Improving Water Management in Fuel Cell Flow Channels via Oscillation of Water Droplets

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ABSTRACT

To achieve maximum efficiency and reliability in a PEM fuel cell, a balance between keeping the membrane from becoming too dry or too wet must be monitored carefully. At high current densities, the production of liquid water may exceed the capacity of the gas streams to evaporate the water out of the fuel cell stack and drops of water will appear within the flow channels. If the water accumulation becomes too great, the gas flow channel may become completely blocked by water and the fuel cell efficiency drops dramatically and eventually ceases to function. This is a phenomenon commonly known as "flooding" of the fuel cell. To avoid flooding, measures must be taken to remove the water drops from the flow channels. At present, water drops are moved through the channels to the exit via shear due to gas flow. The movement of the water drops in the gas flow channels is inhibited by pinning of the contact line region; that is, the line of contact where the gas, liquid and solid coincide.

Water removal from the gas flow channels can be greatly enhanced by exciting the pinned water drops at their natural frequency. For oscillations near a natural frequency of the liquid-gas surface, minimal energy is required to induce large surface oscillations and, therefore, relatively large inertia within the drop. The inertia generated by the surface oscillations is sufficient to overcome the contact line pinning resulting in drops that easily move through the flow channels and exit the cell.

Explorations in the design and manufacture of fluidic elements to produce the reactant flow modulation are undergoing. This includes the design of non-vented fluidic oscillators that will interface with the fuel cell channels. Also, work is being conducted on manufacturing fluidic oscillators using a soft-lithography technique. The cast fluidic elements are used for frequency verification and investigation of oscillator design. This technique has significant potential due to the absence of external actuators and controls. There are no moving parts and the oscillators could be cast directly into the bipolar plates during manufacturing.

Keywords: PEM fuel cell, water management, fluidic oscillator

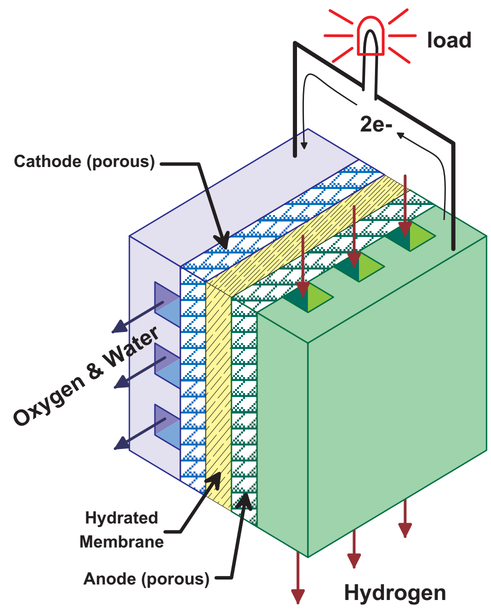

Figure 1: Cross-sectional illustration of PEM fuel cell.

INTRODUCTION

A PEM[1] fuel cell operates via a controlled hydrogen-oxygen reaction; the byproducts of which are heat and water. The design of the fuel cell varies with manufacturer, but generally the fuel cell consists of a porous anode, a proton-conducting membrane, and a porous cathode all sandwiched between two bi-polar plates which have gas flow channels machined or stamped into the faces as illustrated in Figure 1.

A balance between keeping the membrane from becoming too dry or too wet must be maintained for efficient and reliable operation. At high current densities, the production of liquid water may exceed the capacity of the gas streams to evaporate the water out of the fuel cell stack and drops of water will appear within the gas flow channels (see Figure 2). If the water accumulation becomes too great, then the gas flow channel may become completely blocked by water and the fuel cell will "flood". The water drops must be removed from the gas flow channels for reliable operation. Removal of the

[1] PEM is short for Proton Exchange Membrane or Polymer Electrolyte Membrane. Polymer Electrolyte Fuel Cell (PEFC) is also a commonly used description.

