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A Review on Proton Exchange Membrane Fuel Cell

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Abstract *– Global warming, Shortage of conventional energy sources & environmental pollution are the matter of greatest importance in today's world. Due to the complete dependence on fossil fuel as a source of energy, a constant depletion of the world's limited fossil fuel reservoir is also demanding the investigation and development of new energy technologies for energy conversion and power generation. The new energy transformation technology should be more efficient than the conventional heat engine, with minimal emissions, and also well-suited with renewable energy sources for sustainable development. Solution for this is availability of energy with less or no pollution. Solution to these challenges is fuel cell technologies which generate Electrical energy from chemical energy. It has been described as the chemical engineering Method of producing energy through electrochemical redox reaction which takes place at anode & cathode of the cell. Fuel cells are most promising & clean energy technology which meet all the requirements such as energy security & environmental sustainability. There are various types of fuel cells depending on type of electrolyte used such as solid oxide fuel cell, proton exchange membrane fuel cell, alkaline fuel cell, molten carbonate fuel cell & phosphoric acid fuel cell. PEMFC & SOFC are having solid electrolyte & others are having liquid electrolyte. Among all these type's, proton exchange membrane fuel cell has gained much attention to the technology of renewable energy due to its ideal & zero emission power source. This paper represents general concept of proton exchange membrane fuel cell & its applications.*

Keywords *– Fuel cell, Proton exchange membrane fuel cell (PEMFC), Applications.*

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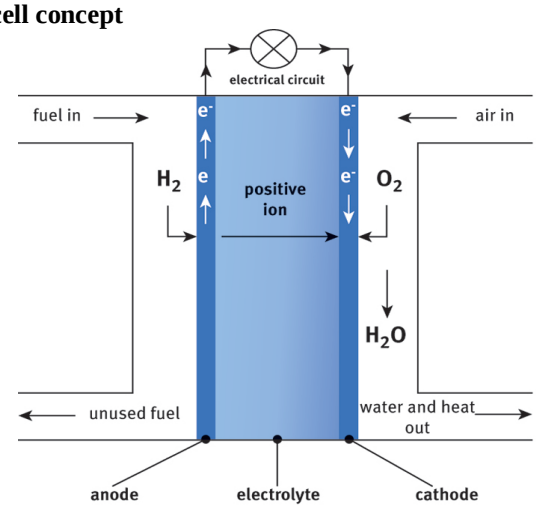
I. Introduction

Fuel cell technologies have received much attention in recent years due to the depletion of conventional energy sources and climate change. The efficiency of Fuel cell can reach as high as 60% in electrical energy conversion and overall 80% in co-generation of electrical and thermal energies. Fuel cell can be considered as one of the pillars of a future energy system. [1, 2]

1.1 Fuel cell concept



Anode reaction: $2\,H_2 \rightarrow 4\,H^+ + 4\,e^-$

Cathode reaction: $O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$

Overall reaction: $2\,H_2 + O_2 \rightarrow 2\,H_2O$

Fig 1- Represent working of fuel cell. [19]

A fuel cell is a device that yields electricity by a chemical reaction. Every fuel cell has two electrodes called, the anode and the cathode. The reactions that yield electricity occur at the electrodes. Fuel cell having an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.[3] Hydrogen is the basic fuel for fuel cell. [1,4] They generate electricity with very little pollution–much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, namely water.[4] In practice, many fuel cells are usually assembled into a stack. The use of a fuel cell is to produce an electrical current that can be directed outside the cell to do work, such as powering an electric motor. [2,6,7] Proton Exchange Membrane Fuel cell (PEMFC) is most widely used among all other fuel cell system for portable power generation due to compactness, quick start-up, and high output power density & clean by-product. [5]

