FUEL CELL SYSTEMS

Akifusa Hagiwara
Energy and Environment R&D Center, The Tokyo Electric Power Co., Yokohama, Japan

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Summary

Fuel cells are devices that utilize electrochemical reactions to generate electric power. They are believed to give a significant impact on the future energy system. In particular, when hydrogen can be generated from renewable energy resources, it is certain that the fuel cell should play a significant role. Even today, some types of fuel cells have been already used in practical applications such as combined heat and power generation applications and space vehicle applications. Though research and development activities are still required, the fuel cell technology is one of the most important technologies that allows us to design the environment-friendly society in the twenty-first century. This section describes the general introduction of fuel cell technology with a brief overview of the principle of fuel cells and their historical background.

1. Introduction

Fuel cells are devices that utilize electrochemical reactions to generate electric power; they are very different from the widely used electric power generation systems today which make use of the mechanical power of heat engines and the principle of electromagnetic induction discovered by Michael Faraday. Because electricity is generated directly from oxidation and reduction of a fuel and oxidizing agent, it is sometimes referred to as “direct” electric power generation. Sir Francis T. Bacon, who is a pioneer in the development of fuel cells in the second half of the twentieth century, noted in 1979 that with the discovery of the principle of electromagnetic induction in 1831, the electrochemical methods for electricity production which had until then been favored, had been replaced by the electromagnetic induction method, and continue to be so to this day. But it is thought that the current advances in fuel cell technology may lead to another paradigm shift in technology for electric power production in future.

2. Fuel Cell Structure and Principle of Operation

A fuel cell consists of two electrodes and an electrolyte layer; the electrolyte is placed between the two electrodes, one an anode and the other a cathode. The fuel is supplied to the anode, at which a reaction to oxidize the fuel takes place. At the same time, an oxidizing agent is supplied to the cathode, and a reaction to reduce the oxidizing agent occurs. When lead wires from the two electrodes are connected to an external load to form a load circuit, charged particles move within the electrolyte, and a current can be drawn from the cell. This principle of fuel cell operation is in fact exactly the same as that of dry batteries and other primary (non-rechargeable) batteries of the kind we all use on a daily basis. However, in a dry battery the reactants are stored within the battery, and its lifetime is reached when these reactants are consumed. In a fuel cell, in contrast, reactants are supplied externally, so that in principle, power can be generated continuously for as long as there is a supply of reactants.

