and condensation at the T-fitting.

4. Connect electrode wires of BT-112 Conductivity Cell to the 850e/885 Potentiostat as shown in Figure 8. See also the BT-112/115 manual for other measurement configurations (*e.g.*, two electrode measurement). Refer to manufacturers manual if using a 3rd party potentiostat.

5. On the 850e rear panel, connect hydrogen (or other test gas) to both the anode and cathode gas inlets as shown in Figure 9.

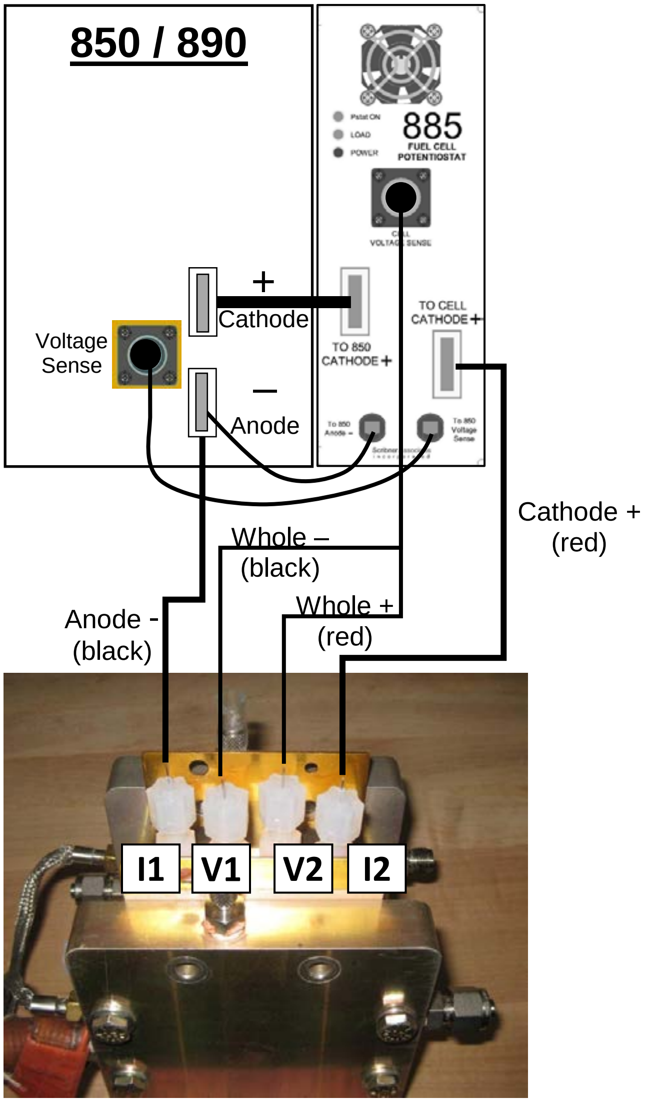
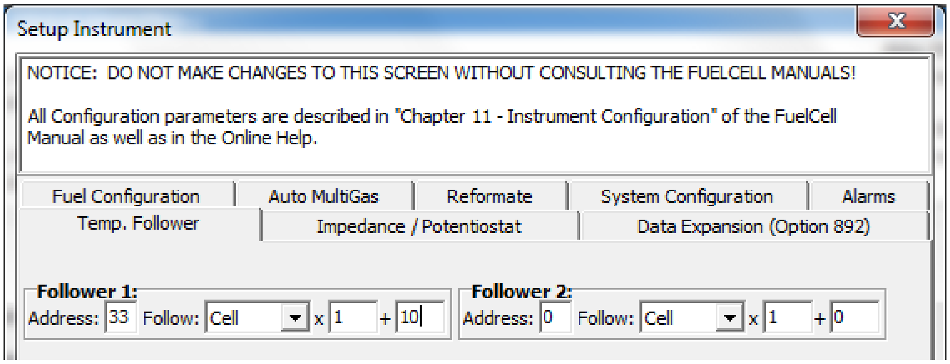


Figure 8. Schematic showing the connections between the cell and the 850e Fuel Cell Test System and 885 Potentiostat.

Figure 9. Anode and cathode fuel connection.

Running Experiment

1. Turn on 850e Fuel Cell Test System and 885 Potentiostat.
2. Start *FuelCell* software.
3. Turn on the temperature control box for dew point chamber. Set the temperature to 90 °C, or 10 °C above the cell temperature. NOTE: the temperature can either be set through the front panel of the control box or though the Temp. Follower option in the Fuel Cell software. Under Follower 1 set Address to 33, Follower to Cell x 1 + 10 (Figure 10).



NOTICE: DO NOT MAKE CHANGES TO THIS SCREEN WITHOUT CONSULTING THE FUELCELL MANUALS!

