Dynamic Water Management Test Station for Open-cathode PEMFC Systems

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1 Introduction

Hydrogen fed polymer electrolyte membrane fuel cells (PEMFC) are energy conversion devices that can be implemented into a wide range of applications such as automotive, stationary and portable systems. However, to optimize performance, they require active control and thus in-depth understanding of the system dynamics.

Understanding water transport mechanisms through the membrane and membrane water content is one of the keys to improving PEMFC system performance. Once these mechanisms are identified and modelled, effective control strategies can be implemented.

Hence, the main objective of this test station design is to experimentally characterize the water transport mechanisms through the membrane and its water content for the purpose of studying their dynamic influence on fuel cell system performance for numerical model verification and validation. The analysis will then lead to an in-depth understanding of how a system with minimal parts and complexity can be improved in terms of overall efficiency, stability and operating rage. These conclusions will provide guidelines to develop a proper control strategy with the necessary sensors to ensure that the system operates properly under a wide range of environmental conditions.

2 Design Objectives

2.1 *Test station objectives*

The test station has been designed to independently control, simulate and monitor the various phenomena that affect the fuel cell system performance. The system is controlled with an internally developed LabView® program. The main focus is on the transport of water across the membrane. This is a unique test station because it allows the full characterization of a simple open cathode fuel cell system under a wide range of environmental and operational conditions. The simplicity of the fuel cell comes from its open-cathode and self-humidified design. However, this simplicity comes with a cost since the fuel cell will be more sensitive to the surrounding environmental conditions. Therefore, the fuel cell will be tested in an environmental chamber that will have the capability to control and measure the air temperature, relative humidity, and oxygen concentration. The environmental chamber will have a dual purpose. The first will be to maintain very specific inlet conditions for the air delivered to the stack to isolate the water transport phenomena through the membrane, and the second one will be to emulate a wide range of environmental conditions for the purpose of investigating the combined effects of the fuel cell systems thermal and mass balance with respect to performance and the control mechanisms.

2.2 *Test station specifications*

The main subsystems of the test station can be split in four different subsystems; the environmental chamber (cathode), the anode, the fuel cell stack, and the data acquisition/control sub-systems.

A custom designed environmental chamber has been developed, which has the capability of controlling the chamber temperature from 5°C to 70°C, relative humidity from 10%-90% and oxygen concentration from 19% to 25% per volume. The environmental chamber is equipped with all the necessary safety systems for use with a flammable gas.

Fig. 1. Picture of fuel cell test station with the environmental chamber.

The anode sub-system has two modes of operation to control the hydrogen flow rate: mass flow controller or forward pressure regulator in conjunction with a purge valve. In the first mode of operation, which is used for identifying the water transport coefficients, the mass flow controller is set to the control mode and in combination with a humidifier to control the inlet dew point temperature. In the second mode of operation the mass flow controller is set only to measure the flow and the forward pressure regulator maintains the pressure in the anode while the purge valve is closed. So, as hydrogen is consumed, the pressure will decrease and the regulator will open to refill the system. There are temperature and dew point sensors at both the inlet and outlet to calculate the mass and thermal balances. The gas line heaters, in combination with the dew point sensors, ensure that all the water is vaporized for accurate measurements.

The test station is equipped to measure individual cell temperatures and voltages. An electrochemical impedance spectroscopy (EIS) system analyzer is wired to the stack or cell voltages in combination with the current drawn from the fuel cell to measure either the global or individual cell impedances.

The data acquisition and control system is composed of two computers and an internally developed LabView® program. The first computer is responsible for the graphical user interface, start up, shut down, configuration changes and control settings during operation. The second computer runs under a real-time operating system offering consistent and stable functionality, implementation of controllers, data acquisition and storage. To overcome hazardous voltages, transient signals, fluctuating ground potentials and common-mode voltages the sensors/actuators are isolated using galvanic and optical based electronics.

3 Expected Results

3.1 System energy and mass balance

The mass and energy balance equations that will be solved are as follows.

Energy balance:

$$\dot{m}_{ca,in}h_{ca,in} + \dot{m}_{an,in}h_{an,in} + \dot{Q}_e + \dot{Q}_{hx} =$$
$$\dot{m}_{ca,out}h_{ca,out} + \dot{m}_{an,out}h_{an,out} \qquad (1)$$

Mass balance:

$$\dot{m}_{ca,in} + \dot{m}_{an,in} + \dot{m}_{H_2O,gen} = \dot{m}_{ca,out} + \dot{m}_{an,out} \qquad (2)$$

The enthalpies are determined from ideal gas properties tables.

The experimental water mass balance will be calculated based on the inlet cathode air velocity meter, H_2 mass flow meter, O_2 sensor, stack current, inlet & outlet temperature, dew point and pressure sensors. These sensors give the following relations:

$$\dot{m}_{H_2O,ca,in} = f\left(c_{O_2,ca,in}, T_{ca,in}, T_{dp,ca,in}, v_{ca,in}, P_{ca,in}\right) \qquad (3)$$

$$\dot{m}_{H_2O,an,in} = f\left(\dot{m}_{H_2,an,in}, T_{dp,an,in}, P_{an,in}\right) \qquad (4)$$

$$\dot{m}_{H_2O,gen} = f\left(I\right) \qquad (5)$$

$$\dot{m}_{H_2O,ca,out} = f\left(I, T_{dp,ca,out}, P_{ca,out}, \dot{m}_{air,ca,in}\right) \qquad (6)$$

$$\dot{m}_{H_2O,an,out} = f\left(I, T_{dp,an,out}, P_{an,out}, \dot{m}_{H_2,an,in}\right) \qquad (7)$$

The equations for these parameters can be found in Barbir 2005 [1]

Nomenclature	
c	Gas volumetric concentration
h	Fluid enthalpy (J/kg)
I	Fuel cell stack current (A)
$\dot{m}$	Mass flow rate (kg/s)
P	Pressure (Pa)
$\dot{Q}$	Power or energy flow rate (J/s)
T	Temperature (°C)
v	Gas velocity (m/s)
Nomenclature subscript:	
an	Anode subsystem
ca	Cathode subsystem
e	Electrical
gen	Generation
H_2O	Water
hx	Heat generated
in	Inlet of the subsystem
out	Outlet of the subsystem

Table 1. Nomenclature

3.2 Numerical modeling

The test station will be used to characterize the fuel cell system where certain parameters need to be identified, such as the water diffusion coefficient, electro-osmotic drag coefficient, membrane water content and the heat transfer coefficients. Finally, the test station will be used to verify the numerical model and to test new control strategies.

4 Discussion

The current data indicates that the control mechanisms for the fuel cell can be greatly improved. The fuel cell system efficiency will be calculated by using cell voltage, hydrogen consumption and parasitic losses. The stability will be calculated by the variation from the mean cell voltage, and the performance will be calculated using the average voltage and current to create a polarization curve of the fuel cell. These will be the three main indicators of improvements to the system.

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6 References

[1] F. Barbir, *PEM Fuel Cells Theory and Practice*, Elsevier Academic Press, (2005)