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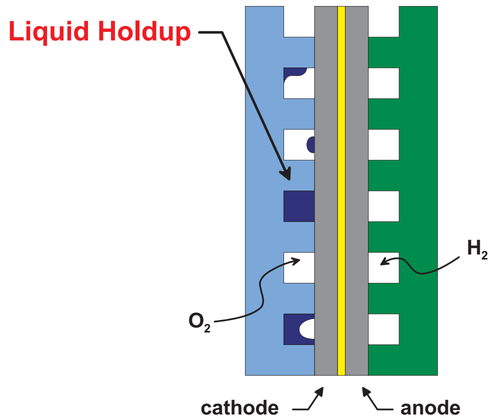

Figure 2: Flooding of the gas flow channels; also known as liquid holdup.

product water is a particularly acute problem in freezing environments where the freeze-thaw cycling of a fuel cell results in rapid degradation of fuel cell components.

Efficient removal of the product water is a major impediment to commercialization of PEM fuel cells and is an important step in fuel cell operation. In a PEM fuel cell the membrane must be hydrated, requiring water to be evaporated at precisely the same rate that it is produced. If water is removed too quickly, the membrane dries and resistance to proton transport increases; eventually leading to membrane failure allowing the hydrogen and air to combine directly and generating heat which will damage the fuel cell. If the water is removed too slowly, flooding may occur which creates a maldistribution of reactants which results in electrochemical degradation of fuel cell components. [1] The importance of water management is widely recognized within the fuel cell community and the Department of Energy has recently awarded a number of research contracts specifically targeting fuel cell water management. A successful water management system is an enabling technology for PEM fuel cells. [2]

At present, water drops are moved through the channels to the exit via the gas flow. The movement of the water drops in the gas flow channels is inhibited by pinning of the three-phase region commonly referred to as the contact line region; that is, the line of contact where the gas, liquid and solid coincide. At high gas flow rates the water drops can be adequately removed. However, at low gas flow rates the water drops remain pinned to the gas diffusion layer and grow to the point where the gas flow channels become plugged. This is a critical problem within the automotive fuel cell industry since most of the automotive drive cycle is at idle (low gas flow rates) with short periods of high power required for acceleration (high gas flow rates). Water drops can effectively be removed during acceleration, but not during idle. The current method for removing water from the fuel cell is to rely upon the shear and pressure of the reactant flow in the bipolar plate to move water drops to the exit. A variety of channel surface treatments, channel surface roughness, channel geometry, and channel orientation with respect to gravity have been tried; though no technique has been satisfactory. Gas reactant flow control and/or flow modulation has not been attempted. Herein is described a method for assisting in the removal of water drops through oscillation of the drop at or near one of its natural frequencies.

DROP OSCILLATION

For oscillations near a natural frequency of the liquid-gas surface minimal energy is required to induce large surface oscillations and, therefore relatively large inertia within the drop (see Figure 3). The inertia generated by the surface oscillations is sufficient to overcome the resistance of the pinned contact line which allows for easy removal of the water drop via the gas flow.

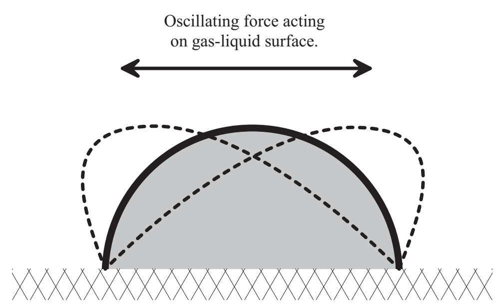

Figure 3: Water drop on porous electrode illustrating normal mode response to oscillating force acting on the gas-liquid interface.

Oscillation of the drop surface may result from any number of cyclic forces acting on the gas-liquid surface. The cyclic force could be from a pulsed gas flow via a fluidic oscillator designed into the inlet manifold, a cyclic acoustic wave, a pulsed electromagnetic wave and/or mechanical vibrations. Figure 4 is an image sequence of a 5-mm-diameter water drop oscillating due to a small impulse force. The observed frequency corresponds to that predicted computationally for a pinned sessile drop. [3]

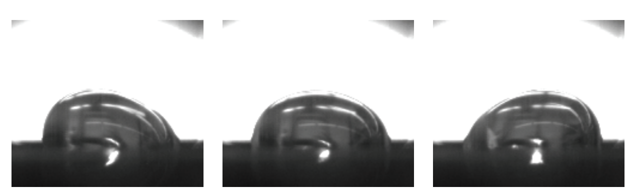

Figure 4: Oscillating water drop; approximately 5 mm diameter.

