

BASICS OF HYDROGEN FUEL CELL

Kaushal Kishor Singh¹, Ph. D. & Yogendra Kumar Saraswat², Ph. D.

¹Department of Chemistry; S V College Aligarh, U.P.

E-mail: kksinghsvc@gmail.com

²Department of Chemistry; S V College Aligarh, U.P.

Abstract

A hydrogen fuel cell uses the chemical energy of hydrogen to produce electricity. It is a clean form of energy with electricity, heat and water being the only products and by-products. Fuel cells offer a variety of applications, from transportation to emergency back-up power, and can power systems as large as a power plant or as small as a laptop. Fuel cells provide advantages over traditional combustion-based technologies, including greater efficiencies and lower emissions. Since hydrogen fuel cells only emit water, there are no carbon dioxide emissions or other pollutants released into the atmosphere. Fuel cells are also quiet during operation as they have fewer moving parts than combustion technologies. A hydrogen fuel cell uses the chemical energy of hydrogen to produce electricity. It is a clean form of energy with electricity, heat and water being the only products and by-products. Fuel cells offer a variety of applications, from transportation to emergency back-up power, and can power systems as large as a power plant or as small as a laptop. Fuel cells provide advantages over traditional combustion-based technologies, including greater efficiencies and lower emissions. Since hydrogen fuel cells only emit water, there are no carbon dioxide emissions or other pollutants released into the atmosphere. Fuel cells are also quiet during operation as they have fewer moving parts than combustion technologies.



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Working of Hydrogen Fuel Cell

Hydrogen fuel cells generate electricity using a chemical reaction. Each fuel cell has two electrodes; a negative anode and a positive cathode. The reaction to produce the electricity happens at these electrodes, with an electrolyte carrying electrically charged particles between them and a catalyst to speed up the reactions. Hydrogen acts as the basic fuel in a hydrogen fuel cell, but the cell also needs oxygen to work. One of the largest advantages of these fuel cells is that they generate electricity with very little pollution, as the hydrogen and oxygen used to generate the electricity combines to produce water as a by-product. Cells that use pure hydrogen as fuel are completely carbon-free. Other types of fuel cell system include those that use hydrocarbon fuels like natural gas, biogas, or methanol. Because fuel cells use

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an electrochemical reaction rather than combustion, they can achieve higher efficiencies than with traditional energy production methods. This can be improved further by with combined heat and power generators that use waste heat from the cell for heating or cooling applications.

The process by which a fuel cell works can be summarized as follows:

1. Hydrogen atoms enter at the anode, while oxygen is fed to the cathode
2. The hydrogen atoms are separated into protons and electrons at the anode
3. The now positively charged protons pass through the membrane (or electrolyte) to the cathode, with the negatively charged electrons take a different route as they are forced through a circuit to generate electricity
4. After passing through the circuit and the membrane accordingly, the electrons and protons meet at the cathode where they combine with oxygen to produce heat and water as by-products.

Single fuel cells do not generate a large amount of electricity, so they are arranged into stacks to create enough power for their intended purpose, whether that is powering a small digital device or a power plant. Fuel cells work like batteries but, unlike batteries, they will not run down or need recharging and can continue to produce electricity while the fuel source (in this case, hydrogen) is supplied. Being comprised of an anode, cathode and an electrolyte membrane, there are no moving parts in a fuel cell, making them silent in operation and highly reliable.

Polymer electrolyte membrane (PEM) fuel cells are the current focus of research for fuel cell vehicle applications. PEM fuel cells are made from several layers of different materials. The main parts of a PEM fuel cell are described below.

The heart of a PEM fuel cell is the **membrane electrode assembly (MEA)**, which includes the **membrane**, the **catalyst layers**, and **gas diffusion layers (GDLs)**.

Hardware components used to incorporate an MEA into a fuel cell include **gaskets**, which provide a seal around the MEA to prevent leakage of gases, and **bipolar plates**, which are used to assemble individual PEM fuel cells into a fuel cell stack and provide channels for the gaseous fuel and air.

The design of fuel cell systems is complex and can vary significantly depending upon fuel cell type and application. However, several basic components are found in many fuel cell systems:

Fuel cell stack, Fuel processor, Power conditioners, Air compressors, Humidifiers.

Fuel Cell Stack

The fuel cell stack is the heart of a fuel cell power system. It generates electricity in the form of direct current (DC) from electrochemical reactions that take place in the fuel cell. A single fuel cell produces less than 1 V, which is insufficient for most applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure of the gases supplied to the cell. Learn more about the parts of a fuel cell.

Fuel Processor

The fuel processor converts fuel into a form usable by the fuel cell. Depending on the fuel and type of fuel cell, the fuel processor can be a simple sorbent bed to remove impurities, or a combination of multiple reactors and sorbents.

If the system is powered by a hydrogen-rich, conventional fuel, such as methanol, gasoline, diesel, or gasified coal, a reformer is typically used to convert hydrocarbons into a gas mixture of hydrogen and carbon compounds called "reformat." In many cases, the reformat is then sent to a set of reactors to convert carbon monoxide to carbon dioxide and remove any trace amounts of carbon monoxide remaining and a sorbent bed to remove other impurities, such as sulfur compounds, before it is sent to the fuel cell stack. This process prevents impurities in the gas from binding with the fuel cell catalysts. This binding process is also called "poisoning" because it reduces the efficiency and life expectancy of the fuel cell.

Some fuel cells, such as **molten carbonate** and **solid oxide fuel cells**, operate at temperatures high enough that the fuel can be reformed in the fuel cell itself. This process is called internal reforming. Fuel cells that use internal reforming still need traps to remove impurities from the unreformed fuel before it reaches the fuel cell. Both internal and external reforming release carbon dioxide, but due to the fuel cells' high efficiency, less carbon dioxide is emitted than by internal-combustion engines, such as those used in gasoline-powered vehicles.