1.2 Concept of PEMFC

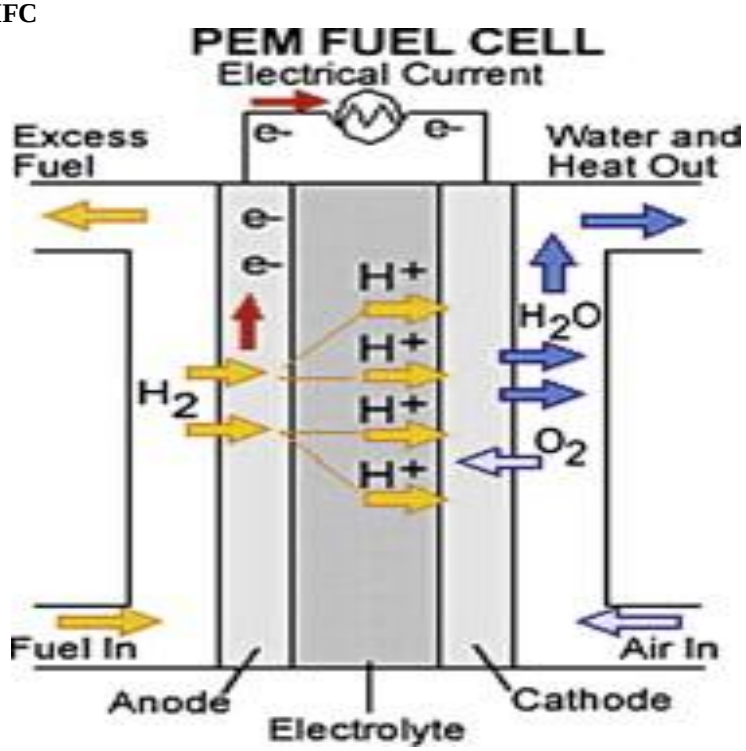


Fig 2-Proton exchange membrane fuel cell [24]

Proton-exchange membrane fuel cells (PEMFC) or polymer electrolyte membrane (PEM) fuel cells, are a type of fuel cell mainly used for transport applications, as well as for stationary fuel-cell applications and portable fuel-cell applications. [8] Their unique features include lower temperature ranges (50 to 100 °C) and a special proton-conducting polymer electrolyte membrane.[5] Proton Exchange Membrane Fuel Cell (PEMFCs) has developed importance as a hopeful technology due to its high energy conversion efficiency. [9, 12]

In PEMFCs, hydrogen atoms from the fuel sources are exposed of their electrons at the anode, and the positively charged protons diffuse through one side of the porous membrane and migrate toward the cathode. The electrons pass from the anode to the cathode through an exterior circuit and provide electric power along the way.[13,17] At the cathode, the electrons, hydrogen protons and oxygen from the air combine to form water. Proton exchange membrane electrolyte must allow hydrogen protons to pass through, but exclude the passage of electrons and heavier gases. There are two categories of proton exchange membrane fuel cells, i.e., Hydrogen Fuel Cells and Direct Methanol Fuel Cells (DMFC). In both the fuel cell, proton exchange membrane is used to transfer protons. High power fuel cell and high performance favor the choice of Hydrogen Fuel. Also hydrogen powered fuel cells are the greenest fuel cells. [18]

Anode electrode- $H_2 \quad 2H^+ + 2e^-$ →

Cathode electrode - $O2 + 4H^+ + 4e^-$ → $2H_2O$

After combination, above two reactions will be change to the general reaction.

General reaction of cell – $2H_2 + O_2$ → $2H_2O$

The heart of a single electrolyte fuel cell assembly is membrane electrode assembly.