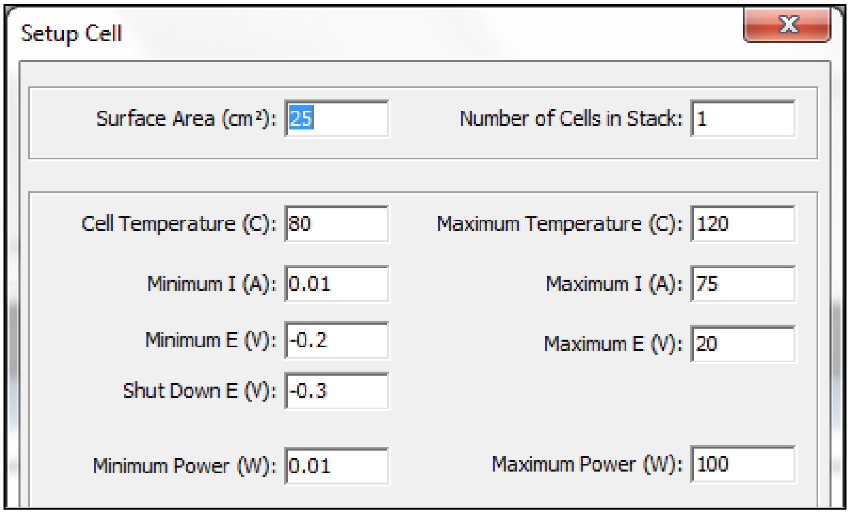
All Configuration parameters are described in "Chapter 11 - Instrument Configuration" of the FuelCell Manual as well as in the Online Help.

Follower 1: Address: 33 Follow: Cell x 1 + 10

Follower 2: Address: 0 Follow: Cell x 1 + 0

Figure 10. Temp. Follower setup window in *FuelCell* software.

4. Under Setup Cell, set the temperature to 80 °C, and change min E to -0.2 and shutdown E to -0.3 as shown in Figure 11.



Surface Area (cm^2): 25

Number of Cells in Stack: 1

Cell Temperature (C): 80

Maximum Temperature (C): 120

Minimum I (A): 0.01

Maximum I (A): 75

Minimum E (V): -0.2

Maximum E (V): 20

Shut Down E (V): -0.3

Minimum Power (W): 0.01

Maximum Power (W): 100

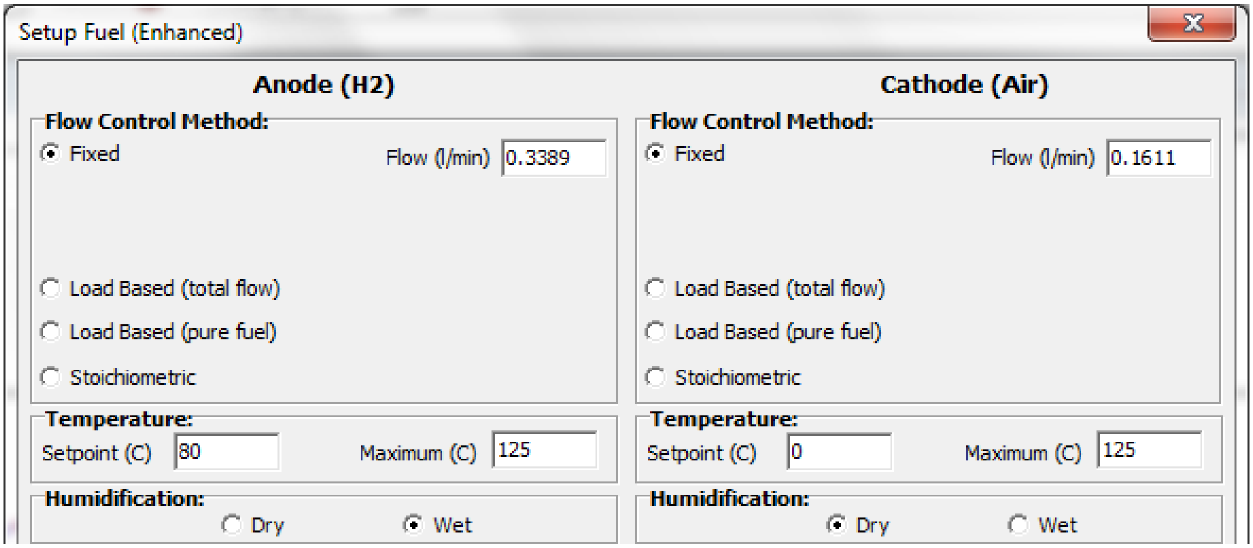
Figure 11. Cell Setup window in *FuelCell* software.

5. Under Setup Fuel menu (shown in Figure 12)
   a. Set Anode humidifier to 80 °C. Set the Cathode Humidifier to 0 °C.
   b. Set Anode flow rate to 0 L/min, and Cathode flow rate to 0.5 L/min.
   c. If test system has Wet-Dry By-Pass capability, set Anode to “Wet”, and Cathode to “Dry” – see Figure 1. If test system does not have wet/dry capabilities, follow the instructions above for draining the cathode humidifier tank.

6. Apply heat to the Cell and Anode and allow system to heat up. Uncheck the box next to Cathode to ensure that this will not be heated. All other heaters should also be turned on.

