Research into fuel cell technology holds out the promise of clean and abundant energy in the future.

THE search for alternative fuels for a sustainable economy and conservation of the environment has brought fuel cell technology to the forefront. A fuel cell creates electric energy by converting a fuel into a negative charge on one terminal and a positive charge on the other terminal. It converts chemical energy of a fuel into electrical energy without the internal combustion steps of a heat engine.

Such conversions are possible because the combustion reactions are also redox reactions in nature. That is why a fuel cell uses lightweight but active oxidants and reductants as its fuel. It creates electric energy from a fuel (input on anode side) and an oxidant (input on cathode side) in the presence of an electrolyte. While the electrolyte remains permanently inside the cell, the reactants flow in and byproducts flow out.

When a load is connected across a fuel cell the current flows. When it powers a load like car, bus, autorickshaw etc. the fuel is slowly consumed. It works continuously as long as the oxidizing and reducing agents are supplied at the electrodes.

A fuel cell does not come under the category of either primary or secondary cell. It differs from a secondary cell in that it cannot be charged in the conventional manner. It is also different from a primary cell in that it consumes reactants that must be replenished continuously and not prepacked.

The materials used in fuel cells differ by type because many combinations of fuel and oxidants are possible. The most commonly used fuel cell is the hydrogen cell that uses hydrogen as fuel and oxygen as oxidants. However, a fuel cell does not create any pollution and so can play a leading role in meeting the national goals of clean air, climate protection and energy security.

History of Fuel Cells

The principle of the fuel cell was discovered by German scientist Christian Friedrich Schonbein in 1838. He found that a phenomenon opposite to electrolysis of water could create electric energy.

The first fuel cell based on this principle was built in 1845 by Welsh scientist Sir William Grove. He discovered that immersing the ends of two platinum electrodes in sulphuric acid and each of

FEATURE ARTICLE

FUEL CELLS: HOPE FOR FUTURE ENERGY

M. GOSWAMI & S. SAHOO

Fuel cells were also extensively used on Apollo missions and on current space shuttle programmes fuel cells continue to be the main power supply unit.

the other two ends in separate sealed containers of oxygen and hydrogen would cause a constant current to flow. By combining several such cells in series circuit he created a battery, which he named gas battery.

Later, several scientists worked on different combinations of reactants, electrolytes, electrodes and catalysts. However, fuel cells garnered serious interest in the 1960s when NASA chose fuel cells over risky nuclear and bulky and expensive solar energy. The fuel cell was soon proved to be a compatible and reliable energy source to all manner of electrical devices. Today, it continues to be the sole supplier of fuel to space shuttle programmes of NASA.

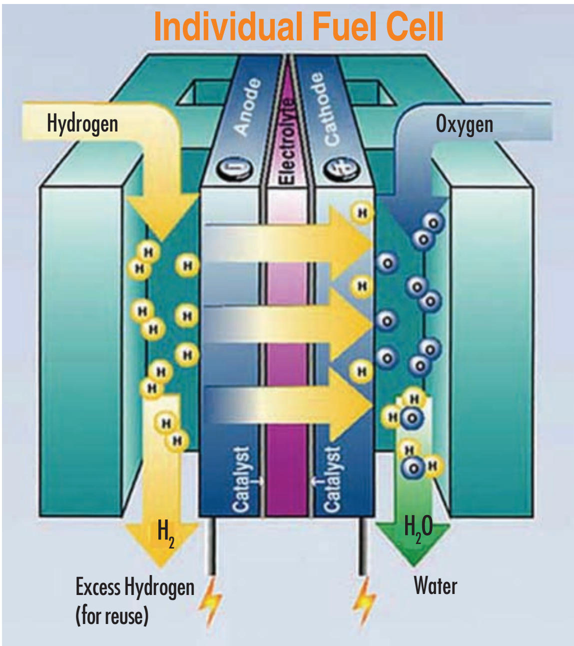
Fuel Cell System

The hydrogen-oxygen (H_2–O_2) fuel cell has been by far the most successful research in this field. It works on the principle of catalysis, separating the electrons and protons of the reactant fuel at one electrode, and forcing the electrons to travel through a circuit, converting them to electric power. Another catalytic process takes the electrons back to another electrode, combining them with the protons and oxidants to form waste products.

Broadly, the H_2–O_2 fuel cell is made from the following components: (i) the electrodes (ii) the electrolyte, and (iii) the catalysts.

(i) Electrodes: The bipolar plates or electrodes are usually made of carbon nanotubes. The negative post of the cell, the anode, conducts electrons freed from the hydrogen molecule that are used in the external circuit to maintain current. Normally hydrogen atoms do not dissociate into protons and electrons. But in a fuel cell, hydrogen atoms enter at the anode where a chemical reaction strips them of their electron. This reaction takes place in the presence of a catalyst. The energy for this dissociation comes from the thermal energy of the surrounding air. The positive post of the fuel cell, the cathode, conducts electrons back from the external circuit to the catalyst, where they are

A fuel cell system running on hydrogen can be compact and lightweight and has no major moving parts.



recombined with hydrogen ions (protons) and oxygen to form water.

