

Fuel Cell Performance and Technology Overview

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Course Author: Mathew Holstrom

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1. TECHNOLOGY OVERVIEW

This chapter provides an overview of fuel cell technology. First it discusses the basic workings of fuel cells and basic fuel cell system components. Then, an overview of the main fuel cell types, their characteristics, and their development status is provided. Finally, this chapter reviews potential fuel cell applications.

1.1 Introduction

Fuel cells are electrochemical devices that convert chemical energy in fuels into electrical energy directly, promising power generation with high efficiency and low environmental impact.

Because the intermediate steps of producing heat and mechanical work typical of most conventional power generation methods are avoided, fuel cells are not limited by thermodynamic limitations of heat engines such as the Carnot efficiency. In addition, because combustion is avoided, fuel cells produce power with minimal pollutant. However, unlike batteries the reductant and oxidant in fuel cells must be continuously replenished to allow continuous operation. Fuel cells bear significant resemblance to electrolyzers. In fact, some fuel cells operate in reverse as electrolyzers, yielding a reversible fuel cell that can be used for energy storage.

Though fuel cells could, in principle, process a wide variety of fuels and oxidants, of most interest today are those fuel cells that use common fuels (or their derivatives) or hydrogen as a reductant, and ambient air as the oxidant.

Most fuel cell power systems comprise a number of components:

- Unit cells, in which the electrochemical reactions take place
- Stacks, in which individual cells are modularly combined by electrically connecting the cells to form units with the desired output capacity
- Balance of plant which comprises components that provide feedstream conditioning (including a fuel processor if needed), thermal management, and electric power conditioning among other ancillary and interface functions

In the following, an overview of fuel cell technology is given according to each of these categories, followed by a brief review of key potential applications of fuel cells.



1.2 Unit Cells

1.2.1 Basic Structure

Unit cells form the core of a fuel cell. These devices convert the chemical energy contained in a fuel electrochemically into electrical energy. The basic physical structure, or building block, of a fuel cell consists of an electrolyte layer in contact with an anode and a cathode on either side. A schematic representation of a unit cell with the reactant/product gases and the ion conduction flow directions through the cell is shown in Figure 1-1.



Figure 1-1 Schematic of an Individual Fuel Cell

In a typical fuel cell, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen from air) is fed continuously to the cathode (positive electrode). The electrochemical reactions take place at the electrodes to produce an electric current through the electrolyte, while driving a complementary electric current that performs work on the load.

Although a fuel cell is similar to a typical battery in many ways, it differs in several respects. The battery is an energy storage device in which all the energy available is stored within the battery itself (at least the reductant). The battery will cease to produce electrical energy when the chemical reactants are consumed (i.e., discharged). A fuel cell, on the other hand, is an energy conversion device to which fuel and oxidant are supplied continuously. In principle, the fuel cell produces power for as long as fuel is supplied.

Fuel cells are classified according to the choice of electrolyte and fuel, which in turn determine the electrode reactions and the type of ions that carry the current across the electrolyte. Appleby and Foulkes (1) have noted that, in theory, any substance capable of chemical oxidation that can be supplied continuously (as a fluid) can be burned galvanically as fuel at the anode of a fuel cell. Similarly, the oxidant can be any fluid that can be reduced at a sufficient rate. Though the direct use of conventional fuels in fuel cells would be desirable, most fuel cells under development today use gaseous hydrogen, or a synthesis gas rich in hydrogen, as a fuel.

Hydrogen has a high reactivity for anode reactions, and can be produced chemically from a wide range of fossil and renewable fuels, as well as via electrolysis. For similar practical reasons, the most common oxidant is gaseous oxygen, which is readily available from air. For space



applications, both hydrogen and oxygen can be stored compactly in cryogenic form, while the reaction product is only water.

