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RET (ME-604 C)

Energy is necessary for all activities in and around us. Energy provides comfort, increases productivity and allows us to live the way we want to. At present most of our energy demand is met by the energy obtained from conventional fossil fuels such as coal, petrol, diesel, natural gas, kerosene etc. It is estimated that we could run out of oil in about 40 years and of natural gas soon after. Not only are fossil fuels running out, but they're adding to our environmental problems by releasing harmful byproducts that increase pollution and contribute to global warming. In view of the limited store of fossil fuels and ever-increasing gap between the demand and supply of energy, it is necessary to switch to new and renewable sources of energy. It is a fact that India has one of the highest potentials for effective use of renewable energy. During the last one decade, there has been a visible impact of renewable energy in the Indian energy scenario. Apart from contributing to about 12.5 per cent in the national electric installed capacity, renewable energy based applications have benefitted millions of people in the Indian villages by providing for their energy needs in an environment friendly manner. India is the world's fifth largest producer of wind power after Denmark, Germany, Spain, and the USA. Other renewable energy technologies, including solar photovoltaic (PV), solar thermal, small hydro power, geothermal, sea wave and biomass energy are also spreading. As greater reliance on renewable energy sources offers enormous economic, social, and environmental benefits, we need to explore more sources of renewable energy. Geothermal energy is one of the renewable sources of energy available in the form of vast natural reservoirs of heat energy in the earth's interior. Several geothermal power plants, which generate more than 10,000 MW power are operational in at least 24 countries of the world. Besides, geothermal energy is being used directly for heating in at least 78 countries. The largest producer of this energy is USA that generates about 3,086 MW of electricity.

Overview of Geothermal Energy

Geothermal energy is one of the potential alternative sources of energy which has been successfully catering to both industrial and domestic energy requirements in many parts of the world over the last few decades. Geothermal is made of two Greek words – geo which means 'earth', and therme, which means 'heat'. Thus, geothermal energy is the heat from the earth. It is a clean and sustainable source of energy. Resources of geothermal energy range from the moderate-to-low temperature hot spring systems to hot rock found a few miles beneath the earth's surface, and down even deeper to the extremely high temperatures of molten rocks. Below the earth's crust, there is a layer of hot and molten rocks called magma. Heat is continually produced there, mostly from the decay of naturally radioactive materials such as uranium and potassium. Heat flows outward from the earth's interior.

Normally, the crust of the earth insulates us from earth's interior heat. The mantle is semi-molten, the outer core is liquid, and the inner core is solid. It is interesting to mention here that the amount of heat within 10,000 meters of earth's surface is 50,000 times more energy than all the oil and natural gas resources in the world. In fact, geothermal energy is one of the oldest natural sources of heat and dates to the Roman times, when the heat from the earth was used instead of fire to heat rooms and/or warm water for baths. Presently, it is being used as a source for producing electricity, mainly along plate margins.

Capture of Geothermal Energy

Now, the basic question is how do we use geothermal energy for the benefit of mankind? Normally geothermal energy is captured from geothermal hotspots. Basically, a hotspot is an area of reduced thickness in the mantle which allows the excess internal heat from the interior of the earth to flow to the outer crust. These hotspots include the volcanic islands, mineral deposits, and geysers normally known as hot springs. Following are some ways in which heat from these geothermal hotspots is obtained.

Hot Springs for Geothermal Power Plants: The most common way of capturing energy from geothermal heat is to tap into naturally occurring 'hydrothermal convection' systems where cooler water seeping into earth's crust is heated up, and it then rises to the surface. When heated water from the hot springs is forced to the surface, it is a relatively simple matter to capture that steam and use it to drive electric generators. To set up geothermal power plants, holes are drilled into the rock to capture steam more effectively to drive electric generators. If the water comes out of the hot spring as steam, it can be used directly whereas the hot water can be used as a flash system.

Direct uses of Geothermal Heat: Geothermal reservoirs of hot water, which are found a couple of miles or more beneath the Earth's surface, can also be used to provide heat directly. This is called the direct use of geothermal energy. Direct use of geothermal energy is a very old method when people used hot springs for bathing, cooking food, and other day to day heating purposes. Besides, the hot spring water was used to heat greenhouses, fish farms and spas, to dry fish, de-ice roads, and improve oil recovery, and to heat. But now, modern systems are being used for direct-using in which a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well and a mechanical system - piping, a heat exchanger, controls, which delivers the heat directly for its intended use.