   WARNING: DO NOT APPLY HEAT TO EMPTY CATHODE TANK

7. Setup a change fuel experiment, set the anode flow rate at 0.339 L/min, and cathode flow rate at 0.161 L/min. As shown in the following experiments, the total dry gas flow is always set to 0.5 L/min, partitioned between the “wet” (anode) side and the “dry” (cathode) side as required to obtain the desired RH in the cell.



Setup Fuel (Enhanced)

Anode (H2)

Flow Control Method:
● Fixed — Flow (l/min) 0.3389
○ Load Based (total flow)
○ Load Based (pure fuel)
○ Stoichiometric

Temperature:
Setpoint (C) 80 — Maximum (C) 125

Humidification:
○ Dry ● Wet

Cathode (Air)

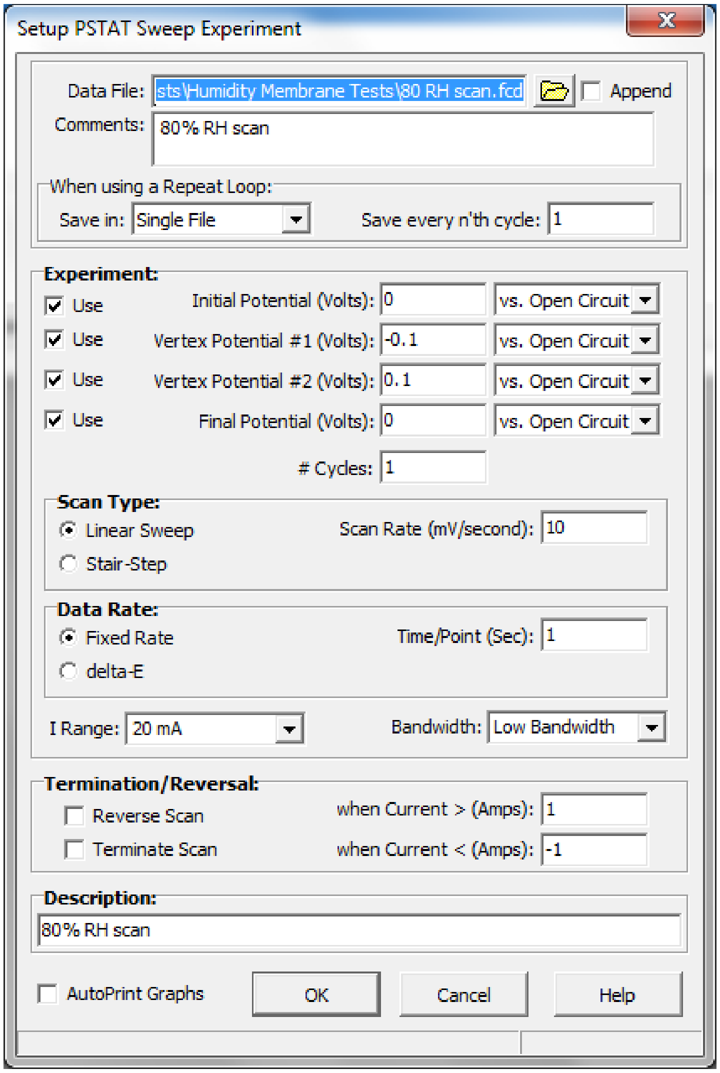
Flow Control Method:
● Fixed — Flow (l/min) 0.1611
○ Load Based (total flow)
○ Load Based (pure fuel)
○ Stoichiometric

Temperature:
Setpoint (C) 0 — Maximum (C) 125

Humidification:
● Dry ○ Wet

Figure 12. Fuel Setup menu in *FuelCell* Software for 80% RH.

8. Set up Open Circuit Experiment
    a. Set duration to 15 minutes; this step is simply to allow time for the fuel settings to adjust, and to record accurate cell temperature information.
9. Set up PSTAT Sweep Experiment as shown in Figure 13, the first experiment will have approximately 80% RH. When finished, click OK.



Setup PSTAT Sweep Experiment

Data File: sts\Humidity Membrane Tests\80 RH scan.fcd ☐ Append

Comments: 80% RH scan

When using a Repeat Loop:

Save in: Single File Save every n'th cycle: 1

Experiment:

☑ Use Initial Potential (Volts): 0 vs. Open Circuit

☑ Use Vertex Potential #1 (Volts): -0.1 vs. Open Circuit

☑ Use Vertex Potential #2 (Volts): 0.1 vs. Open Circuit

☑ Use Final Potential (Volts): 0 vs. Open Circuit

Cycles: 1

Scan Type:

● Linear Sweep Scan Rate (mV/second): 10

○ Stair-Step

Data Rate:

● Fixed Rate Time/Point (Sec): 1

○ delta-E

I Range: 20 mA Bandwidth: Low Bandwidth

Termination/Reversal:

☐ Reverse Scan when Current > (Amps): 1

☐ Terminate Scan when Current < (Amps): -1

Description:

80% RH scan

☐ AutoPrint Graphs

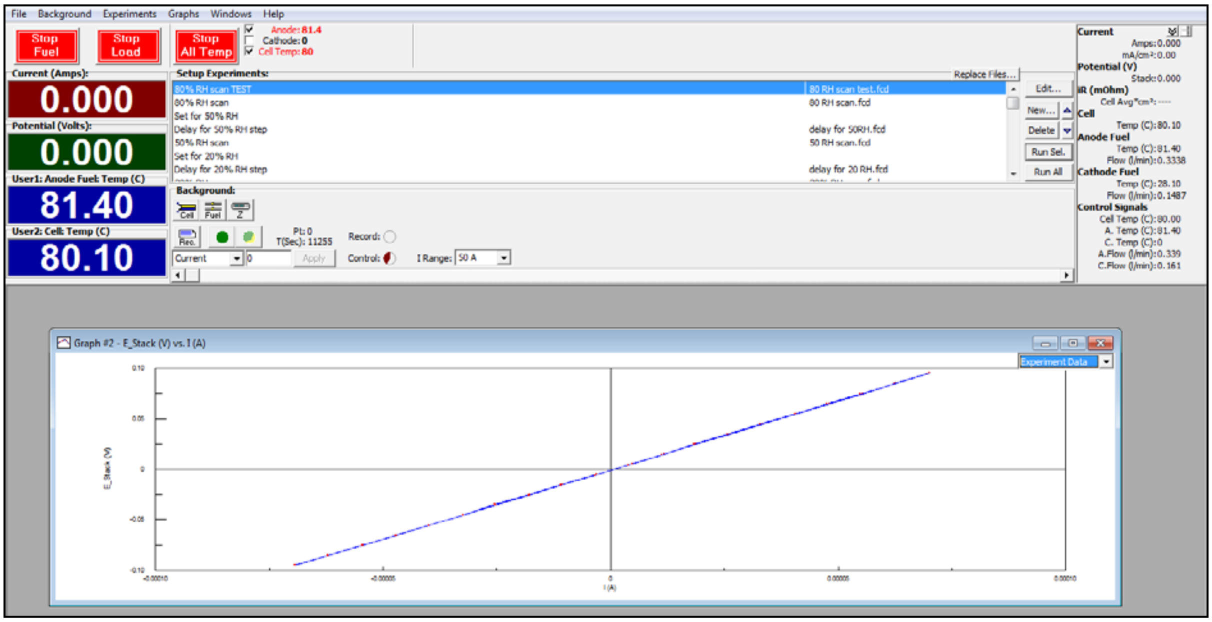
Figure 13. PSTAT Sweep Experiment Setup.

10. Select all 3 experiments and copy. Paste 6 times. There should be a total of 21 experiments repeating, in order, the following: fuel setup, open circuit, and PSTAT sweep.
11. Change each Setup Fuel experiment so that the following settings are in place for each successive experiment. NOTE: the first test shown in the table coincides with the test settings done in step (6).
12. Change the description and filename for each of the different scans (see Figure 13), as well as the open circuit tests. Check the Cell Temp data box so that it is saved in the data files for later reference. NOTE: The Experiment Setup described above can be found on our website. For more specific information, see Appendix A
13. Once the dew point chamber temperature is above 70 °C, insert the Vaisala Dew Point Probe into the dew point chamber. Wait five minutes for the probe to heat, so that condensation will not affect the measurement. **NOTE: Apply Fuel should not be on when inserting probe. This could result in flammable gas leakage.**

Table 1. Wet and dry side flow rates for target dew point.

Step No.	Target RH, %	"Wet Side" Anode Flow Rate, L/min	"Dry Side" Cathode Flow Rate, L/min
1	80	0.339	0.161
2	50	0.172	0.328
3	20	0.058	0.442
4	10	0.028	0.472
5	50	0.172	0.328
6	80	0.339	0.161
7	95	0.454	0.046

14. In the Fuel Cell software, by clicking the Fuel button under Background, you can change the Anode flow rate to 0.2 L/min, and the Cathode flow rate to 0.3 L/min. This will hydrate the membrane before the start of experiments.
15. Once all temperatures have reached their set points, and stabilized, click Start Fuel and Start Load. Then click "Run All"



☑ Anode: 81.4
☐ Cathode: 0
☑ Cell Temp: 80

Current (Amps): 0.000
Potential (Volts): 0.000
User1: Anode Fuel: Temp (C) 81.40
User2: Cell: Temp (C) 80.10

80% RH scan TEST	80 RH scan test.fcd
80% RH scan	80 RH scan.fcd
Set for 50% RH	
Delay for 50% RH step	delay for 50RH.fcd
50% RH scan	50 RH scan.fcd
Set for 20% RH	
Delay for 20% RH step	delay for 20 RH.fcd

Pt: 0
T(Sec): 11255
Record: ○
Control: ●
Current ▾ 0
I Range: 50 A

Current
Amps: 0.000
mA/cm²: 0.00
Potential (V)
Stack: 0.000
iR (mOhm)
Cell Avg*cm²: ----
Cell
Temp (C): 80.10
Anode Fuel
Temp (C): 81.40
Flow (l/min): 0.3338
Cathode Fuel
Temp (C): 28.10
Flow (l/min): 0.1487
Control Signals
Cell Temp (C): 80.00
A. Temp (C): 81.40
C. Temp (C): 0
A.Flow (l/min): 0.339
C.Flow (l/min): 0.161

Figure 14. Full screenshot of running experiment. Note that Fuel, Load, and Temp are all applied except the cathode temperature.

