

DEVELOPMENT OF COMPLEX BIPOLAR PLATES FOR INCREASED PEMFC STACK POWER

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ABSTRACT

High power density along with low gravimetric and volumetric characteristics for Proton Exchange Membrane Fuel Cell stacks are needed in order to be successfully implemented on the market. It is well known that the heat transfer coefficients with liquid flow are much higher than airflow for the same pumping power, therefore liquid cooling is currently the most widely used cooling strategy in high power PEMFC stacks. This paper presents the manufacturing steps and preliminary tests results for an in house production of graphite type bipolar plates with liquid cooling circuit for PEMFC stacks.

Keywords: *fuel cell, bipolar plates, liquid cooling*

1. INTRODUCTION

Due to high power density, low operating temperature, rapid startup, high efficiency and near zero-emissions, proton exchange membrane fuel cell (PEMFC) are recognized as potentially candidate for the next generation power source for transportation, stationary, auxiliary and portable applications.

The bipolar plate (BPP) is a crucial component in PEMFC stack due to following functions:

- connect and separate the individual fuel cells in series to form a fuel cell stack: good conductivity especially through-plane direction and impermeable to gases;
- distribute fuel gas and oxidant over the whole active surface area of the membrane-electrode assemblies;
- conduct electrical current from the anode of one cell to the cathode of the next and also carry the electrical current away from the cell;
- conduct heat away from active zones: good thermal conductivity;

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- they support thin membrane and electrodes and clamping forces for the stack assembly: good mechanical properties;

- facilitate water management within the cell;

In order to perform the functions of the bipolar plates listed above, ideally the composite plates should meet the following requirements:

- High electrical conductivity (DOE target $>100 \text{ S/cm}$);

- Chemical stability in the presence of fuel, oxidant and product water, which is acidic ($\text{pH} = 2\text{-}3$) (DOE target : Corrosion resistance ($<16 \mu\text{A/cm}^2$);

- Chemical compatibility (no emissions affecting the electrode performance, no plate surface degradations occur);

- High thermal conductivity (PlugPower's target $>10 \text{ W/(mK)}$);

- Low thermal expansion coefficient;

- Low permeability to fuel and oxidant (DOE target: H_2 permeability ($<2 \times 10^{-6} \text{ cm}^3/(\text{cm}^2 \cdot \text{s})$))

- Good mechanical properties (PlugPower's targets: tensile strength $> 41 \text{ MPa}$, flexural strength $> 59 \text{ MPa}$, impact strength $> 40.5 \text{ Jm.1}$ (0.75 ft-lb/ in); DOE target: crush strength $> 4200 \text{ kPa}$);

- Thermal stability at fuel cell operating temperature (- 40 to 120°C for fuel cell driven vehicles);

- Low volume, light weight, and low cost;

- Easy manufacturability and rapid processability;

- Low thickness for applications in automotive vehicles;

The design of a Proton Exchange Membrane Fuel Cell stack comprising a large number of cells and requires careful design in order to achieve high stack performance. Ideally, each cell in the stack requires identical operating conditions to ensure optimal performance. In reality, however, it is difficult to achieve such ideal conditions, especially when a big stack contains tens or even hundreds of cells. For this reason, one key component in the stack which is directly linked to the operating performance is thermal management, i.e., careful cooling of every cell in the stack. This is due to the substantial amount of heat generated by each cell during operation from entropy changes and irreversibility's.

If too much heat is removed, the reaction kinetics is adversely affected, resulting in lower stack performance. Conversely, if the stack reach higher temperatures beyond optimal step will result in drying the membrane, with water content and its proton conductivity drop.

Different heat management techniques was reported [G. Zhang, S. G. Kandlikar, 2012] and are presented in Fig. 1.