Ground-source heat pumps: It is found that the temperature of the upper 10 feet of the earth is nearly constant - between 10°-16°C. During winter this region is warmer than the air above it, whereas in summer it is cooler. To take advantage of this resource, geothermal heat pumps can be set up to heat and cool buildings. Geothermal heat pump systems consist of a ground heat exchanger, a heat pump unit, and an air delivery system. The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. Geothermal heat pumps use much less energy than conventional systems, since they draw heat from the ground. A much more conventional way to tap geothermal energy is by using geothermal pumps to provide heating and cooling to buildings.

Advantages and limitations of Geothermal Energy: Geothermal energy is used for heating homes and for generating electricity without producing any harmful emissions. The first advantage of using geothermal heat as a source of energy is that, unlike most power stations, a geothermal power plant does not create any pollution and geothermal energy can be used to produce electricity 24 hours a day. Thus, geothermal energy is an excellent source of clean, inexpensive and renewable energy. If the geothermal energy is harnessed correctly, it leads to no harmful by-products. Geothermal power plants are generally small and have little effect on the natural landscape, or the nearby environment. As no fuel is used to generate the power from the geothermal heat, running costs for geothermal power plants are very low. Moreover, the cost of the land to build a geothermal power plant, is usually less as compared to the cost of constructing an oil, gas, coal, or nuclear power plant. Though geothermal energy has several advantages, it also has certain disadvantages and limitations. If harnessed incorrectly, geothermal energy can sometime produce pollutants. Improper drilling into the earth can release hazardous minerals and gases from deep down inside the earth, which can be contained quite easily. It is also feared that the geothermal power plant sites may run out of steam in the long run.

Prospects of geothermal energy In India

India has huge potential to become a leading contributor in generating eco-friendly and cost effective geothermal power. Around 6.5 per cent of electricity generation in the world would be done with the help of geothermal energy and India would have to play a bigger role in the coming years in this direction. But, the power generation through geothermal resources is still in nascent stages in India. Geological Survey of India has identified about 340 geothermal hot springs in the country. Most of them are in the low surface temperature range from 37 C-90 C which is suitable for direct heat applications. These springs are grouped into seven

geothermal provinces i.e. Himalayan (Puga, Chhumathang), Sahara Valley, Cambay Basin, Son-Narmada-Tapi
(SONATA) lineament belt, West Coast, Godavari basin and Mahanadi basin. Some of the prominent geothermal resources include Puga Valley and Chhumathang in Jammu and Kashmir, Manikaran in Himachal Pradesh, Jalgaon in Maharashtra and Tapovan in Uttarakhand. A new location of geothermal power energy has also been found in Tattapani in Chhattisgarh. In addition, Gujarat is set to tap geothermal electricity through resources which are available in Cambay between Narmada and Tapi river. Puga, which is located at about 180 km from Leh in the Ladakh region of Jammu and Kashmir across the great Himalayan range, is a good potential of geothermal energy. In Puga valley, hot spring temperatures vary from 30C to 84C (boiling point at Puga) and discharge up to 300 liters /minute. A total of 34 boreholes ranging in depths from 28.5 m to 384.7 m have been drilled in Puga valley. Thermal manifestations come in the form of hot springs, hot pools, sulphur condensates, borax evaporates with an aerial extent of 4 km. The hottest thermal spring shows a temperature of 84oC and the maximum discharge from a single spring is 5 liters /second.

Chhumathang spring is another geothermal area located about 40 km north of Puga. The thermal water from
Chhumathang is quite similar to the thermal waters at Puga except the difference that its water has relatively
higher pH and sulphate. Geothermal activity at Manikaran occurs in the form of hot springs over about 1.25 km on the right bank of Parvati river with a temperature range of 34 C-96 C whereas on the left bank over a distance of about 450 m with a temperature range of 28 C-37 C. At Tapovan geothermal area, the highest temperature recorded is 65 C. The discharge from this spring varies between 0.83-9.2 litre/second. Similarly, Tattapani is a promising geothermal resource in Peninsular India. Thermal manifestation at Tattapani is very intense in an area of 0.05 sq. km with several hot spots, hot water pools and marshy land. The surface manifestations show occurrence of white to dirty white deposits identified as silica and moderate to low sag activity. Sixty thermal water springs occur at eighteen localities in the West Coast hot spring belt. One geothermal power project has a capacity of 25MW. Himurja, Himachal Pradesh has decided to select some geothermal resources in Beas valley, Parvati valley, Satluj valley and Spiti valley in Himachal Pradesh for deep drilling up to 2 km for exploitation of geothermal energy.