NOTE: The entire experiment sequence should take over an hour and forty-five minutes.

Table 2. Summary of experiment data. The analysis for RH, resistance and conductivity are demonstrated in the Data Analysis section but included on this table for completeness.

Test No.	Target RH, %	Cell Temp., °C	Dew Point, °C	Relative Humidity, %	Measured Resistance, Ω	Conductivity, mS/cm
1	80	80.0	74.7	80.4	1,379	60.4
2	50	80.1	65.3	53.4	4,373	19.1
3	20	80.6	51.3	27.2	21,251	3.9
4	10	80.0	44.1	19.4	45,395	1.8
5	50	79.7	64.6	52.5	4,613	18.1
6	80	79.9	74.4	79.7	1,4412	57.8
7	95	79.8	77.3	90.3	619.2	134.6

Important: Once testing is complete, if the cathode humidifier was drained of water, it is now important to re-enable the Low Water Cathode Alarm using the same method describe above for disabling it.

Data Analysis

Open the Voltage Sweep data in *FCView*. Select the data, then under Graph select ‘vs. I’, then select ‘E_Stack (V)’. A graph of the 20% and 80% RH scan is shown below, Figure 15. Click on the icon showing 📈

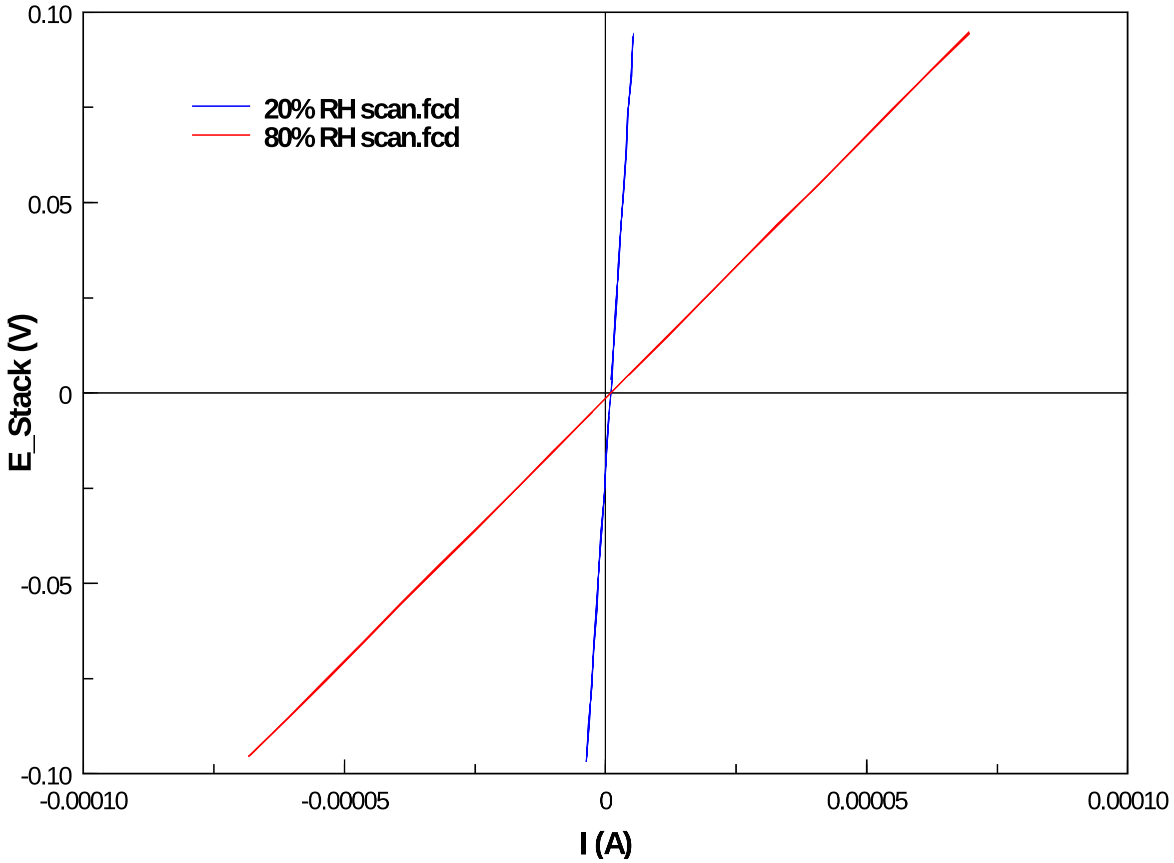


Figure 15. Graph showing the Voltage vs. Current for 80% and 20% RH scans. Note that the 20% RH scan is a higher slope and therefore higher resistance.

Under the tab ‘Fit Y vs. X’, for ‘X Type’ select ‘I (A)’, and for the ‘Y Type’ select ‘E_Stack (V)’. Then, click ‘Fit’. The ‘b’ value is the resistance; the software has calculated the slope, which is Y/X, or V/I, otherwise known as resistance.

