Cyclic Compression Washout Test (CCWT) to simulate changes in GDL Critical Properties under Representative PEMFC Operating Conditions

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Abstract

Recently, the main reported failures of Carbon Fiber Gas Diffusion Layers (GDL) in PEMFC are: GDL fracturing, hydrophobicity losses with time and loss in mechanical properties due to over-compression and chemical degradation. These observed failure modes greatly affect PEMFC performance and lead to potential down stream system contamination concerns due to washout products as well. A novel Cyclic Compression Washout Test (CCWT) has been developed to address the key non - chemical GDL failure modes under automotive and residential representative operating conditions. The main stressors are: temperature, water flow/amount through the GDL and GDL compression cycling. The CCWT accelerates regular GDL aging by a factor of up to 200 and accurately simulates the effects of wet-dry cycling, changes in GDL mechanical strength over time and accurately quantify the GDL Washout.

Introduction

CCWT is a further development of a washout test, earlier proposed in Ballard by Guy Faubert and Lynn Erickson. It addresses a GDL washout Failure Mode (FM) accelerated by cyclic compression of GDL. Cyclic compression stressor simulates pressure fluctuations under the landings of FC due to PEM swelling/drying, which takes place during startup and shutdown cycles.

Description of the Method

CCWT is based on passing flow of water through GDL structure and measuring GDL weight loss due to washout. A GDL sample is put between flow plates of a stack, which undergo cycling compression by means of changeable gauge bladder pressure. Washout material is also collected on a membrane filter for further analysis and gravimetrical determination. Schematically the Tool is presented in Fig.1. It consists of four main blocks: 1 - Stack with GDL; 2 - Water Circulating Loop, imitating flux of water, generated at cathode during FC operation and used as a stressor; 3 - Cooling/Heating Loop of the Stack; 4 - Line of cycling compressed Air supplied to Bladder Plate of Stack.

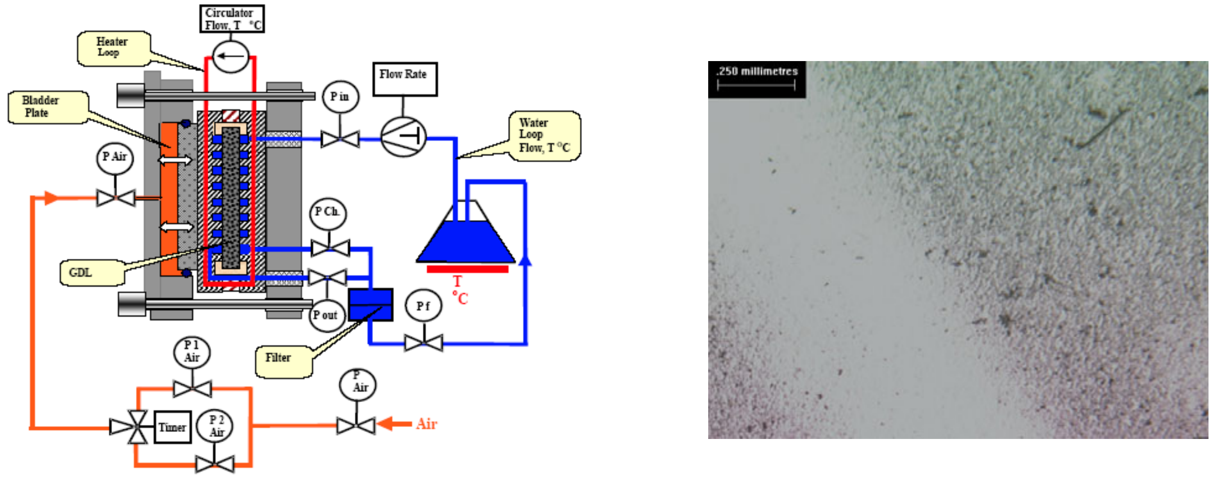


Figure 1. Schematics of the Tool (left) and collected washout at membrane filter (right) – white line is an unexposed to washout area of filter.

Typical GDL washout data is presented in Fig.2.