(ii) Electrolytes: The H_2–O_2 fuel cell uses concentrated aqueous solution of alkalis like KOH or NaOH. This is called Alkaline Fuel Cell (AFC). This alkaline electrolyte is a specially treated material that conducts positively charged ions (protons) exclusively and blocks electrons. A fuel cell using such an electrolyte is termed a Proton Exchange Membrane Fuel Cell (PEMFC).

(iii) Catalysts: To accelerate electrode reactions, suitable catalysts are added to the porous carbon electrodes. The reaction between hydrogen and oxygen at the operating temperature (400K) of the cell is not very fast. Hence, the presence of catalyst accelerates various chemical reactions involving hydrogen and oxygen at the electrodes. The catalyst, often made from fine platinum or palladium powder or nano iron powder coated on to carbon paper or cloth, is used at the anode to induce the hydrogen atom to freely dissociate into protons and electrons.

Materials used in the fuel cell differ by type. The bipolar plates or electrodes are made of metals, like nickel or carbon nanotubes and are coated with catalysts like palladium, nanoiron powders or palladium for higher efficiencies. A carbon paper separates them from the electrolyte.

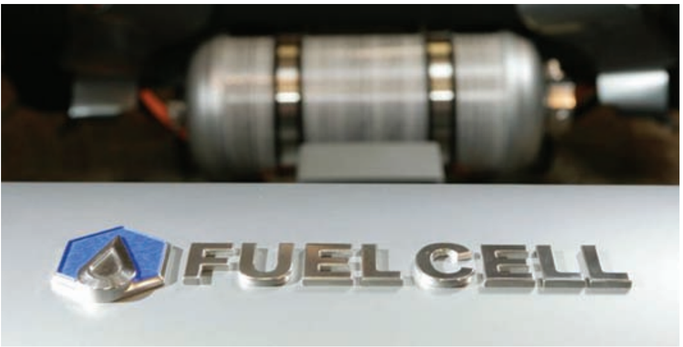
Fuel cell developers are often constrained by the choice of electrolyte. The design of electrodes and the materials used to make them depends on the electrolyte. The main electrolyte types used these days are alkali, molten carbonate, phosphoric acid, proton exchange membrane and solid oxide. In H_2–O_2 fuel cell a proton conducting polymer membrane is used as electrolyte.

Depending upon the electrolytes, hydrogen–oxygen fuel cells can be classified as: (a) aqueous, (b) non-aqueous, and (c) hybrid.

Aqueous cells are metal or carbon electrodes and operate at low temperatures, incorporating electrocatalysts. In such cells very strong acids or alkaline electrolytes are used. The non-aqueous cells are invariably fused salt or solid electrolyte system. The ion/proton exchange membrane serves dual purposes. The solid polymer membrane takes the role of the electrolyte and the cell works at low temperature like aqueous system. So, it is of hybrid type.

The type of fuel also depends on the electrolyte. Some cells need pure hydrogen and therefore demand extra equipment such as a reformer to purify the fuel. Other cells can tolerate some impurities, but might need higher temperature to run efficiently. In addition to pure hydrogen type, there are hydrocarbon fuels for fuel cells including diesel, methane, ethane, methanol and chemical hydrides. The waste products of these types of fuel cells are carbon dioxide and water.

Larger fuel cells use fuel exchanger, a device that converts any hydrocarbon fuel into hydrogen and other components. In fuel cells using pure hydrogen and oxygen, water is the only waste product. The theoretical efficiency of the hydrogen–oxygen fuel cell is 83%. But the actual efficiency of the fuel cell is 60 to 70 %. It is still regarded better in terms of efficiency of thermal power plants (40%).



Fuel Cell Design Issues

There are several issues related to design of fuel cells that need to be taken care and managed effectively.

(i) Temperature management: In H_2–O_2 fuel cell temperature management is particularly challenging as $2H_2 + O_2 = 2H_2O$ reaction is highly exothermic, so a large quantity of heat is generated within the fuel cell. In order to prevent damage to the cell due to thermal loading the same temperature must be maintained throughout the fuel cell.

(ii) Water and air management: In proton exchange membrane fuel cell, the membrane must be hydrated, requiring water to be evaporated at precisely the same rate that it is produced. If the water is evaporated too quickly, the membrane dries, resistance across it increases and eventually it will crack, creating a gas short circuit, where hydrogen and oxygen combine directly, generating heat that will damage fuel cell. On the otherhand if water evaporates too slowly, the electrodes will flood, preventing the reactants from reaching the catalyst and stopping the reaction. The management of water in cells is being developed like electroosmotic pumps (osmosis in presence of electric field) focusing on the flow control. Like a combustion engine, a steady ratio between the reactants and oxygen (air) is necessary to keep the fuel cell operating properly.