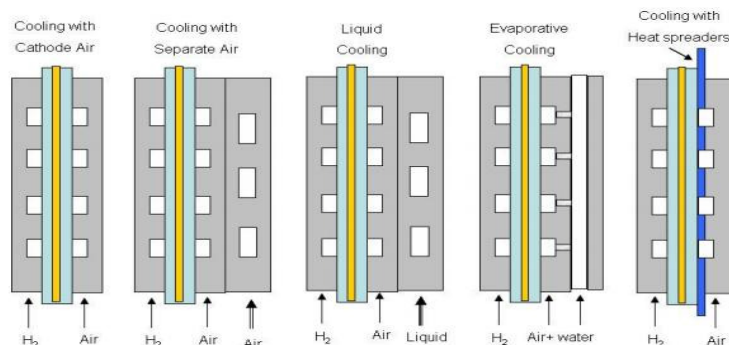


Figure 1. PEMFC cooling types

- Cooling with cathode air, when the cooling can be achieved only with cathode airflow. This type of cooling is suitable only with small size stacks when usually the exposed (external) stack area is much larger than the active area (air breathing PEM fuel cell stacks) so that the stacks are capable to dissipate heat at a rate comparable to the rate of heat generation. A disadvantage here is that it requires relatively bigger channel size for cathode side of the stack compared with the anode side, which consequently increases the volume of the stack.

- Cooling with separate air, for stacks bigger than few hundred watts require separate cooling channels, in which air can be blown to carry out the heat generated by virtue of the exothermic reaction occur in the fuel cell; This type of cooling can be used for stacks where volumetric power density is not so important, especially in stationary applications;

- Liquid cooling may be accomplished with deionized water, antifreeze coolant, or air. The thermal properties (specific heat capacity, thermal conductivity) of liquid are several orders higher than gas or air so for higher cooling load of the stack, liquid as a coolant is a natural choice instead of air. Cooling may be arranged between each cell, between the pair of cells (in such configuration one cell has the cathode and other cell has the anode next to the cooling arrangement), or between a group of cells (this is feasible only for low-power densities because it results in higher temperatures in the center cells). Equal distribution of coolant may be accomplished by the manifolding arrangement similar to that of reactant gases.

- Evaporative cooling (cooling with phase change) is used when the enthalpy of water vaporization is involved in cooling by injecting additional water to the reactant streams of PEM fuel cell. The heat generated at the electrodes is taken by the water for its phase change while keeping the temperature constant. This method of cooling also helps in preventing the drying of the membrane.

- Cooling with heat spreaders, also called edge cooling or passive cooling, relies on heat conduction in the in plane direction of cooling plates to remove the heat from the central region to the edges of the PEMFC stack. A major challenge in the cooling with heat spreaders is that the in-plane thermal conductivity of the cooling plates must be very high to control the temperature variation across the active area.

From the cooling techniques above mentioned, the liquid cooling is currently the most widely used cooling strategy in high power PEMFC stacks (>5 kW). It is especially suitable for automotive PEMFC stacks or co-generation applications.

2. EXPERIMENTAL

Our technique to develop a bipolar plate with liquid cooling consist in bonding by gluing with a graphite type cement of two identical semi-plates with corresponding channels for fluids (reactants and cooling liquid). The plates are heated in an oven to thermally cure the graphite cement and to form the desired internal cooling circuit and manifolds for liquid and gas distribution. (Fig. 2).

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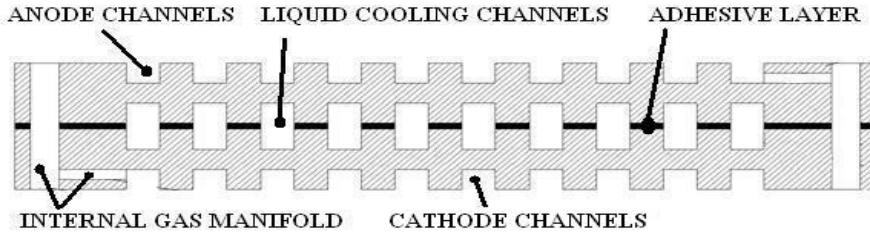


Figure 2. Bipolar plate with internal liquid circuit and manifolds

2.1. Samples preparation

Because many experiments were carried out, the initial tests was made with 28x28x2.5mm graphite plates samples based on Grafcell FFP200 Series to determine the electrical resistance and gas tightness of cement.

The graphite cement is based on heterocyclic organic compound mixed with graphite powder with different grain size. The mass ratio between filler and powder will determine the electrical (conductivity of cured cement) and mechanical (viscosity of uncured) behavior that have an important influence in the deposition method and cement layer thickness. This properties will be choose individually for different graphite types, surface roughness and contact pressure during thermal treatment in order to have compatible conditions for optimal results. [L. Patularu, et al., 2012]

2.2. Electrical measurement

The measurement principle used for samples electrical resistance measurement [F. Barbir et all, 1999] consists in following: two gold plated cooper plates (GPCP) positioned above and below sample plate allowing contact pressure to be applied in the Z-direction. Two gold pin electrodes, used as passive voltage sensors, are symmetrically positioned in the center of the compressing plates, on the system's axis of symmetry, in electric contact with gold plated cooper plates, which probe the bulk properties (Fig. 3).

