Hydrogen Production in a Steam-Carbon Fuel Cell

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Introduction

Hydrogen is a desirable fuel because it is an effective energy carrier and because it has minimal impact on the environment. However, there are no large natural reservoirs of hydrogen, and the majority of hydrogen currently used is produced either from steam reforming of hydrocarbons or electrolysis of water. Both of these methods have significant drawbacks. Hydrogen from steam reforming of hydrocarbons contains trace amounts of CO, which acts as a poison for the catalyst in PEM fuel cells, and hence limits the usability of the hydrogen produced. Electrolysis of water is an electrochemically uphill process, which requires significant energy input. A steam-carbon fuel cell (SCFC) is a viable alternative that is capable of producing carbon-free hydrogen and electricity spontaneously.

The SCFC concept utilizes steam at the cathode and a carbon bed at the anode. Yttria stabilized zirconia (YSZ) electrolyte membrane is employed for selective transport of oxide ions from the cathode to the anode, as shown in Figure 1. At the elevated operating temperatures of an SOFC, the carbonaceous fuel maintains an oxygen activity at the anode significantly lower than that in the steam environment at the cathode, providing more than 0.5 V spontaneous of steam into hydrogen. This novel scheme eliminates the need to overcome the OCV and significantly reduces the energy budget for production of pure, carbon-free H_2.

This presentation consolidates modeling with experimental studies of carbon fuel cells conducted in our lab [1-4] and describes how this novel idea can transform how we produce hydrogen from solid carbonaceous fuels.

Modeling of the Steam-Carbon Fuel Cell

A model of a SCFC has been developed that takes into account electrochemistry at the electrodes, reaction chemistry in the carbon bed, mass transport of gases, and heat transfer. The kinetic parameters needed to describe the half-cell reactions are derived experimentally. By introducing CO_2 into the system, the CO required for the anode reaction is generated from the Boudouard reaction in the carbon bed:

$$C + CO_2 \rightarrow 2CO \qquad (1)$$

The cell oxidizes the CO to generate both hydrogen and electricity, producing an outlet stream of nearly pure CO_2, part of which can be recycled to the anode and the remainder of which can potentially be captured and stored. A detailed reaction mechanism for the Boudouard reaction is used to predict the gasification rate.

Mass transport is important in determining the fuel utilization. The operation of the cell results in an anode exhaust containing largely CO_2 with the remaining balance CO. Carbon dioxide formed at the anode surface can diffuse back into the bed and further gasify the solid carbon. The CO from this gasification can then diffuse back to the anode, or it can diffuse through the carbon bed and leave the cell. Any CO in the exhaust is carbon fuel that is not fully oxidized, still capable of undergoing the oxidation reaction to produce electricity in the cell. Thus, fuel utilization improves with an increase in the ratio of CO_2/CO in the exit gas, and this influences the overall efficiency of the cell.

Since both the Boudouard gasification and the half-cell reactions are temperature dependent, it is important to understand the coupled relationship between reaction rates, heat release, and local temperature. Thus, consideration of heat transfer effects is necessary to develop a better understanding of the cell operation.

The model is used to map out the operating space for hydrogen production and cell efficiency. Furthermore, geometrical parameters are tuned to minimize the mole fraction of CO in the exhaust and maximize the overall efficiency. Optimal operating conditions are identified for maintaining high efficiencies while also achieving realistic hydrogen production rates.

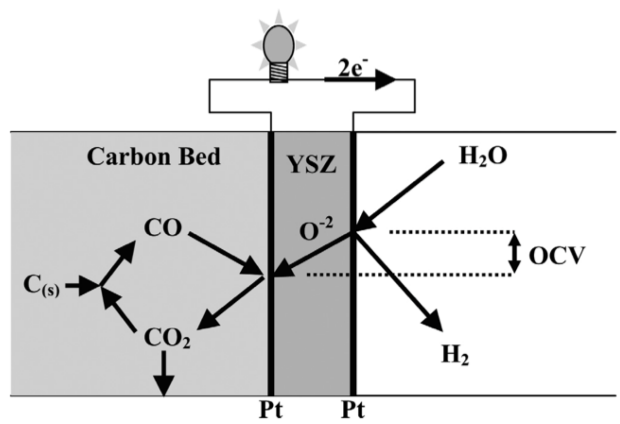

Figure 1: Operating principle of the steam-carbon fuel cells [2].

References

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