

## PHOSPHORIC ACID FUEL CELLS

**Hiroko Sotouchi and Akifusa Hagiwara**

*Tokyo Electric Power Company, Japan*

**Keywords:** phosphoric acid, hydrogen ion, three-phase contact surfaces, cell lifetime, cogeneration, digestive gas, biologically produced methane, normal-pressure plant, CO converter, heat utilization

### Contents

1. Introduction
  2. Cell Structure
  3. Features of Phosphoric Acid Fuel Cells
  4. Cell Lifetime
  5. Plant Experiences
- Glossary  
Bibliography  
Biographical Sketches

### Summary

A substantial number of natural gas fueled 200 kW PAFC systems are already in operation. Also, numerous examples of plant experience are available. Although PAFCs have evolved to where the performance reliability and other engineering parameters required of practical power plants are to a considerable degree satisfactory, further refinement is required for economic market penetration. In this article, the principle of operation and cell structure of phosphoric acid fuel cells are discussed, as well as the features derived from them.

### 1. Introduction

Fuel cells, which use phosphoric acid solution as the electrolyte, are called phosphoric acid fuel cells (PAFCs). As Eq. 1 indicates, the phosphoric acid in aqueous solution dissociates into phosphate ions and hydrogen ions; the hydrogen ions ( $H^+$ ) act as the charge carrier.



Phosphoric acid is chemically stable, and is easy to handle. It also has an extremely low vapor pressure even at an operating temperature of 200 °C (473 K). This implies that phosphoric acid in the electrolyte layer cannot be easily discharged from the fuel cell together with the cell exhaust gas, although even such minute discharge, results in the degradation of cell performance in the long term.

A conceptual working principle is described in Figure 1. At the fuel electrode, pure hydrogen or reformat fuel gases the principal component being hydrogen is supplied,

and air is supplied at the air electrode; the resulting electrochemical reaction yields an electric power output. At the fuel electrode, hydrogen reacts at the electrode surface to become hydrogen ions and electrons, and the hydrogen ions migrate toward the air electrode within the electrolyte.



At the air electrode, the hydrogen ions, which have migrated from the fuel electrode; electrons, which have passed through the external circuit, and oxygen supplied from outside, combine to produce water in the following reaction:



Hence the net fuel cell reaction produces water as follows:

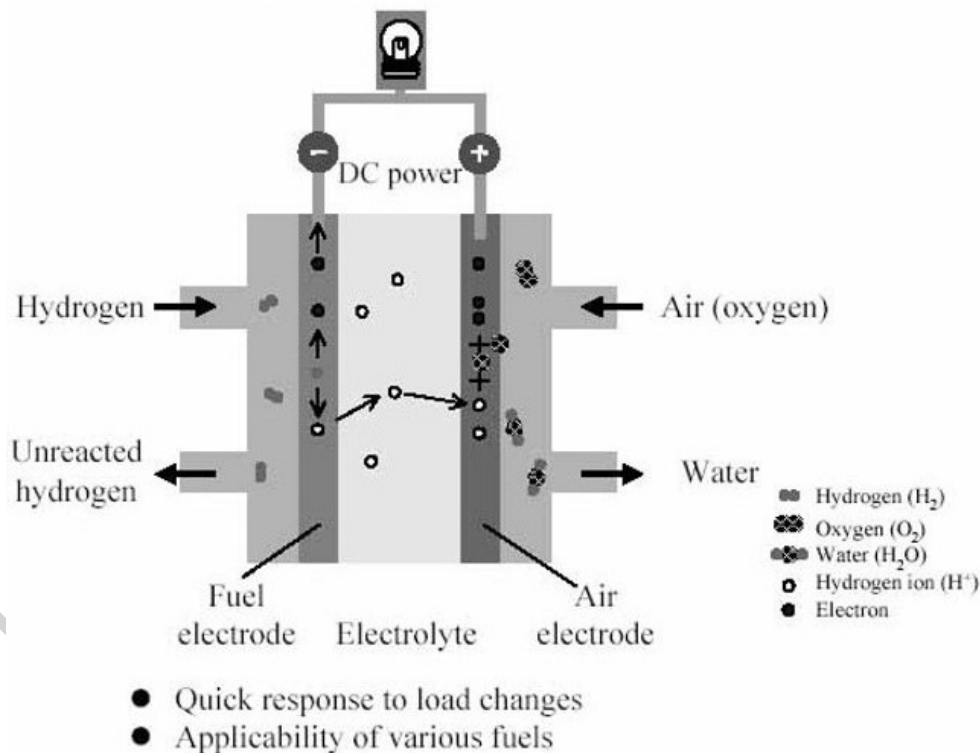


Figure 1. Principle of Operation of Phosphoric Acid Fuel Cells (PAFCs)

## 2. Cell Structure

The PAFC itself consists of a pair of porous electrodes (the fuel electrode and air electrode) formed from mainly carbon material, between which is placed an electrolyte layer consisting of a matrix impregnated with highly concentrated phosphoric acid solution. The catalytic layer of the electrodes where reactions take place consists of the carbon material, minute metal catalyst particles, and water repellent material, in a

construction such that the reaction gas is supplied and the electrolyte retained effectively.