(iii) Activation loss management: In fuel cell, voltage decreases as current increases due to several activation factors. Due to resistance of the cell components and interconnects ohmic loss occurs and voltage drops. Hence, résistance of the

Golf Cart

Bicycle

Car

fuel cell components needs to be maintained for a steady voltage. Moreover, the depletion of reactants at catalyst sites under high load causes rapid loss of voltage. This is called mass transport loss.

Benefits & Drawbacks

Fuel cells are the only technology that can provide pollution free energy for both transportation and electric utilities. Fuel cells are reliable, easy to maintain and safe. They can be fabricated in a wide range of sizes without sacrificing either efficiency or environmental performance. This flexibility allows fuel cells to generate power in efficient manner for automobiles, utilities and buildings.

Fuel cells are used as power sources in remote locations, such as spacecraft, remote weather stations, large parks, rural locations and in certain military applications. A fuel cell system running on hydrogen can be compact and lightweight and has no major moving parts.

Since fuel cells have no moving parts and do not involve combustion, they are safe for space programmes. The alkaline fuel cell was first used by NASA and McDonnell Aircraft during project Gemini mission. Fuel cells were also extensively used on Apollo missions and on current space shuttle programmes fuel cells continue to be the main power supply unit.

Now-a-days fuel cell is also used for back-up power in hospitals and factories, and increasingly for city and university buses, and airports. Proton Exchange Membrane Fuel Cells (PEMFCs) are used for transportation, demonstrations and small-power applications. PEMFCs are also used to power a car, bus or an autorickshaw.

However, there are certain drawbacks as well. For instance, a single fuel cell only produces approximately 0.7 volts. In order to produce large quantities of electricity, we require many cells. When combined in series it yields higher voltage and when combined in parallel it allows a stronger current to be drawn – such a design is called a "fuel cell stack". Besides, it is difficult to use hydrogen as fuel due to difficulties of storage and distribution.

New Developments

The technological development of fuel cell has been oriented to address two major difficult areas related to fuel cell. They are (i) High cost of fuel cell due to use of expensive material like platinum as catalyst, and (ii) Hydrogen economy.

Recent (2009) research from the University of Dayton has shown that arrays of vertically grown carbon nanotubes could be used as catalyst in place of platinum to reduce the overall cost of the fuel cell. The nanotubes that are doped with nitrogen prevent the carbon from reacting with oxygen and forming carbon monoxide (CO), called CO poisoning. Nitrogen doped nanotubes are more resistant to this carbon monoxide corrosion and would be long lasting and cheaper than the expensive platinum catalyst used now.

Another group of scientists from Max Planck Institute for Solid State Research has composed a network of single walled carbon nanotube electrodes that boast of the same properties of amorphous carbon electrodes used earlier, but weigh far less. These nanotube electrodes are ten times thinner and lighter than the traditional electrodes. The long and thin shape of such nanotubes not only increases the surface area and porosity of the electrodes but also gives them high conductivity, more than one thousand times larger than the amorphous carbon electrodes. It is now believed that the use of carbon nanotubes in fuel cell will lead to much simpler fuel cell architecture.

It is now believed that the use of carbon nanotubes in fuel cell will lead to much simpler fuel cell architecture.

Another recent advance in the field of fuel cell is the development of a highly efficient electronic converter that can boost low DC (Direct Current) voltage produced by Solid Oxide Fuel Cell (SOFC) stacks to the higher voltage required for conversion to AC (Alternating Current) for household and commercial application.

Production of Green Hydrogen from renewable sources has been taken up as a challenge by United Kingdom for hydrogen economy. Novel technologies have been adopted for low carbon emission hydrogen production, for development of materials for hydrogen storage and transportation.

China is studying the development of an appropriate hydrogen infrastructure system to achieve fuel cell vehicle commercialization. Many in China feel that chemical companies producing enough hydrogen as an unneeded industrial byproduct can meet the need.

In India several industries and research organizations are involved in the development of fuel cell. The Defence Research and Development Organization (DRDO) and Reva electric car company jointly displayed the first fuel cell car of India in 2007 and expect the car to reach the mass market soon. The development of Direct Methanol Fuel Cell (DMFC) is also under way at IISc, Bangalore.

Dr M. Goswami is with the Department of Physics, Regional Institute of Education (NCERT), Bhubaneswar-751022, Orissa; Email: manasigoswami1@yahoo.com
Dr S. Sahoo is with the Department of Physics, National Institute of Technology, Durgapur–713209, West Bengal; Email: sukadevsahoo@yahoo.com