Obviously, geothermal energy has great potential as a clean, green and naturally occurring renewable source of energy. Geothermal hot water can be used for many applications that require heat including heating buildings, raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes. It can be used for generating electricity as well. It is therefore necessary to explore the possibility of setting up more geothermal power plants to use the naturally occurring renewable source of energy.

Site Selection

Underground rocks with a high thermal gradient, permeability of these rocks to allow the flow of fluids, and perpetual supply of fluids are the main requirements of a geothermal source. Generally, locations near to places with volcanic activity, places with geysers, hot water springs and the like are potential geothermal sites. Areas subject to tectonic plate movements and frequent earthquakes are also potential areas. However, it is not necessary that these must lead to a viable thermal reservoir. There could be blind geothermal resources as well with no indications at the top surface. Thermal imaging and electric and magnetic imaging are some of the methods applied in searching for geothermal energy sources. Shallow temperature prospecting is another method to make a preliminary find, as is finding the ratio of Helium isotopes in groundwater. More Helium 3 can indicate potential geothermal reservoirs. Trial and error drills are the best way, but a costly proposition. The risk of the unknown is what makes the initial investments in geothermal much costlier than other forms of power generation. Developing in established areas to augment capacity is less risky. In most cases, it is accidental finds during oil prospecting that lead to the discovery of geothermal reserves.

Hydrogen Energy

Of all elements present in the universe, hydrogen is the most abundant. Hydrogen gas has remarkable characteristics including colorless, tasteless and invisible that make it hotly pursued. It can also be transformed into a renewable, nonpolluting and zero emission energy resource. It's considered the cornerstone of the new energy economy. The pursuit of hydrogen energy began way back in 1776 by the British scientist Henry Cavendish. He first identified it as a distinct element after he developed hydrogen gas by subjecting zinc metal to hydrochloric acid. Henry Cavendish made another remarkable discovery during a demonstration to the Royal Society of London when he introduced a spark to hydrogen gas, producing water in the process. This historic development led to his conclusion that water (H2O) is composed of hydrogen and oxygen. Since then, hydrogen technology has grown in leaps and bounds, and today, it is used as an energy source to power cars, electric systems, and production of pure water.

Hydrogen is the simplest and most abundant element in the universe. It does not occur naturally. While it exists pretty much everywhere- in the air, in space, in the ground- it is rarely alone. It's obtainable in combination with other elements such as water. Water is made up of hydrogen and oxygen. This means that it is usually combined with another element, making it necessary to extract and convert it to make it a usable energy source. Hydrogen also occurs in numerous organic compounds, for example, hydrocarbons that result in fuels like natural gas, gasoline, propane, and methanol. The biggest challenge to harnessing hydrogen is harvesting it in its purest form. Hydrogen's chemistry is very simple- a single atom is made up of only a proton and an electron. In a gaseous form, it can be burned as a fuel. It can be stored in power cells that generate explosive energy and propel rockets and spaceships. It is volatile and combustible, and very, very powerful. Hydrogen can be stored cryogenically (frozen) or in compressed air containers as a gas. It takes a lot of storage space to house significant amounts of hydrogen. This is because the molecules are far apart, and the gas is lightweight, making it very spread out. To contain the same amount of hydrogen in a cylinder as gasoline, for example, creates a much heavier container.

Production of Hydrogen

Hydrogen gas is an expensive and complex fuel to make because it has to be separated from whatever element it is joined to. It often takes a lot of energy to make hydrogen gas, making it a costly power source. There are a number of ways to separate hydrogen from its companion elements.

Before we look at how hydrogen is converted into electricity, it would be beneficial to know how hydrogen is produced. Hydrogen is produced using two main methods; steam reforming and electrolysis (commonly referred to as water splitting).

