



Corrosion of metallic bipolar plates for PEMFCs: towards a more representative test method

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Bipolar plate materials





Extremely challenging material requirements!

US DoE targets (2020)



Property	Target	Notes
Cost	< 3 \$ kW ⁻¹	2002 dollars, 500,000 stacks per year
Corrosion resistance (anode)	< 1 μA cm ⁻²	pH 3, 0.1 ppm HF, 80 °C, Ar purge Potentiodynamic test -0.4 V – 0.6 V(Ag/AgCl), 0.1 mV/s
Corrosion resistance (cathode)	< 1 μA cm ⁻²	pH 3, 0.1 ppm HF, 80 °C, aerated Potentiostatic test (> 24 h) 0.6 V(Ag/AgCl), i _{passive} < 50 nA cm ⁻²
Electrical conductivity	> 100 S cm ⁻¹	_
Areal specific resistance	< 0.01 Ω cm ²	including contact resistance at 138 N cm ⁻²
Hydrogen permeability	< 1.3.10 ⁻¹⁴ cm ³ (s cm ² Pa)	ASTM D1434, 80 °C, 3 atm, 100% RH
Flexural strength	> 25 MPa	ASTM D790-10
Forming elongation	40%	ASTM E8M-01

Conventional corrosion testing



- Corrosion resistance of candidate bipolar plate materials typically ranked by fully immersed electrochemical testing in H₂SO₄ solution
- Historically 0.5 M or 1 M H₂SO₄ but trend towards pH 3 based on stack run-off water measurements

Common assumption: Potential of bipolar plate is equal to that of the nearest Pt electrode

- But ionic conductivity in GDL is low due to discontinuous and dilute aqueous phase - coupling may not be effective
- Other potential issues
 - Galvanic and crevice corrosion effects due to contact between bipolar plate and GDL
 - Effect of transients, e.g. start-up/shut-down



In situ pH measurement



AMANI Leak-free Series Microcombination pH Electrode

Model	AMANI-1000L
Tip Diameter	1000 µm
Tip Length	75 mm
Material	All Plastic
Depth of Immersion	<100 µm
Min. Sample Volume	500 nL
Response Time	< 3 sec
Temperature Range	0° to 100°C
Internal Reference	Ag/AgCI
Slope	Nernstian
pH Range	0 to 14
Storage	Wet or dry
Connector	BNC
Electrode Holder	4.5 x 50 mm
OD x Length	0.18 x 2 in
Lead Wire	0.9 m (3 ft)



In situ pH measurement



Authors	Measured pH	Notes
This work	3.4 - 4.0 5 - 7	Cathode, T = 70 °C, RH 100% Anode, T = 70 °C, RH 100%
Healy et al. [1]	3.7 - 5.3	T = 75 °C – 82 °C, RH variable pH correlated with p[F ⁻]
Hou et al. [2]	3 - 7	T = 30/60/90 °C Dew point: 30/60/90 °C
Abdullah et al. [3]	4 - 6	T = 50/70/90 °C, RH = 35/60/100%, Lowest pH 1.5 (35% RH, 50 °C)

[1] J. Healy et al., Fuel Cells 5 (2005) 302.
[2] K.-H. Hou et al., Int. J. Hydrogen Energy 37 (2012) 3890.
[3] A.M. Abdullah et al., J. Power Sources 190 (2009) 264.

In situ E_{corr} (anode plate)





In situ E_{corr} (cathode plate)





Ex situ E_{corr} measurements





Current cycling (cathode plate)





Current cycling (anode plate)





SUSD (cathode plate)





SUSD (anode plate)





Conclusions



- Degradation mode is more akin to corrosion in relatively dilute thin liquid layers rather than the fully immersed conditions employed in conventional ex situ screening tests
- E_{corr} of the bipolar plate is largely independent of the potential of the Pt electrode due to low ionic conductivity of the discontinuous aqueous phase in the GDL
- Localised polarisation of the steel can occur as a result of galvanic coupling with the carbon GDL at wetted interfaces
 – a similar effect may be experienced with some coatings
- The pH of water in contact with the bipolar plate is 3.4 4.0 (cathode) and 5 7 (anode), although this could be decreased by evaporation as a result of wet/dry cycling

Implications



- US DoE test protocols and acceptance criteria need to be reassessed in the light of these results
- Representative ex situ test methods for screening of corrosion resistance of candidate bipolar plate materials and coatings should reflect the following:
 - Corrosion in relatively dilute thin liquid layers
 - Localised galvanic crevice corrosion due to intimate contact with the carbon GDL
 - Wet/dry cycling leading to concentration of aggressive species by evaporation
 - Start-up/shut-down cycling
 - Accelerated effects by variation of test parameters