The voltage obtained from a single fuel cell is from 0.6 to 0.8 V or so; in actual power plants several hundred cells are stacked and connected in series, forming a sub unit called a “cell stack.” Heat is generated due to energy losses in the course of the electrochemical reaction of hydrogen with oxygen, and so cooling plates are inserted at regular intervals between fuel cells, and cooling water is passed through them to maintain a cell operating temperature of about 200 °C (473 K).

### **3. Features of Phosphoric Acid Fuel Cells**

The PAFC do not suffer the carbon dioxide-induced electrolyte degeneration seen in alkaline fuel cells, and so can use reformed gas derived from fossil fuels, though expensive platinum catalyst is necessary in order to promote the electrode reactions.

Thus it can make use of city gas (natural gas-based) and other existing fuel infrastructure. However, when CO exists at high concentrations, as in coal-gasified gas, the platinum catalyst used in electrodes is poisoned, leading to performance degradation, so that use of such fuels is impractical without effective means of eliminating CO. This gives an additional constraint.

The operating temperature is about 200 °C (473 K). Consequently if the cell is designed such that it does not make direct contact with the phosphoric acid, copper, iron and other metals can be used. Also, in order to endow the electrode catalyst layer with water-repelling properties, a fluoride resin (PTFE) or other highly heat-resistant organic material may also be used. In order to remove the heat generated by the electrode reactions, the fuel cell is itself water-cooled as mentioned above.

Waste heat at a temperature range below 200 °C is available; which cannot just be used for space heating and water heating, but can also be extracted in part as steam and used as the heat source of refrigeration equipment for cooling. The electric power generation efficiency of PAFCs under atmospheric pressure operation is approximately 40% (LHV basis), which is superior, or at least competitive with existing gas turbine and gas engines. Properties of low Nox and low noise make them suitable for cogeneration systems for urban environmentally friendly power sources.

Unlike the high temperature fuel cell systems such as MCFCs and SOFCs, a combined cycle system with gas turbine or steam turbine generators to maximize the system efficiency is generally difficult for PAFCs, since the quality of plant exhaust heat is inadequate for such purposes.

In pressurized PAFC systems, thought reformer exhaust gas at elevated pressure and temperature can be passed through an expander to drive an air compressor or an electric power generator, the total power generation efficiency stays in a range of 44–46% (LHV basis).

-  
-  
-

TO ACCESS ALL THE 7 PAGES OF THIS CHAPTER,  
Visit: <http://www.eolss.net/Eolss-sampleAllChapter.aspx>

### Bibliography

Hirschenhofer J. H., Stauffer D. B., Engleman R. R. and Klett M. G. (1998). *Fuel Cell Hand Book*, 4th edn., Section 4, DOE/FETC-99/1076. Morgantown, WV, US Department of Energy. [This is a review of most advanced technologies in PAFCs.]

Mori T, Honji A, Kahara T, and Hishinuma Y. (1988). Acid absorbancy of an electrode and its cell performance history. *Journal of The Electrochemical Society*, **135**(5), 1104. [This presents the relation amount of phosphoric acid and cell voltage.]

Yoshioka Y. (1985). *Cell Technologies for High Pressure Type PAFC*. Washington DC, Courtesy Associates, INC, 1985 Fuel Cell Seminar, p. 43. [This report is on the increase in the size of platinum under high voltage.]

### Biographical Sketches

**Akifusa Hagiwara** was born in 1954, and received his master's degree in mechanical engineering from Waseda University, Japan, in 1979. He joined the International Flame Research Foundation in the Netherlands in 1981, and engaged in the research projects in combustion engineering and applied fluid dynamics. Since 1987, he has been employed by the Tokyo Electric Power Company, and involved in the fuel cell R&D activities. Currently, he is acting as Manager and Senior Researcher of Material Science Group in the Energy and Environment R&D Center.

**Hiroko Sotouchi** was born 26 February 1965, in Japan. She received a bachelor's degree from the Department of Applied Chemistry, Keio University.