Open the open circuit data for each experiment, also in *FCView*.

Under Graph, select ‘vs. Time’, then select Temp (C). Find the temperature of the cell at the end of each open circuit data; this is the membrane temperature of the *following* Voltage sweep scan. Find the temperature of the cell at the beginning of each open circuit data; this will be the ending membrane temperature of the *previous* Voltage sweep scan. Average the starting and ending temperatures of each scan to determine the cell temperature during each scan.

Using the Dew point data from the Vaisala excel sheet, find the dew point before the change in fuel setup. This is the point before the dew point begins to change rapidly due to the change in wet-dry ratio (see Figure 16).

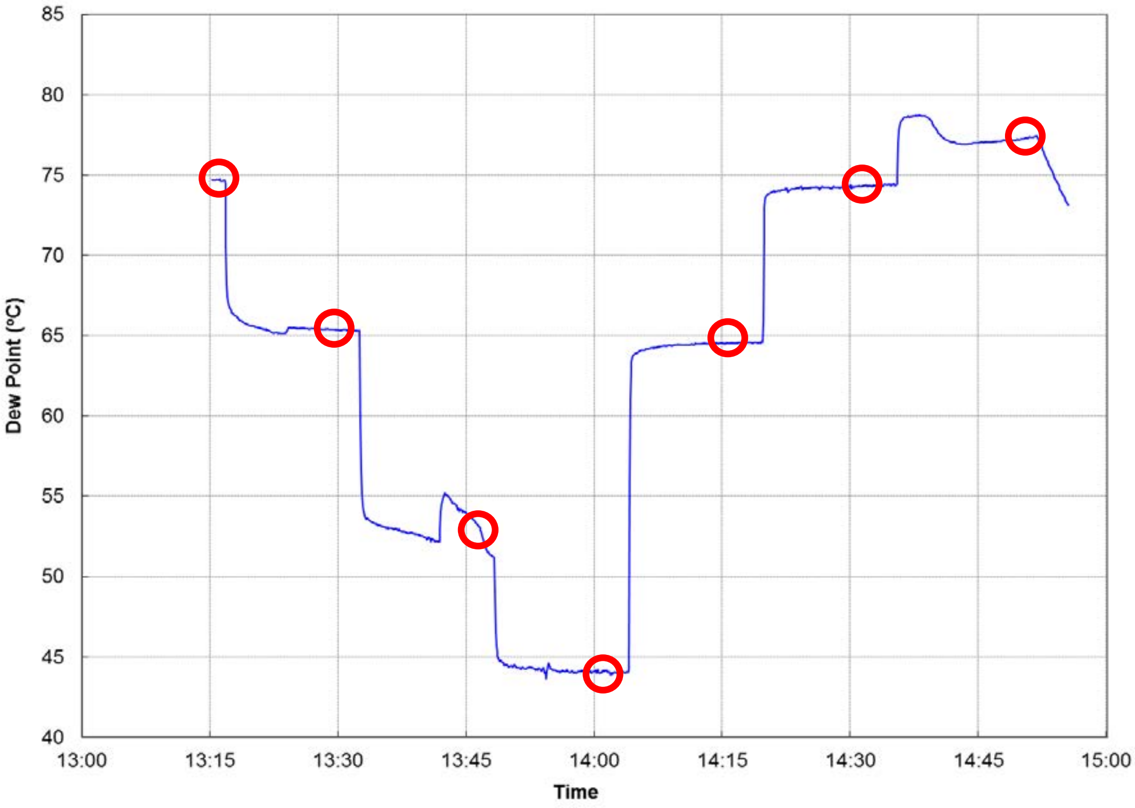


Figure 16. The dew point data recorded during the PSTAT Sweep Experiment. Red circles indicate regions where the values were used as the dew point to calculate RH.

Accurate RH can be calculated using the dew point and cell temperature for each experiment. These values differ slightly from the target values because RH is very sensitive to small changes in temperature and dew point. Any deviation in cell, humidifier dew point, and/or wet-dry gas ratios can lead to differences between the actual and the target RH.