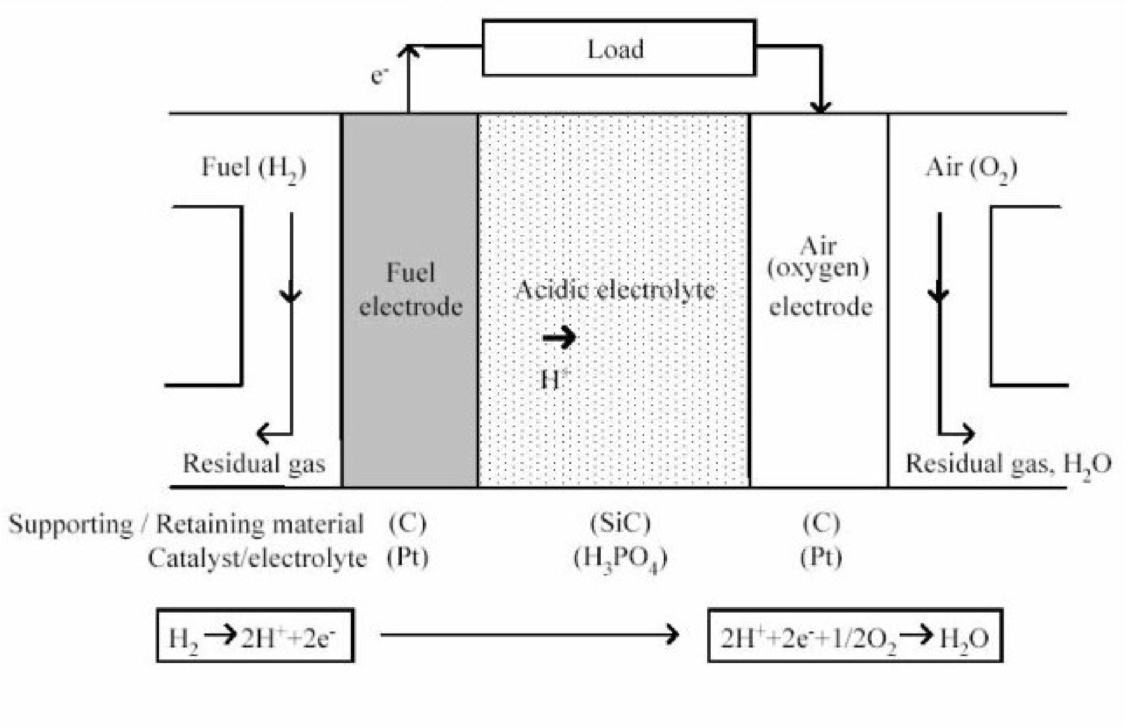

Figure 1. Configuration of fuel cells: acidic electrolyte (PAFCs)

The charge carriers within the electrolyte in fuel cells are either positive or negative ions, with different directions of motion to each other. For example, in fuel cells using acidic electrolytes such as phosphoric acid fuel cells, hydrogen ions (H^+) move from the anode to the cathode side, where reactions with oxygen occur to generate water (see Figure 1). On the other hand, in molten-carbonate fuel cells using an alkaline electrolyte, carbonate ions (CO_3^{2-}) move from cathode to anode, at which they react with hydrogen to produce water (see Figure 2). Hence, the water produced by the electrode reactions is discharged from different electrodes depending on the type of ion, and this affects the design of the power generation system. Also, note that the cell structure and materials used in fuel cells will also differ depending on such other conditions as the operating temperature and pressure and the fuel used.

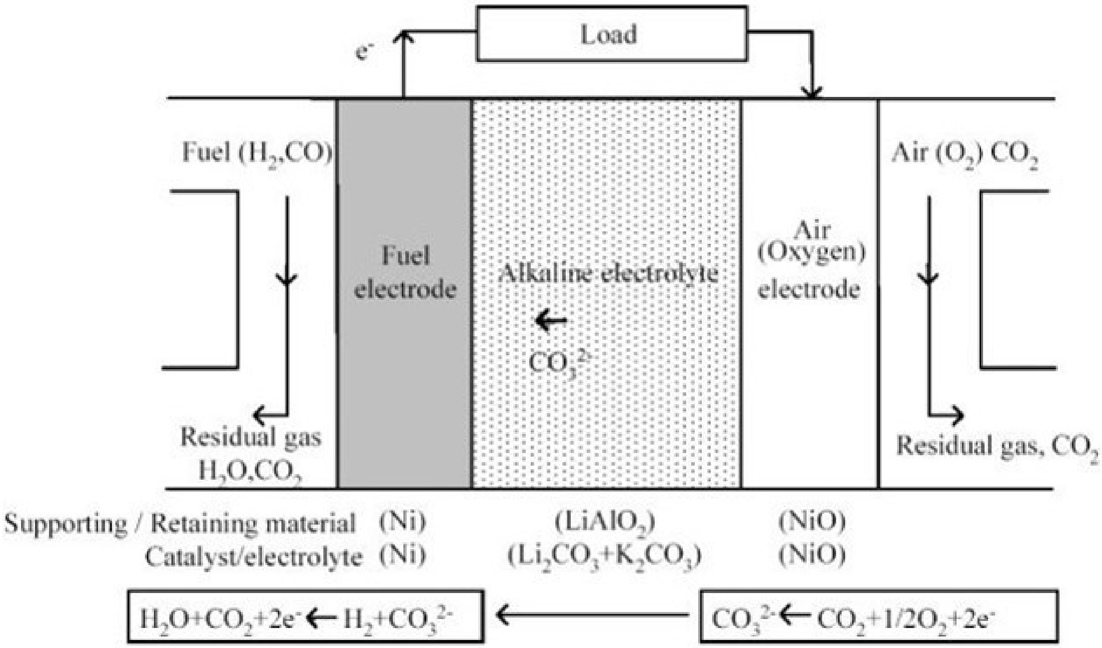

Figure 2. Configuration of fuel cells : alkaline electrolyte (MCFCs)