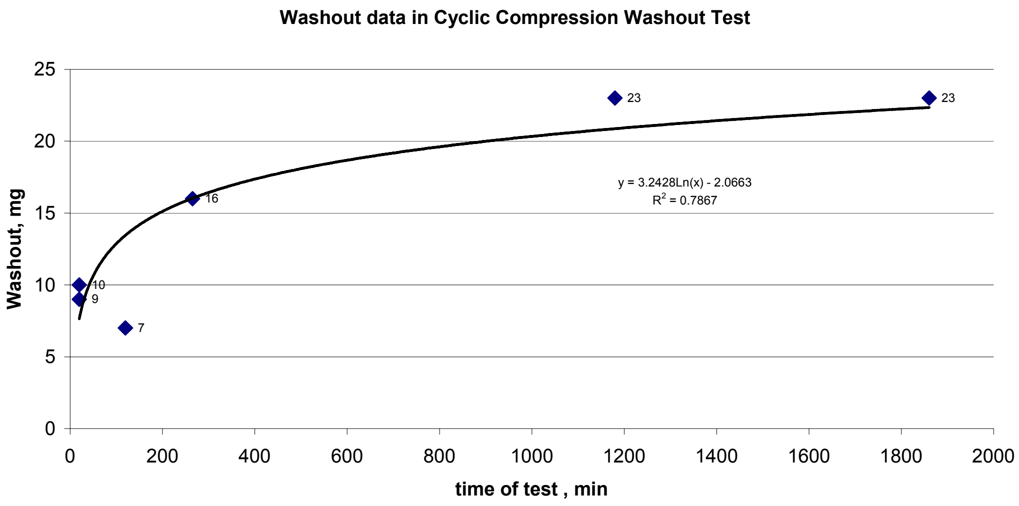
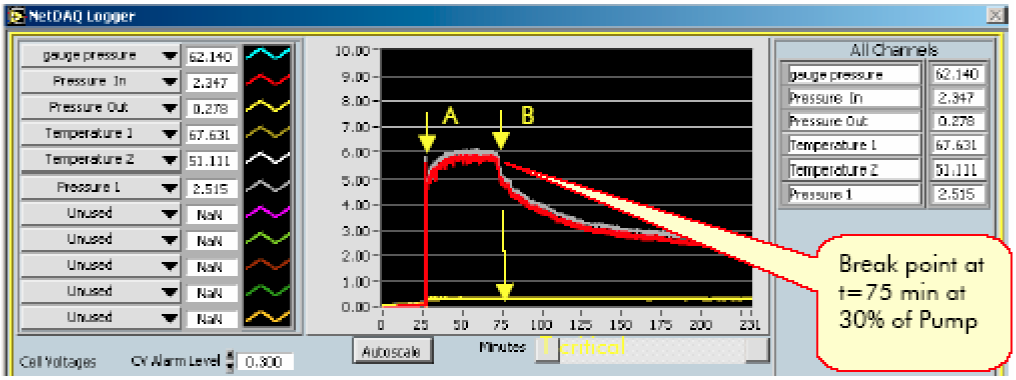


Figure 2. Washout versus time

For lifetime prediction of GDL we can choose any measurable and sensitive for the GDL performance parameter, having a design constraint value: Washout, Pressure Drop of Water across GDL, GDL Gas Permeability, GDL break load in Tensile or 3-bend Test, Flexural Modulus in 3-bend Test, GDL electro-conductivity, GDL thermo-conductivity or others.

Each of those parameters has its own specific critical value for given material and application. After exceeding this value, some “catastrophic” consequences may occur, that may lead to the replacement of the material or the unit.

For example, we may consider pressure drop of water across GDL as a parameter characterizing GDL integrity, the effect of passing water through GDL and washout results in GDL becoming more porous, a decrease in water pressure drop could characterize to some extent the beginning of GDL disintegration. In the case of GDL fracturing, the pressure drop of water will decrease significantly. The advantage of measuring pressure drop of water across GDL is the possibility of in-situ control of GDL washout and degradation under selected stressors in the test, as illustrated in Fig. 3.



gauge pressure 62.140
Pressure In 2.347
Pressure Out 0.278
Temperature 1 67.631
Temperature 2 51.111
Pressure 1 2.515
Unused NaN
Unused NaN
Unused NaN
Unused NaN
Unused NaN