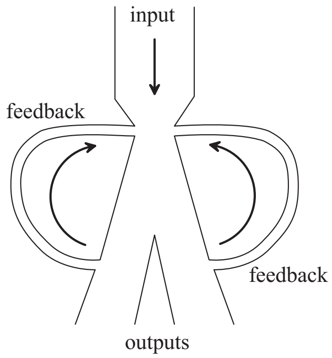

Figure 5: Typical bi-stable fluidic oscillator where a feedback signal is taken from each output and fed back to the control ports.

FLUIDIC OSCILLATOR

Fluidic elements are particularly attractive for inducing drop oscillations in automotive PEM fuel cells because a fluidic oscillator requires no external power other than a clean, pressurized gas stream. Large PEM fuel cells typically use filtered, compressed reactants (hydrogen and air). Therefore, the fluidic elements could be integrated directly into the reactant flow fields without any additional active components required to induce flow oscillation and, subsequently, drop oscillation.

An example of a fluidic oscillator is illustrated in Figure 5. A signal from each output leg is fed back through a control port to deflect the inlet stream. The signal in the control port forces the primary fluid flow to the opposite outlet port. Then the signal from that outlet port is fed back to the respective control part where the primary fluid flow is pushed back to the original output. The frequency of flow switching between the two output ports is easily adjusted through temperature and/or flow path.

Each output leg could be directed to separate gas flow channels thereby providing a pulsed gas stream which would cause oscillations of water drops. A pressurized gas stream is all that is required in order to induce flow oscillations.

A novel method of integrating fluidic amplifiers and oscillators into the manifold of a PEM fuel cell flow field for the purpose of enhanced water management has been developed at Michigan Tech and a patent application [4] has been filed with the university. Figure 6 is a schematic of the approach. A single, large capacity fluidic oscillator (Element 1) is used to induce flow switching in multiple, parallel small capacity fluidic amplifiers (Elements 2 and 3) each of which modulates flow into a separate flow channel. The isolation of the fluidic oscillator from the flow fields via the small capacity amplifiers eliminates disruption of flow oscillation due to channel back pressure. The stability and robustness of the approach shown in Figure 6 has been demonstrated at Michigan Tech. [5] Integration of the fluidic components in a fuel cell bipolar plate has not yet been demonstrated.

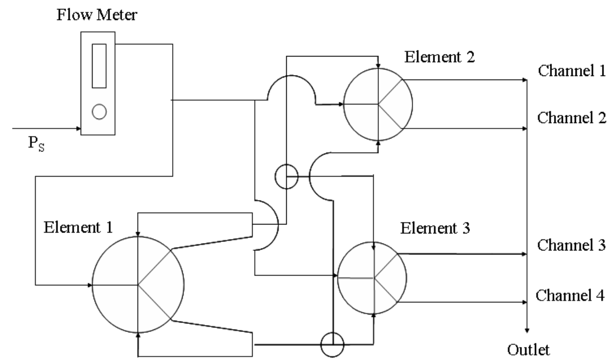

Figure 6: Schematic of oscillator network.

CONCLUSIONS

The fluidic oscillator technique proposed will work at both low and high gas flow rates because of the resonance excitation of the water drop occurs independently of the flow rate. There are no additional system components or controls required to implement this technique. The existing pressurized reactant streams can naturally create the flow modulation. The only modification required is to cast or stamp the fluidic amplifiers into the bipolar plate inlet headers. Currently, an *ex situ* experiment is being developed to test the ability to effectively induce drop oscillation and drop removal from a small channel having the same characteristics as a PEM fuel cell gas flow channel.

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