Fuel Cell

A fuel cell is a device that produces electrical energy directly from the chemical energy released when a hydrogen-containing fuel is oxidized. Fuel cells resemble electrochemical power cells in many respects; the main difference is that fuel cells are designed to use a continuous supply of fuel, whereas a cell contains a fixed amount of fuel that is consumed as the cell provides energy. A functioning fuel cell produces pure water, which is a useful by-product in isolated vehicles such as spacecraft and submarines.

A fuel cell can produce around 15 times as much power as a lead–acid automobile battery of the same weight, which is useful where space is limited. Fuels cells are also extremely robust and require little maintenance, making them good power sources for remote locations.

Principles and early models

The inventor of the fuel cell is generally held to be the British physicist William Grove, whose gas battery of 1838 used a reaction that is the basis of modern fuel cells. Grove's device comprised two platinum electrodes dipped in sulfuric acid. Hydrogen bubbles played over one of the electrodes, while oxygen bubbled over the other.

Platinum catalyzes the dissociation of hydrogen molecules (H_2) into hydrogen ions according to the following equation:

$$H_2 \rightarrow 2H^+ + 2e^-$$

The electrons released by this reaction passed into the platinum electrode of Grove's cell. When he connected the two electrodes through an electrical circuit, a current flowed and the electrons that passed into the other electrode took part in the dissociation of oxygen:

$$O_2 + 4e^- \rightarrow 2O^{2-}$$

Oxide and hydrogen ions combine immediately, so the overall reaction was an oxidation of hydrogen to form water. Most of the heat energy that would have been released by burning hydrogen was instead converted into electrical energy.

Early drawbacks

Grove's gas battery had three major failings that prevented it from being a commercially viable power source. First, the cell's output was limited by the small contact areas between gases, electrolyte, and electrodes. Second, by-product water gradually diluted the electrolyte, reducing its effectiveness and eventually halting the reaction. The third failing was the high cost of platinum.

Developments

Modern fuel cells, developed since the 1950s, resolve the problems of Grove's device in various ingenious ways. First, their electrodes are porous membranes that separate the electrolyte from the fuel gas and oxygen while providing a large surface area per unit volume, which facilitates the inter-actions between the gases and the electrolyte. Second, by-product water is removed by evaporation from a hot electrolyte or by simple drainage from the fuel-gas side of the electrode where it forms. Finally, many fuel cells use relatively cheap electrode materials, such as carbon or nickel.

Several limitations remain, however. The electrodes and electrolyte of a fuel cell may eventually decompose. This process is much slower than the breakdown of the equivalent components of conventional power cells, in which the electrolyte and sometimes the electrodes are consumed by the energy-providing reaction.

The pressures of the fuel gas and the oxidant (air or oxygen) are critical to the efficiency and power output of a cell. Too little pressure allows the electrolyte to escape through the porous electrodes; too much pressure forces the electrolyte from the electrodes' pores, reducing the vital area of contact between gas, electrolyte, and electrodes.

One type of fuel cell uses solutions of alkali-metal hydroxides, such as potassium hydroxide (KOH), as electrolytes. The hydroxide ion acts as a carrier of oxide ions in these cells, and the electrode reactions are as follows:

$$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$$
$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Variations of this type of cell use hot, molten metal carbonates, in which the carbonate ion (CO_3^{2-}) is the oxide-ion carrier, or even solid modified zirconium dioxide (ZrO_2), which conducts oxide ions through its lattice at operating temperatures of around 1800°F (1000°C).

Other types of fuel cells use acidic electro-lytes, such as phosphoric acid or sulfuric acid. The electrode reactions in such fuel cells are identical to those of the Grove gas battery.

Alternative fuels

Hydrogen is not the only fuel that can be used in fuel cells, although most fuels are compounds

of hydrogen. Alternatives include methane (CH_4) and methanol (CH_3OH), which are oxidized to form carbon dioxide and water, and hydrazine (NH_2NH_2), which forms water and nitrogen. Fuel cells that use molten carbonate electrolytes can even use carbon monoxide as fuel, converting it into carbon dioxide and producing no water.

Fuel cells that can use the complex mixtures of hydrocarbons found in gasoline are in development, as are reformers—devices that produce hydrogen from gasoline. Such systems will improve the acceptability of fuel cells as power sources for electric road vehicles, since they will allow such vehicles to use the extensive infrastructure of gas stations that already exists.

Operating efficiency and costs

The electrochemical reaction in a fuel cell releases around 95 percent of the chemical energy theoretically available from a fuel, the remaining energy being lost to the internal resistance of the cell. Some of the power output is diverted to heaters and pumps that keep the fuel cell operating, and the typical efficiency is around 60 to 65 percent once these demands have been met.

Fuel cells are considerably more efficient than conventional fossil-fuel power plants. A large coal-fired power plant can convert around 35 percent of the thermal energy of burning coal into electrical energy, while a natural-gas-burning power plant converts up to 45 percent of the total thermal energy into electricity. Nevertheless, the relatively high costs of the fuels and components used in fuel cells make them uncompetitive for power outputs greater than around 100 megawatts.

Applications

One of the earliest applications of fuel cells was in the *Gemini 5* spacecraft, which undertook a nine-day flight in 1965. The advantages of the fuel cell for space flights include their lack of harmful emissions and their by-product—water—which astronauts can drink and use for washing. Fuel cells were also used in the Apollo missions, when efficiencies around 75 percent were attained, and they continue to be used in NASA's space shuttles.

The complete lack of harmful emissions also makes fuel cells attractive for use with electric motors in vehicles. One such fuel cell, General Motors' HydroGen 1, produces 80 kilowatts of power at 53 to 67 percent efficiency. The power output and compactness of the HydroGen 1 are sufficient for it to be used to power the motor of an electric automobile. On a larger scale, the first of 25 prototype fuel-cell powered electric buses went into service for the SunLine Transit Agency of Palm Springs, California, in September 2000.

Many of the current projects related to expanding the exploitation of fuel cells focus on making hydrogen cheaper and more readily available. One such scheme uses concentrated sunlight to convert water into hydrogen and oxygen by thermal decomposition. This system has the advantage over conventional solar power that the hydrogen and oxygen can be stored and used in fuel cells to provide power according to demand. Another project aims to develop a domestic electrolysis cell for producing hydrogen for fuel-cell vehicles from electricity and water.

See also: BATTERY; CATALYST; LOW-EMISSION ROAD VEHICLE.

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