All Channels
gauge pressure 62.140
Pressure In 2.347
Pressure Out 0.278
Temperature 1 67.631
Temperature 2 51.111
Pressure 1 2.515

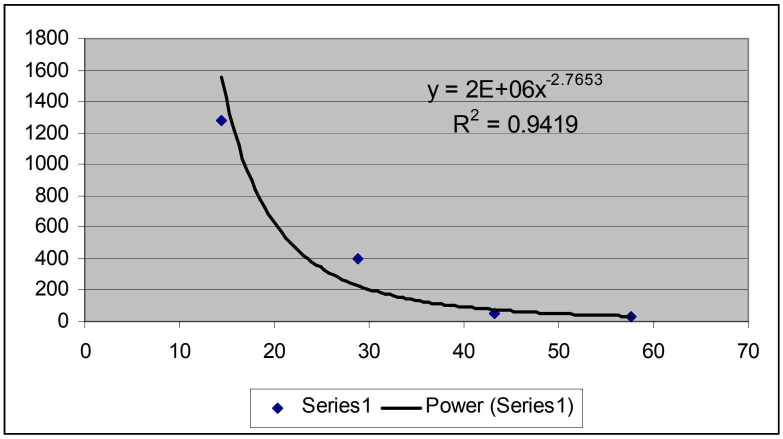
CV Alarm Level 0.300

Break point at t=75 min at 30% of Pump

Figure 3. Kinetic curve (dependence of pressure drop of water across GDL with time) of GDL disintegration

There are three main elements for each curve:
I. 0 to A: Start up of the test and build up of pressure (~ 5-6 psi) across the GDL
II. A to B: Pressure builds up to 7 psi. Some washout particles block some pores in the GDL

III. B to C: At point B we have significant pressure drop due to GDL disintegration, when some large water channels in GDL are created, increasing water permeability through the GDL If we make similar tests for different water flows we will get a family of curves similar to that in Fig. 3. At each curve we could locate the critical time - $t_{critical}$ (point B), when major GDL perforation take place. From such set of curves, measured for different flows, we could build a new curve showing the dependence of water flow (X –axis) from t critical (Y-axis), as in Fig. 4. Extrapolating the curve (Fig 4) to real value of water flow, generated by chosen value of current in Stack, we get an estimated value of GDL lifetime, when a major crack in the GDL is expected to occur.



Flow%	Flow ml/min	Time before Break, min ($t_{critical}$–t_A)
10%	14.4	1280
20%	28.8	400
30%	43.2	50
40%	57.6	35
Target	0.1	1516822 (25280 hr)

Figure 4. Experimental data plotted from the Table (at the right). X-flow, ml/min; Y-time before break, min. Evaluated by extrapolation GDL Lifetime before major perforation (for given GDL design) is 25280 hours. O.1 ml/min is a Target flow, created by chosen current.

The mechanical strength of GDL to washout failure mode could be evaluated from a Kinetic Curve (a dependence of Pressure drop across GDL from Time) shown in Fig. 3. If we multiply water flow passing across GDL by a value of Pressure drop across GDL we will get Power, which flow of water is developing passing though GDL. To evaluate Work, done by water flow on destruction of GDL structure, we simply integrate a curve dP (t) from t_{start} to t_{end}:

$$\int [(dP(t) - P\ end) \times flow(t)] \times dt$$

This Work on GDL disintegration is done by water flow (flow is constant all the time). It characterizes the transition of GDL from the initial state to the perforated state. This Work could be used for the comparison of various GDL deSigns for mechanical integrity and strength.

Conclusions

- The Cyclic Compression Washout Test for express comparative evaluations of washout of various GDL designs under Cyclic Compression, Temperature, Water flow and Time stressors is developed.
- A tendency of increasing total washout with time at a given fixed flow was experimentally confirmed. This tendency is specific to each type of the GDL sample. It allows the GDL lifetime prediction using CCWT.
- Pressure drop of water across GDL could be considered as an important parameter in developing new GDL and Membrane Electrode Assemblies (MEA) for PEMFC with minimal mass-transport losses.
- The CCWT accelerates regular GDL aging by a factor of up to 200 and accurately simulates the effects of washout and wet-dry cycling of PEM on GDL mechanical strength with time.

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