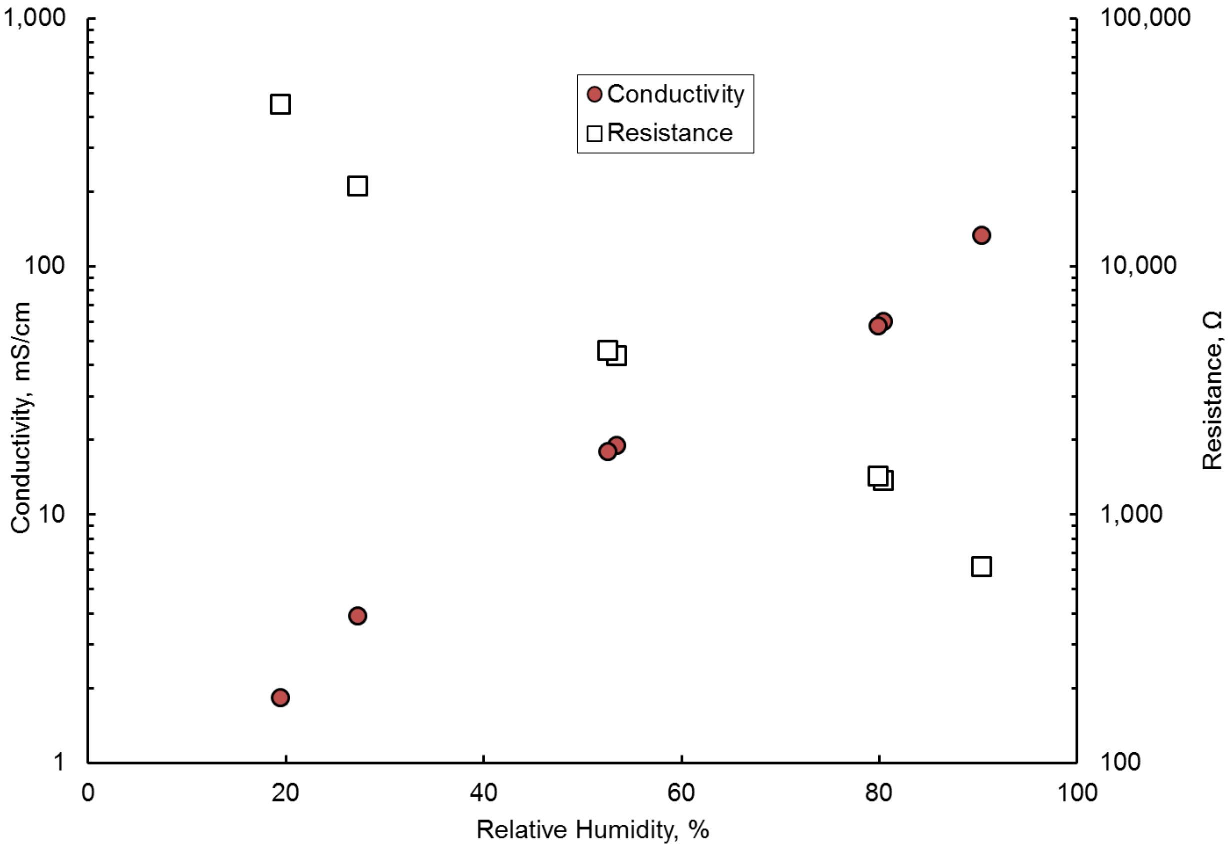


Figure 17: Resistance and calculated conductivity as a function of RH at 80 °C for Nafion NR-212 membrane. RH was calculated from the measured cell temperature and the dew point.

As shown in Figure 17, the membrane resistance decreases with increasing humidity.

The resistance *R* (Ω) of a conductor is dependent upon the sample dimensions as well as the intrinsic conductivity σ (S/cm) of the material. The relationship is defined as,

$$R = \frac{1}{\sigma} \cdot \frac{L}{A} = \frac{1}{\sigma} \cdot \frac{L}{W \cdot T}$$

where L (cm) is the distance between the voltage sense electrodes and *A* (cm^2) is the cross-sectional area through which the charge passes. For the in-plane ion conductivity measurement, *A* is the product of the sample width *W* (cm) and the membrane thickness *T* (cm). Rearranging for conductivity σ,

$$\sigma = \frac{1}{R} \cdot \frac{L}{W \cdot T}$$

For the BT-112 Conductivity Cell, *L* = 0.425 cm. *T* = 0.0051 cm (The dry thickness of the Nafion® NR-212). In this test, the sample width was *W* = 1 cm. For the first RH test (approximately 80% RH), the calculation was,

$$\sigma = \frac{1}{R} \cdot \frac{L}{W \cdot T} = \frac{1}{1379.3\ \Omega} \cdot \frac{0.425\ \mathrm{cm}}{1.0\ \mathrm{cm} \times 0.0051\ \mathrm{cm}} = 0.062\ \mathrm{S/cm}\ = 62\ \mathrm{mS/cm}$$

Summary

This Application Note provides instructions for the setup and operation of a Scribner 850e Fuel Cell Test System, 885 Fuel Cell Potentiostat and BekkTech BT-112 Conductivity Cell for in-plane measurement of polymer electrolyte membrane resistance and conductivity as a function of RH and temperature. The example results demonstrate the use of *FCView* for analyzing the resistance data collected using the 885 PSTAT and *FuelCell* software.

Appendix A – Example Experiment Setups

The following example experiment setups for *FuelCell* software can be found on our website at www.scribner.com/

Method	Cell Temperature (°C)	*FuelCell* Setup File Name	Additional Notes
Humidifier Set-Point	80	Fuel Cell Testing Setup 80 degree dew point humidity.fc3	
Wet-Dry Gas Mixing	80	Fuel Cell Testing Setup 80 degree wet-dry humidity.fc3	
Wet-Dry Gas Mixing	30	Fuel Cell Testing Setup 30 degree wet-dry humidity.fc3	The Humidifier Set-Point Method cannot be used to attain low RH at low temperatures due to the inability to generate dew points less than ambient temperature.
Humidifier Set-Point	120	Fuel Cell Testing Setup 120 degree dew point humidity.fc3	High temperatures with a dew point (>100°C) requires back-pressure. An 850e-HT unit with Back-pressure unit is required.
Wet-Dry Gas Mixing	120	Fuel Cell Testing Setup 120 degree wet-dry humidity.fc3	High temperatures with a dew point (>100°C) requires back-pressure. An 850e-HT unit with Back-pressure unit is required.