No backing material was inserted between GPCP and sample, in order to avoid any additional interfaces. For obtaining a mean value of setup resistance, each experiment has been repeated 4 times; every time the sample was rotated to 90°.

A DC current of 50mA is supply to the system at the GPCP from a Yew type 2554 DC source, and the voltage drop is measured on gold pin electrodes with an HP 3458A multimeter.

The total electrical resistance of the setup was calculated according Ohm's law. There are several serial resistances in this experiment, namely contact resistance between gold contact plates and graphite plate (R_{Cu-Gr}), bulk resistance of the graphite plate R_{Gr} , and contact resistance between graphite plates do to adhesive bonding (R_{con})

$$R_{measured} = 2R_{Cu-Gr} + 2R_{Gr} + R_{con} \quad (1)$$

Because all the electrical measurements are done at the same contact pressure, R_{Cu-Gr} , R_{Gr} are always constant, the only change in $R_{measured}$ value is due to contact resistance between graphite plates R_{con} .

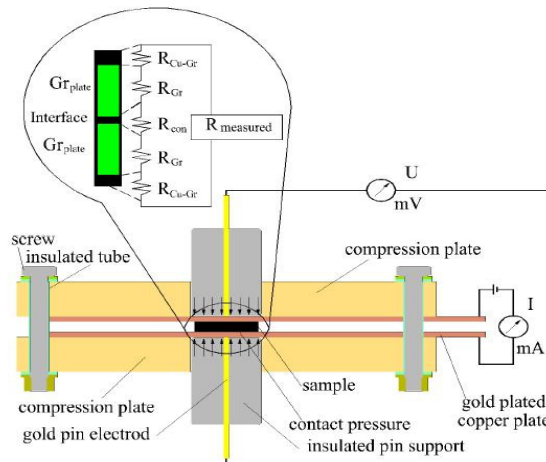


Figure 3. Schematic diagram for electrical resistance measurement

2.3. Sample gas tightness determination

Gas tightness of bipolar plates is one parameter that must be accomplished without any compromise.

In order to have a good gravimetric power density, the bipolar plate “electrical inactive surface” must be used at maximum, for membrane sealing or for internal gas compartments separator. This means that the length between gas chambers and cooling compartment must be as short as possible, without any leakage.

For these experiments, we use the same graphite plate dimensions of 28x28mm, but we made a pocket inside each plate with 1mm deep. The contact land was varied from 3mm up to 7mm, to identify the minimum length for non-leakage state.

For this test, we use a Varian Pro2 Helium leak detector. The test pressure was set at 3bars, in order to compensate the working pressure of hydrogen.

After individual tests, we consider that 6mm of cement length is enough for the sealing of internal compartments.

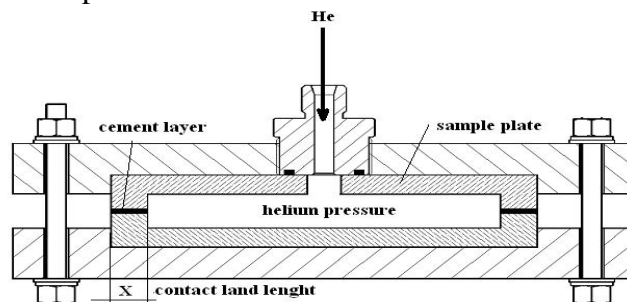


Figure 4. Leakage test fixture for adhesive contact land

3. RESULTS AND DISCUSSION

ICIT PEMFC infrastructure is based on 92cm² quadratic shape active area, with 150x150mm graphite plate dimensions for stack utilization. For cooling channels in this case, (liquid cooling) we chose a simple configuration with straight lines (Fig.5). A certain cooling capacity was not the target of this project, actual channels configuration and size for liquid cooling, cover the thermal necessity of 92cm² active area, especially as this configuration was previously used for cooling with separate air.