The phenomenon that occurs in the course of electric power generation in fuel cells is called an electrochemical reaction. Perhaps, a quite familiar example of electrochemical reactions is the electrolysis of water, where hydrogen and oxygen are produced by passing electricity between electrodes immersed in aqueous (or water) solution as electrolyte. Fuel cells are often described as devices that perform the reverse of this electrolysis reaction. That is, by supplying hydrogen to the anode and oxygen to the cathode of a fuel cell, electricity is generated, and water is produced as the reaction product.

In conventional electric-power generation, typically using fossil fuel fired thermal power plants, the chemical energy of fuel is first converted into heat by combustion in a boiler. This generated heat is used to produce pressurized steam, which in turn drives a turbine generator, to convert the fluid dynamic power into mechanical power, eventually producing electricity. In contrast with the conventional steam turbine generators, the electrochemical method of electric power production is thus referred to as "direct" electricity generation, that is not subject to the Carnot cycle efficiency which limits the maximum efficiency of heat engines. This implies that it is thermodynamically possible for fuel cells to extract all of the Gibbs free energy of fuel, converting in actual work (Figure 3). However, it is presumed that fuels will be used that enable electrode reactions under practical conditions. Hydrogen is the one most suitable for many fuel cells. It is important to note that, when using hydrocarbons as a primary fuel for the fuel cell power generation system, the fuel must be converted into hydrogen-enriched fuel gas by means of chemical reactions such as steam reforming reactions.

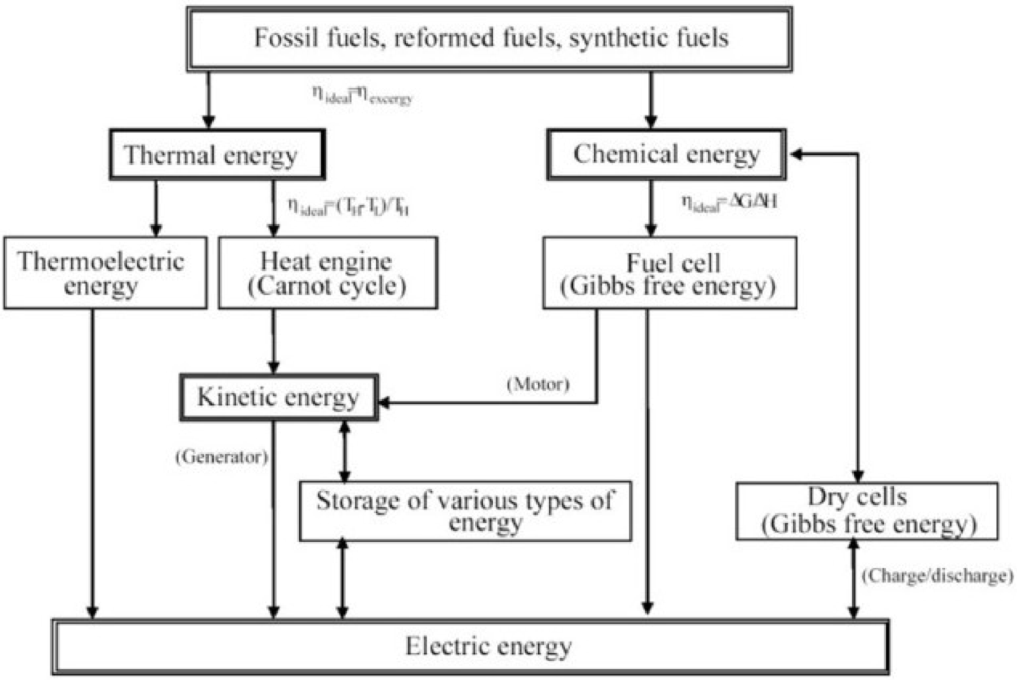

Figure 3. Process of energy conversion

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Bibliography

Abaoud H. A, Ghouse M, Lowell K. V, Al-Motairy G. N. A hybrid technique for fabricating PEMFC's low platinum loading electrode. Int J hydrogen energyy 2005; 30(4): 385-341.