Steam reforming

This method produces hydrogen from hydrocarbon fuels such as methane, oil, renewable liquid fuels, gasified biomass, gasified coal and natural gas. A processing device called a reformer is used in this hydrogen production process. The reformer react steam with the hydrocarbon fuels at extremely high temperatures to generate hydrogen. Today, over 90% of hydrogen gas is produced using the steam reforming technique.

Electrolysis

Electrolysis is a method that utilizes direct current (DC) to instigate a chemical reaction. In the production of hydrogen, electrolysis decomposes water and splits it into its main elements, which are hydrogen and oxygen by use of an electric current. The electricity used in the electrolysis process can be derived from fossil fuels such as oil, natural gas, and coal or hydrocarbons.

Conversion of hydrogen into electricity

The most effective way to convert hydrogen into oxygen is using a fuel cell. A fuel cell converts chemical energy into electrical energy. A fuel cell enables hydrogen and oxygen to blend in an electrochemical reaction. The result is production of electricity, water, and heat. Fuel cells mimic batteries since they both convert the energy generated by the electrochemical reaction into useful electric power. Nonetheless, the fuel cell will generate electric power if fuel, mainly hydrogen, is available.

Fuel cells represent a potential technology for use a source of electricity and heat for buildings. It's also a promising source of power for electric and hybrid vehicles. Fuel cells function best on pure hydrogen. However, other fuels such as gasoline, methanol, or natural gas can be reformed to generate the needed hydrogen for fuel cells. With technology moving fast, hydrogen could come on par with electricity as a vital energy carrier. An energy carrier transmits energy to the customer in a ready to use form. Some renewable energy sources such as wind and sun may not be able to generate energy around the clock, but are able to produce hydrogen and electric power and stored for later use.

Storage of Hydrogen

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

Fuel Cells

A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity. If hydrogen is the fuel, electricity, water, and heat are the only products. Fuel cells are unique in terms of the variety of their potential applications; they can provide power for systems as large as a utility power station and as small as a laptop computer.

Fuel cells can be used in a wide range of applications, including transportation, material handling, stationary, portable, and emergency backup power applications. Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants and passenger vehicles. Fuel cells can operate at higher efficiencies than combustion engines, and can convert the chemical energy in the fuel to electrical energy with efficiencies of up to 60%. Fuel cells have lower emissions than combustion engines. Hydrogen fuel cells emit only water, so there are no carbon dioxide emissions and no air pollutants that create smog and cause health problems at the point of operation. Also, fuel cells are quiet during operation as they have fewer moving parts.

Working

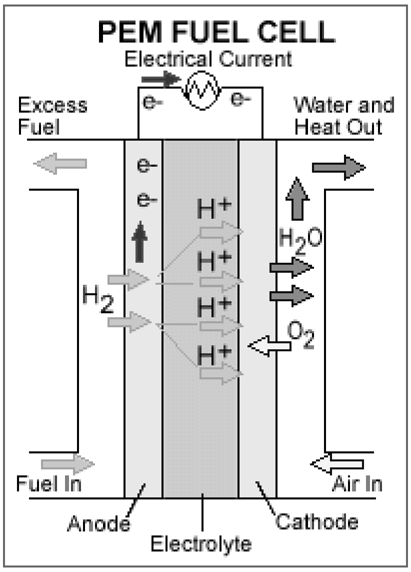
Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat if fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Types of Fuel Cells

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.

1. *Polymer electrolyte membrane Fuel Cell*

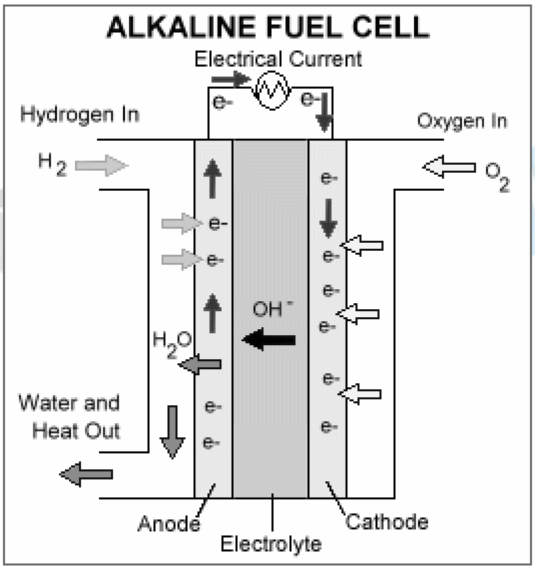
Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum 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. Due to their fast startup time and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.



