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PEM water electrolysis: preliminary investigations using neutron radiography

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Abstract

The quasi-dynamic water distribution and performance of a proton exchange membrane (PEM) electrolyzer at both a small fuel cell's anode and cathode was observed and quantitatively measured in the in-plane imaging geometry direction(neutron beam parallel to membrane and with channels parallel to the beam) by applyingthe neutron radiographyprinciple at the neutron imaging facility (NIF) of NIST, Gaithersburg, USA. The test section had 6 parallel channels with an active area of 5 cm^2 and in-situ neutron radiography observation entails the liquid water content along the total length of each of the channels.The acquisition was made with a neutron cMOS-camera system with performance of 10 sec per frame to achieve a relatively good pixel dynamic range and at a pixel resolution of 10 x 10 μm^2.A relatively high S/N ratio was achieved in the radiographs to observe in quasi real time the water management as well as quantification of water / gas within the channels. The water management has been observed at increased steps (0.2A/cm^2) of current densities until 2V potential has been achieved. These observations were made at 2 different water flow rates, at 3 temperatures for each flow rate and repeated for both the vertical and horizontal electrolyzer orientation geometries. It is observed that there is water crossover from the anode through the membrane to the cathode. A first order quantification (neutron scattering correction not included) shows that the physical vertical and horizontal orientation of the fuel cell as well as the temperature of the system up to 80°C has no significant influence on the percentage water (~18%) that crossed over into the cathode. Additionally,a higher water content was observed in the Gas Diffusion Layer at the position of the channels with respect to the lands.

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1. Introduction

Recently hydrogenProton-Exchange-Membrane (PEM) fuel cells (FC) made significant progress in several countries with roadmaps toward commercialization[USDOE, 2016; Prasad, 2016], causing eventuallya growing interest in technologies for also high quality hydrogen generation. Thus, the use of PEM water electrolysis for hydrogen fuel production became a vector of interest for fuel cell deployment opportunities in sectors such as sustainable mobility, material handling, and back-up power. Hydrogen is the only energy storage concept to address energy storage in range > 100 GWh[Waidhas, 2016]. PEM water electrolysis (PEMEL) is also considered as one of the most favorable technologies for hydrogen generation with many advantages over other available technologies such as simplicity, high current densities, solid electrolyte and high working pressures.

Wateris decomposed by passing an electric current through the waterinto hydrogen and oxygen in the presence of suitable substances, called electrolytes. The operating principle of PEMELs is often referred to as the reversed operation of a fuel cell whereby the water is oxidized at the anode (oxygen production) to produce oxygen electrons and protons (eq-1), however, the materials and configuration thereof are typically different from PEM-FC. Optimized electrolysis plants usually operate at electrolyte temperature of 70-90^{o}C and cell voltage of 1.85-2.05 V (Zouliaset.al., 2006).

$$H_2O\ (l) \rightarrow 4H^+(aq) + 4e^- +\ O_2\ (aq) \tag{1}$$

The protons pass directly through the membrane to the cathode were they recombine and form hydrogen (eq-2).

$$2H^+ + 2e^- \rightarrow H_2 \tag{2}$$

Water electrolysis yield no side reactions that could generate undesired byproducts, therefore the net balance is (eq-3):

$$2H_2O\ \rightarrow (4e^-) \rightarrow O_2 + 2H_2 \tag{3}$$

Unfortunately, gas crossover occurs when either hydrogen or oxygen cross through the membrane to the other side and thus pose safety issues such as explosive gas mixtures but also lowers the efficiency of the electrolyzer and enhances degradation of the membranes. (See Fig. 1.)

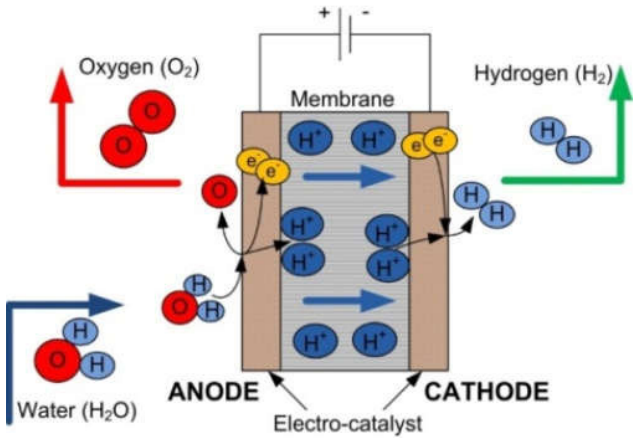

Fig. 1.Schematic of a PEM electrolyser setup [1].

Jacobson, 2004 indicated that the water balance in a normal operating fuel cell is critical to the operation of the cell and that proper humidification of the membranes will allow optimum conduction of protons. Water entering the electrolysis system which is not transformed into ions, and water that has crossed over into the cathode and is not