Power Conditioners

Power conditioning includes controlling current (amperes), voltage, frequency, and other characteristics of the electrical current to meet the needs of the application. Fuel cells produce electricity in the form of direct current (DC). In a DC circuit, electrons flow in only one direction. The electricity in your home and workplace is in the form of alternating current (AC), which flows in both directions on alternating cycles. If the fuel cell is used to power equipment that uses AC, the direct current will have to be converted to alternating current.

Both AC and DC power must be conditioned. Current inverters and conditioners adapt the electrical current from the fuel cell to suit the electrical needs of the application, whether it is a simple electrical motor or a complex utility power grid. Conversion and conditioning reduce system efficiency only slightly, around 2%–6%.

Air Compressors

Fuel cell performance improves as the pressure of the reactant gases increases; therefore many fuel cell systems include an air compressor, which raises the pressure of the inlet air to 2–4 times the ambient atmospheric pressure. For transportation applications, air compressors should have an efficiency of at least 75%. In some cases, an expander is also included to recover power from the high pressure exhaust gases. Expander efficiency should be at least 80%.

Humidifiers

The polymer electrolyte membrane at the heart of a PEM fuel cell does not work well when dry, so many fuel cell systems include a humidifier for the inlet air. Humidifiers usually consist of a thin membrane, which may be made of the same material as the PEM. By flowing dry inlet air on one side of the humidifier and wet exhaust air on the other side, the water produced by the fuel cell may be recycled to keep the PEM well hydrated.

Fuel cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of electro-chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. Learn more about the following types of fuel cells.

POLYMER ELECTROLYTE MEMBRANE FUEL CELLS

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks or reformers.

PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide poisoning, making it necessary to employ an additional reactor to reduce carbon monoxide in the fuel gas if the hydrogen is derived from a hydrocarbon fuel. This reactor also adds cost.

PEM fuel cells are used primarily for transportation applications and some stationary applications. PEM fuel cells are particularly suitable for use in vehicle applications, such as cars, buses, and heavy-duty trucks.

DIRECT METHANOL FUEL CELLS

Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is usually mixed with water and fed directly to the fuel cell anode.

Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cell systems because methanol has a higher energy density than hydrogen—though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using our current infrastructure because it is a liquid, like gasoline. DMFCs are often used to provide power for portable fuel cell applications such as cell phones or laptop computers.

ALKALINE FUEL CELLS

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as

the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide (CO₂). In fact, even the small amount of CO₂ in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating mode, which allows for electrolyte regeneration to help reduce the effects of carbonate formation in the electrolyte, but the recirculating mode introduces issues with shunt currents. The liquid electrolyte systems also suffer from additional concerns including wettability, increased corrosion, and difficulties handling differential pressures. Alkaline membrane fuel cells (AMFCs) address these concerns and have lower susceptibility to CO₂ poisoning than liquid-electrolyte AFCs do. However, CO₂ still affects performance, and performance and durability of the AMFCs still lag that of PEMFCs. AMFCs are being considered for applications in the W to kW scale. Challenges for AMFCs include tolerance to carbon dioxide, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electrocatalysis.

PHOSPHORIC ACID FUEL CELLS

Phosphoric acid fuel cells (PAFCs) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The electro-chemical reactions that take place in the cell are shown in the diagram to the right. The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses. PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide because carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. PAFCs are more than 85% efficient when used for the co-generation of electricity and heat but they are less efficient at generating electricity alone (37%–42%). PAFC efficiency is only slightly more than that of combustion-

based power plants, which typically operate at around 33% efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. They require much higher loadings of expensive platinum catalyst than other types of fuel cells do, which raises the cost.

MOLTEN CARBONATE FUEL CELLS

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Because they operate at high temperatures of 650°C (roughly 1,200°F), non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells. Molten carbonate fuel cells, when coupled with a turbine, can reach efficiencies approaching 65%, considerably higher than the 37%–42% efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be over 85%.

Unlike alkaline, phosphoric acid, and PEM fuel cells, MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost. The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that double cell life from the current 40,000 hours (~5 years) without decreasing performance.

SOLID OXIDE FUEL CELLS

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. SOFCs are around 60% efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 85%. SOFCs operate at very high temperatures—as high as 1,000°C (1,830°F). High-temperature operation removes the need for precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and

reduces the cost associated with adding a reformer to the system. SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types can. In addition, they are not poisoned by carbon monoxide, which can even be used as fuel. This property allows SOFCs to use natural gas, biogas, and gases made from coal. High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 700°C that have fewer durability problems and cost less. Lower-temperature SOFCs have not yet matched the performance of the higher temperature systems, however, and stack materials that will function in this lower temperature range are still under development.

REVERSIBLE FUEL CELLS

Reversible fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, reversible fuel cell systems can also use electricity from solar power, wind power, or other sources to split water into oxygen and hydrogen fuel through a process called **electrolysis**. Reversible fuel cells can provide power when needed, but during times of high power production from other technologies (such as when high winds lead to an excess of available wind power), reversible fuel cells can store the excess energy in the form of hydrogen. This energy storage capability could be a key enabler for intermittent renewable energy technologies.

Conclusion : Hydrogen fuel cells have been used for many decades for a wide range of applications, from small electronic devices to vehicles. Hydrogen is the cleanest available energy and is not as hazardous as you may think. Hydrogen fuel cells are already widely used for vehicles such as forklifts, but there is a need for improved infrastructure before they can really challenge for a place as the primary method of fuelling our transport needs. However, with many very real benefits, hydrogen fuel cells look set to be part of the power generation future in some form.

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