2. *Alkaline fuel cell*

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.

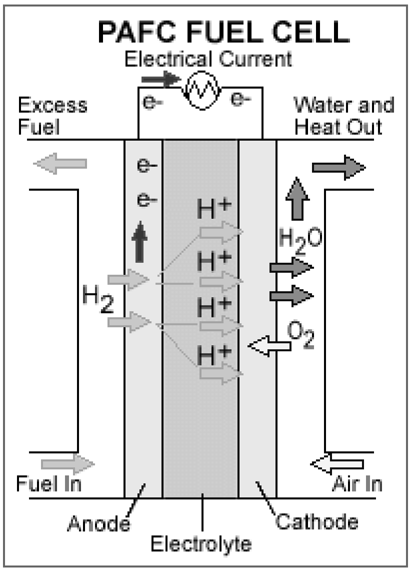
A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide (CO2). In fact, even the small amount of CO2 in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating 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 electro catalysis.



3. *Phosphoric acid fuel cell*

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.

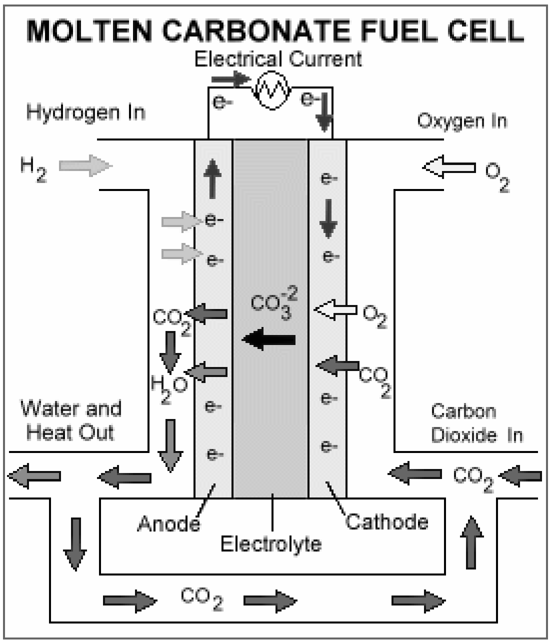


4. *Molten carbonate fuel cell*

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.



Thermodynamics of Fuel Cell

Electrode potential and Electrochemical Potential

It is the electromotive force of a cell built of two electrodes:

Suppose,

on the left-hand side (LHS) is the standard hydrogen electrode (SHE, EH2/H+ = 0.0 V), and

on the right-hand side (RHS) is the electrode the potential of which is being defined.

Note, by convention potential of SHE is zero.

ECell =Eeft - Erigh =0- Eright=- Eelectrode

Thus, if the potential of RHS electrode is positive then Ecell is negative and if it is negative Ecell is positive. Instead of writing LHS and RHS electrode based on the positive side or negative side of EH2/H+ = 0.0 V, an electrode is named positive (anode) or negative (cathode) electrode.

By convention:

ECell= (ECathode -EH2/H+)- (EAnode- EH2/H+)

ECell= ECathode- EAnode

Or, take the sum of the electrode potentials from the LHS and RHS side of standard potential, i.e., EH2/H+= 0.0 V, from the standard electrode potential series or electrochemical series.

Standard electrode potential (E°), is the measure of individual potential of a reversible electrode at standard state. The basis for an electrochemical cell is always a redox reaction which can be broken down into two half-reactions: oxidation at anode (loss of electron) and reduction at cathode (gain of electron). Electricity is generated due to electric potential difference between two electrodes. This potential difference is created because of the difference between individual potentials of the two metal electrodes with respect to the electrolyte. Although the overall potential of a cell can be measured, there is no simple way to accurately measure the electrode/electrolyte potentials in isolation. The electric potential also varies with temperature, concentration and pressure. Since the oxidation potential of a half-reaction is the negative of the reduction potential in a redox reaction, it is sufficient to calculate either one of the potentials. Therefore, standard electrode potential is commonly written as standard reduction potential.

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