1.2.2 Critical Functions of Cell Components

A critical portion of most unit cells is often referred to as the three-phase interface. These mostly microscopic regions, in which the actual electrochemical reactions take place, are found where either electrode meets the electrolyte. For a site or area to be active, it must be exposed to the reactant, be in electrical contact with the electrode, be in ionic contact with the electrolyte, and contain sufficient electro-catalyst for the reaction to proceed at the desired rate. The density of these regions and the nature of these interfaces play a critical role in the electrochemical performance of both liquid and solid electrolyte fuel cells:

- In liquid electrolyte fuel cells, the reactant gases diffuse through a thin electrolyte film that wets portions of the porous electrode and react electrochemically on their respective electrode surface. If the porous electrode contains an excessive amount of electrolyte, the electrode may "flood" and restrict the transport of gaseous species in the electrolyte phase to the reaction sites. The consequence is a reduction in electrochemical performance of the porous electrode. Thus, a delicate balance must be maintained among the electrode, electrolyte, and gaseous phases in the porous electrode structure.
- In solid electrolyte fuel cells, the challenge is to engineer a large number of catalyst sites into the interface that are electrically and ionically connected to the electrode and the electrolyte, respectively, and that is efficiently exposed to the reactant gases. In most successful solid electrolyte fuel cells, a high-performance interface requires the use of an electrode which, in the zone near the catalyst, has mixed conductivity (i.e. it conducts both electrons and ions).

Over the past twenty years, the unit cell performance of at least some of the fuel cell technologies has been dramatically improved. These developments resulted from improvements in the three-phase boundary, reducing the thickness of the electrolyte, and developing improved electrode and electrolyte materials which broaden the temperature range over which the cells can be operated.

In addition to facilitating electrochemical reactions, each of the unit cell components have other critical functions. The electrolyte not only transports dissolved reactants to the electrode, but also conducts ionic charge between the electrodes, and thereby completes the cell electric circuit as illustrated in Figure 1-1. It also provides a physical barrier to prevent the fuel and oxidant gas streams from directly mixing.

The functions of porous electrodes in fuel cells, in addition to providing a surface for electrochemical reactions to take place, are to:

- 1) conduct electrons away from or into the three-phase interface once they are formed (so an electrode must be made of materials that have good electrical conductance) and provide current collection and connection with either other cells or the load
- 2) ensure that reactant gases are equally distributed over the cell
- 3) ensure that reaction products are efficiently led away to the bulk gas phase

As a consequence, the electrodes are typically porous and made of an electrically conductive material. At low temperatures, only a few relatively rare and expensive materials provide sufficient electro-catalytic activity, and so such catalysts are deposited in small quantities at the interface where they are needed. In high-temperature fuel cells, the electro-catalytic activity of the bulk electrode material is often sufficient.

Though a wide range of fuel cell geometries has been considered, most fuel cells under development now are either planar (rectangular or circular) or tubular (either single- or double- ended and cylindrical or flattened).

1.3 Fuel Cell Stacking

For most practical fuel cell applications, unit cells must be combined in a modular fashion into a cell stack to achieve the voltage and power output level required for the application. Generally, the stacking involves connecting multiple unit cells in series via electrically conductive interconnects. Different stacking arrangements have been developed, which are described below.

1.3.1 Planar-Bipolar Stacking

The most common fuel cell stack design is the so-called planar-bipolar arrangement (Figure 1-2 depicts a PAFC). Individual unit cells are electrically connected with interconnects. Because of the configuration of a flat plate cell, the interconnect becomes a separator plate with two functions:

- 1) to provide an electrical series connection between adjacent cells, specifically for flat plate cells, and
- 2) to provide a gas barrier that separates the fuel and oxidant of adjacent cells.

In many planar-bipolar designs, the interconnect also includes channels that distribute the gas flow over the cells. The planar-bipolar design is electrically simple and leads to short electronic current paths (which helps to minimize cell resistance).



Figure 1-2 Expanded View of a Basic Fuel Cell Unit in a Fuel Cell Stack (1)



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