Alkine et al. editors. Advances in electrochemical science and engineering. Vol.5, Weinheim; Germany: Wiley-VCH; 1997.

Andersen J.R, Boudart M. editors. Catalysis science and technology. New York; Springer; 1984.

Appleby A. J. Characteristic of fuel cell systems. In: Blomen L, Mugerwa M. editors. Fuel cell systems, New York; Plenum Press; 1993. 157-99.

Babir F. PEM fuel cells, Theory and practice. Burlington, MA, Academic Press, 2005.

Barbir F, Broun J, Neutaler J. Properties of molded graphite bipolar plates for PEM fuel cell stocks. J new mates eelectrochem systems. 1999; 2: 197-200.

Bar-on I, Kirchain R, Roth R. Technical cost analysis for PEM fuel cells. J power sources 2002; 109: 71-5.

Biyikoglu A. Review of proton exchange membrane fuel cell models. Int J hydrogen energy 2005: 30(11): 1181-1212.

Blomen L.J, Mugeswa M.N. Fuel cell systems. New York; Plenum Press: 1993.

Bockris J'OM, Conway B.E, White R.E, editors, Modern aspects of electrochemistry Vol. 29. New York; Plenum Press, 1995.

Carette L, Friedrick K.A, Stimming U. Fuel cells-fundamentals and applications. fuel cells J 2001; 1: 5-39.

Chalk S. Energy efficiency and renewable energy: FY 2000 progress report for fuel cell power systems, U.S. Department of Energy, 2000.

Hayashi A, Kosugi T, Yoshida H. Evaliation of polymer electrolyte fuel cell application technology R & D by GERT analysis. Int J hydrogen energy 2005; 30(9): 931-941.

Huang Y, Dass R I, Xing Z, Goodenough J B. Science 2006; 312: 254-57.

Larminie J, Dicks A. Fuel cell systems explained. Mew York; Wiley-VCH; 2000.

Li X. Principles of fuel cells. New York; Taylor and Francis; 2005.

Minh N.Q, Takahashi T. Science and technology of ceramic fuel cells. Amsterdam; Elsevier; 1995.

Ota K, Kamiya H. Polymer electrolyte fuel cell. Electrochemical energy conversion 5 in: Sorrell C. C, Sigiura S, Nowworthy J. editors. Materials for energy conversion devices, New York CRC Press; 2005, p.123-239.

Pagain V. A, Ticiane II E.A, Gonzalez E.R. Development and electrochemical studies of gas diffusion electrodes for polymer electrolyte fuel cells. J appl electrochem 1996;26(3): 297-304.

Parsen Inc. Fuel cells: a hand book, business/technology books. Oxford; Elsevier;2000.

Saab A. P, Garzan F. H, Zawodzinski T. A. The effects of processing conditions and chemical composition on electronic and ionic resistivities of fuel cell electrode composites. J electrochem soc 2003; 150: A214-8.

Salgado T. R. C, Antolini E, Gonzalez E. R. Structure and activity of carbon-supported Pt-Co electrocatalysts for oxygen reduction. J. phys. chem. B 2004; 108: 1767-74.

Singhal S.C. Advances in Solid oxide fuel cell technology. Solid state ionics 2000; 135: 305-13.

Springer T. E, Rockward T, Zawodzinski T. A, Gottesfeld S. Model for polymer electrolyte fuel cell operation on reformate feed-effect of CO, H_2 diffusion, and high fuel utilization. J electrochem soc 2001; 146(1):A11-23.

Vielstich W, lamm A. Gasteiger H.A. Hand book of fuel cells fundamentals, technology, and application. Chichester; England: Wiley;2003.

Vogt H.Gas evolving electrodes. In: Comprehensive treatise of electrochemistry, Vol.6. New York; Plenum Press; 1983, 445.

Biographical Sketch

Akifusa Hagiwara was born in 1954; he 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.