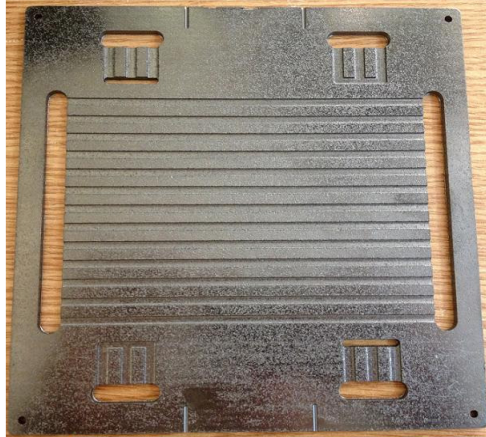


Figure 5. Semi-plate with cooling channels and internal gas manifolds

The bipolar plate was finally made by using a system pressure device realized by two steel plates with 20mm thickness uniformly tighten by 8 M6 screws disposed symmetrically in relation with system central axis allowing a uniform distribution pressure on the sample's surface. The torque was measured with a precise dynamometric torque wrench, model ADS4. The resulting compression force was calculated using the following equation [F. Barbir, 2005]:

$$F = \frac{T \times N_b}{K_b \times D_b} \quad (2)$$

where:

- T = tightening torque, (Nm)
- F = clamping force, (N)
- K_b= friction coefficient (0.20 for dry bolts)
- D_b= bolt nominal diameter, (m)
- N_b= number of bolts, (4)

In this stage the bipolar plates surfaces parallelism was between 15 to 35µm, and this value can be improved by: improving the initial plate parallelism for each semi-plates or by using a surface machining operation for final bipolar plate.

Fig. 6 (left), show the sample electrical resistances for unbonded state. The test was made for 3 roughness values and was carry on at 4 different contact pressures around 22kgf/cm², 44kgf/cm², 66kgf/cm², 88kgf/cm². Every time when

contact pressure was increased, the sample plate resistance decreased due to contact resistance improvement [L. Patularu et al., 2013].

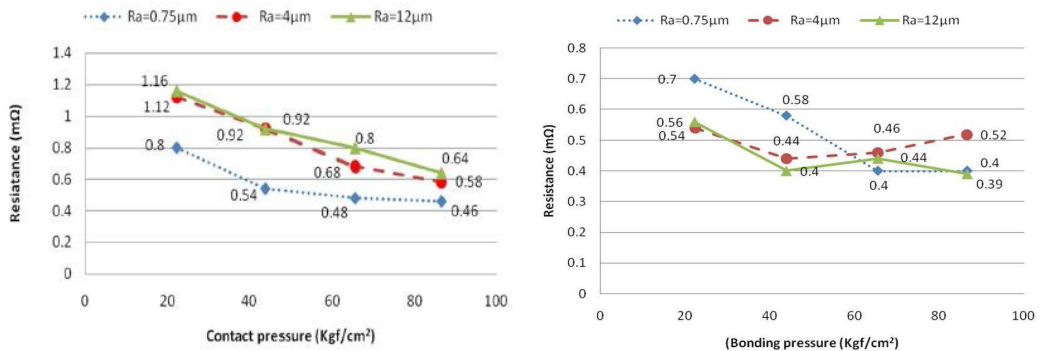


Figure 6. Electrical resistance determination of unbonded (left) and bonded (right) samples for different roughness

Fig. 6 (right) shows the sample electrical resistances for bonded state, with the same surface roughness at the same compression pressure during thermal treatment. We can observe that the values for electrical resistance are lower in the case of bonded plates versus unbonded. This shows us that the influence of electrically conductive bridge formed by graphite cement is positive.



Figure 7. Test fixture for bipolar plate leakage test

The bipolar plate gas tightness test was realized with a device which consists in 2 fiber reinforced glass plates with corresponding holes for gas and cooling manifold, each one having O-rings to prevent leakage. In this case, we supply and test with helium individual gas and liquid holes, in order to detect any leakage from one to another compartments.

4. CONCLUSIONS

The obtained results during the test shows that electrical behavior of bipolar plates are more than satisfactory as against unbonded state by improved contact resistance.

From the gas tightness point of view, we manage to find a 5mm as a minimum acceptable distance to prevent leakages between compartments. Doing this, the weight of future plates will be characterized by good gravimetric power density.

The final plate parallelism is not influenced by manufacturing method and can be improved using one of already mentioned methods.

In practice, there is an issue of the coolant becoming electrically conductive as it degrades due to ion contamination from the bipolar plates or ionic production from oxidation of the coolants, so a future work will investigate the degradation of coolant conductivity in time.

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