The Fuel Cell: Science and Technology

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In this series of tutorial the basic operation and applications of the fuel cells are discussed in the context of the automotive industry. In this issue, however, a brief description of the anatomy of a typical fuel cell and the available choices for key components are given.

The history goes back to 1839 when Sir Willam. R. Grove, a British physicist, developed the principles of the production of electricity through electrochemical union of the oxygen and hydrogen. Francis Bacon generated the first practical cells in 1932. Its first major application occurred in 1965 by NASA as power source in Gemini spacecraft. Its consideration in automotive industry is primarily because of its clean operation, emitting water vapor.

The basic design of a typical fuel cell consists of two electrodes, anode (-) and cathode (+), and a electrolyte as shown in Fig. 1. Fuel cell directly converts chemical energy into electricity. As opposed to conventional batteries, where electrodes themselves are consumed, fuel cells use hydrogen and oxygen gases to produce electricity. Hydrogen atoms release electron which transport through the wire connecting the two electrodes. Then these electron-removed hydrogen atoms (called ions, and in this case, protons) attempt to diffuse through the electrolyte to reach the cathode side joining the oxygen atoms and the electrons arriving through the wire to produce water. To speed up this process, a thin layer of platinum catalyst is used on both sides as shown in Fig. 1. Output of a single cell is typically 0.6 to 0.8 Volt, and when many (200 to 300) of these are stacked, there is sufficient energy to, for example, power a 50kW (or 67hp) 3-phase synchronous motor. Energy conversion efficiency of 45 to 60% has been demonstrated. Note that current internal combustion (IC) engines efficiency may rich to about 35%. Hence, potential for simultaneous achievement of zero emission and high efficiency exists. Efficiency losses in fuel cells stem mainly from the electrical resistance of the electrolyte and spatial nonuniformity of its concentration. Measures to reduce these losses include application of strongly acidic or alkaline electrolytes. Some key characteristics of four major types of electrolytes are given below.

Alkaline electrolyte:

- Must be supplied with clean hydrogen (no CO_2). Otherwise, CO_2 reacts with the electrolyte and produces solid carbon.
- Much less platinum is required than the acidic ones.

Acidic electrolyte:

- Insensitive to presence of CO_2.
- Because typically they require water to conduct H^+ (i.e. proton), cells must be operated below the boiling point of water.
- Exception to the above is the concentrated phosphoric acid type which can function as high as 200° C (or 390° F). However, they do need a warm-up period of hours. Conversion efficiencies of about 45%.

Synthetic polymers as electrolyte:

- Such as DuPont’s Nafian contains sulfuric acid compound that allows easy diffusion of protons.
- It is shaped as a membrane in between the electrodes. Cells of this design is referred to as proton exchange membrane (PEM) fuel cells. A membrane-electrode assembly cell can be as small as 2.5 millimeter (or 0.1 inch).
- They run at about 80° C (or 176° F).
- Expensive as it requires platinum catalyst.
- Energy densities of about 1.0 kW/kg (or 0.6 hp/lb).

Solid oxides:

- It uses hard ceramic material. For example, zirconium oxide stabilized with yttrium oxide. In one design, 40-micron thick layer of this electrolyte is deposited on a lanthanum manganite (air-side) electrode surrounded by the nickel embedded in yettria-stabilized zirconia (fuel-side) electrode. Both electrode materials must be good electrical conductors and porous to allow flow of air and fuel through them to reach on either side of the electrolyte.

- Negatively-charged oxygen ions migrate from the cathode side towards the anode to form water with hydrogen.
- Operating temperature of about 980° C (or 1800° F).
- Conversion efficiency approaching impressive 60%.
- Energy densities of about 10 kW/kg (or 6 hp/lb).

To improve the performance, fuel cells are operated at elevated pressure to increase the diffusion rate of hydrogen and oxygen and also facilitate outflow of water which otherwise tended to clog the cathode gas channels. Also, un-pressurized operation using permeable-graphite-containing microscopic pores were used to control water movement.

This completes a concise description of the anatomy and the basic operation of fuel cells. Applications of this technology is described in the next issue of the Powertrain International.

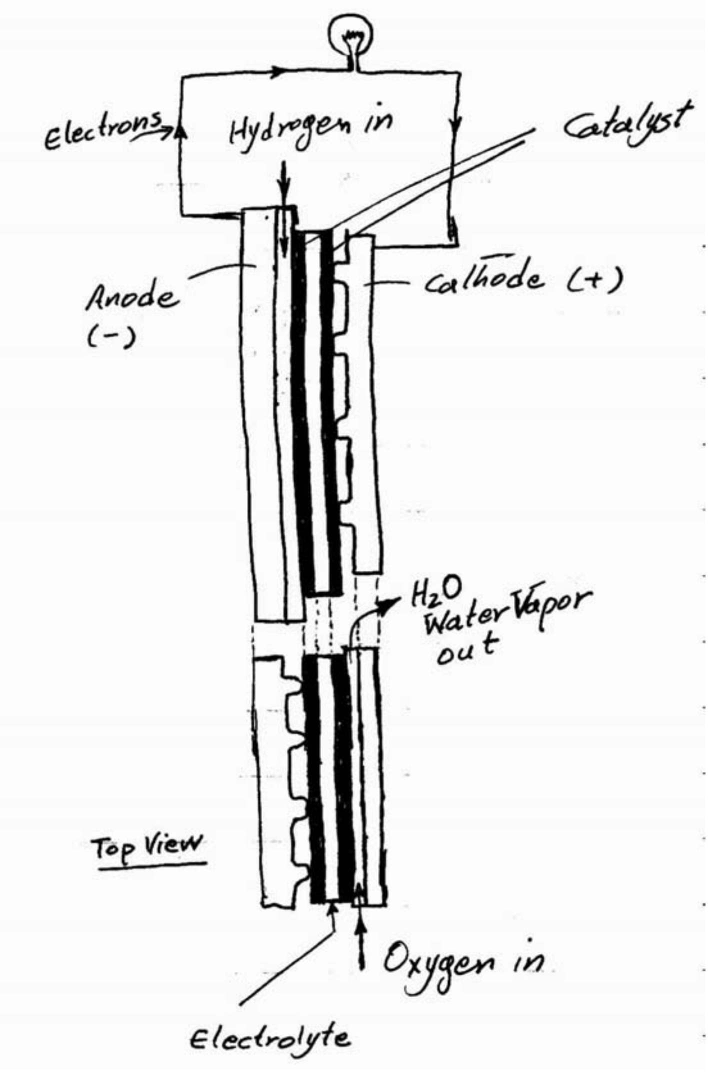

Figure 1. Anatomy of a typical fuel cell. Catalyst size is exaggerated, it is a thin layer of platinum bonded to either side of the electrolyte (PEM- type). Platinum-coated carbon electrodes are often used. Hydrogen and oxygen are fed to the electrodes on either side of the PEM through channels formed in their flow field plates.