Appendix B – Wet Side and Dry Side Gas Flow Rates for Selected Temperature and Relative Humidity Conditions

This appendix provides target dew point, and wet and dry gas flow rates for common RH conditions. To use the mixed wet gas and dry gas method, a humidity control system capable of independently controlling two gas flows is required. For additional test conditions (temperature, RH, and pressure), please use the Humidity Calculator worksheet available *www.scribner.com/images/humidity-dew-point-calculator-for-mts740-customers.xls* [Microsoft Excel^{TM}].

Sample temperature, °C	**30**	Total dry gas flow rate, SLM	**0.5**
Wet side dew point, °C (Humidifier temperature)	**45**	Pressure, kPa_a	**101.3**
		Back pressure, kPa_g	**0.0**

Target RH, %	**Dew Point, °C**	**% Wet**	**Wet Gas Flow Rate, SLM**	**Dry Gas Flow Rate, SLM**
5%	-13.7	2.0%	0.010	0.490
10%	-4.9	4.0%	0.020	0.480
15%	0.6	6.0%	0.030	0.470
20%	4.6	8.1%	0.040	0.460
25%	7.8	10.1%	0.051	0.449
30%	10.5	12.2%	0.061	0.439
35%	12.9	14.2%	0.071	0.429
40%	14.9	16.3%	0.082	0.418
45%	16.8	18.4%	0.092	0.408
50%	18.4	20.5%	0.102	0.398
55%	20.0	22.6%	0.113	0.387
60%	21.4	24.7%	0.123	0.377
65%	22.7	26.8%	0.134	0.366
70%	23.9	28.9%	0.144	0.356
75%	25.1	31.0%	0.155	0.345
80%	26.2	33.2%	0.166	0.334
85%	27.2	35.3%	0.177	0.323
90%	28.2	37.5%	0.187	0.313
95%	29.1	39.6%	0.198	0.302
100%	30.0	41.8%	0.209	0.291

Sample temperature, °C	**80**	Total dry gas flow rate, SLM	**0.5**
Wet side dew point, °C (Humidifier temperature)	**80**	Pressure, kPa_a	**101.3**
		Back pressure, kPa_g	**0.0**

Target RH, %	Dew Point, °C	% Wet	Wet Gas Flow Rate, SLM	Dry Gas Flow Rate, SLM
5%	20.2	2.7%	0.014	0.486
10%	31.9	5.6%	0.028	0.472
15%	39.3	8.6%	0.043	0.457
20%	44.8	11.7%	0.059	0.441
25%	49.2	15.1%	0.075	0.425
30%	52.9	18.6%	0.093	0.407
35%	56.1	22.3%	0.111	0.389
40%	58.9	26.2%	0.131	0.369
45%	61.5	30.3%	0.152	0.348
50%	63.8	34.7%	0.174	0.326
55%	65.9	39.4%	0.197	0.303
60%	67.9	44.4%	0.222	0.278
65%	69.7	49.7%	0.249	0.251
70%	71.4	55.4%	0.277	0.223
75%	73.1	61.5%	0.307	0.193
80%	74.6	68.0%	0.340	0.160
85%	76.0	75.1%	0.375	0.125
90%	77.4	82.7%	0.414	0.086
95%	78.7	91.0%	0.455	0.045
100%	80.0	100.0%	0.500	0.000

Sample temperature, ^{o}C **120**

Wet side dew point, ^{o}C (Humidifier temperature) **120**

Total dry gas flow rate, SLM **0.5**

Pressure, kPa$_a$ **231.3**

Back pressure, kPa$_g$ **130.0**

Target RH, %	**Dew Point, ^{o}C**	**% Wet**	**Wet Gas Flow Rate, SLM**	**Dry Gas Flow Rate, SLM**
5%	45.7	0.7%	0.004	0.496
10%	59.9	1.5%	0.008	0.492
15%	68.9	2.4%	0.012	0.488
20%	75.7	3.4%	0.017	0.483
25%	81.2	4.5%	0.022	0.478
30%	85.8	5.7%	0.028	0.472
35%	89.8	7.0%	0.035	0.465
40%	93.3	8.5%	0.043	0.457
45%	96.5	10.3%	0.051	0.449
50%	99.4	12.3%	0.061	0.439
55%	102.1	14.6%	0.073	0.427
60%	104.6	17.4%	0.087	0.413
65%	106.9	20.6%	0.103	0.397
70%	109.1	24.6%	0.123	0.377
75%	111.1	29.6%	0.148	0.352
80%	113.1	35.9%	0.180	0.320
85%	114.9	44.2%	0.221	0.279
90%	116.7	55.8%	0.279	0.221
95%	118.4	72.7%	0.363	0.137
100%	120.0	100.0%	0.500	0.000