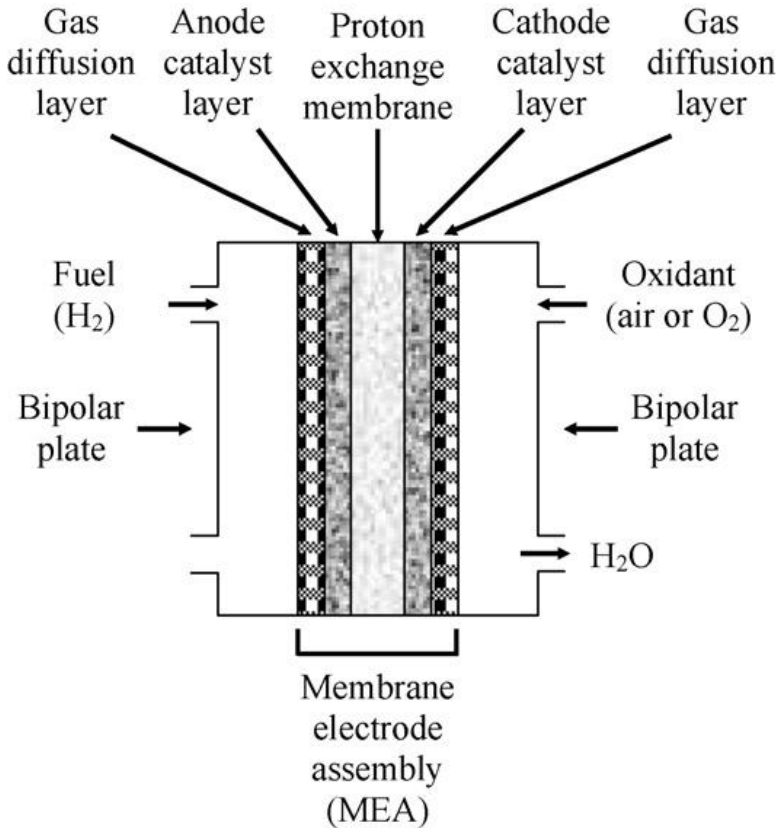


Fig 3-Basic components of proton exchange membrane fuel cell [19]

It consists of a proton exchange membrane (PEM) and two gas diffusion electrodes (GDE), formed by two gas diffusion layer (GDL) & catalyst layers (CL). Membrane electrode assembly plays an important role in three transport processes [19]

1) The transport of protons from the PEM to the CL.
2) The transport of electrons from the current collector to the CL through GDL.
3) The transport of reactant & product gases to and from the CL & gas channels.

II. Proton exchange membrane material & component

A proton-exchange membrane is a semipermeable membrane usually prepared from ionomers and considered to conduct protons while acting as an electronic insulator and reactant barrier. [20] This is their important function when incorporated into a membrane electrode assembly (MEA) of a proton-exchange membrane fuel cell or of a proton-exchange membrane electrolyser: parting of reactants and carrying of protons while blocking a direct electronic pathway through the membrane. There is a need to have good understanding of each proton exchange membrane component to get better performance. [21]

2.1 Proton Exchange Membrane

The polymer electrolyte membrane, or PEM (also called a proton exchange membrane) a specially treated material that conducts only positively charged ions and blocks the electrons. The PEM is the important to the fuel cell technology; it must permit only the required ions to pass between the anode and cathode. Other substances passing through the electrolyte would interrupt the chemical reaction. [21-22]PEMs can be made from either pure polymer membranes or from composite membranes, where other materials are embedded in a polymer matrix. One of the most popular and available PEM materials is the fluoropolymer (PFSA) Nafion. Nafion is an ionomer with a per fluorinated backbone of Teflon. These membranes are primarily categorized by proton conductivity (σ), methanol permeability (*P*), and thermal stability. Advancement of PEM components like the membrane, bipolar flow plate, gas diffusion layer, electro-catalyst layers, etc. has shown over time to have direct effect on the performance and durability of the cell .[23]

2.2 Catalyst layer

A layer of catalyst is added on both sides of the membrane, the anode layer on one side and the cathode layer on the other. Catalyst layers include particles of platinum dispersed on a high-surface-area carbon support. [23-26] This supported platinum catalyst is mixed with an ion-conducting polymer (ionomer) and inserted between the membrane and the GDLs. On the anode side, the platinum catalyst allows hydrogen molecules to be divided into

protons and electrons. On the cathode side, the platinum catalyst allows oxygen reduction by reacting with the protons formed by the anode, producing water. [27] The ionomer mixed into the catalyst layers permits the protons to travel through these layers. The catalyst layer should be designed to achieve high rate of desired reaction & minimize the amount of catalyst necessary for reaching the required levels of power output. [28]

2.3 Gas diffusion layer

Gas diffusion layer is a central supporting material in membrane electrode assembly that plays an important role of electronic connection between the bipolar plate with channel land structure & the electrode. The Gas diffusion layer sit outside the catalyst layers and facilitate transport of reactants into the catalyst layer, as well as removal of product water. Every GDL is composed of a sheet of carbon paper in which the carbon fibers are partially coated with polytetrafluoroethylene (PTFE). Gases diffuse quickly through the pores in the GDL. These pores are kept exposed by the hydrophobic PTFE, which avoids excessive water buildup. In most of the cases, the inner surface of the GDL is coated with a layer of high-surface-area carbon mixed with PTFE.This is known as microporous layer. The micro porous layer can help to regulate the balance between water retention (desired to maintain membrane conductivity) and water release (desired to keep the pores open so hydrogen and oxygen can diffuse into the electrodes).Gas diffusion layers is the electrical conductor that transport electrons to & from the catalyst layer. To ensure that the pores of gas diffusion layer do not become congested with liquid water, gas diffusion layers are waterproofed with polytetrafluroethylene coating. Gas diffusion layers are constructed from porous carbon paper or carbon cloth. [29]

III. Applications of PEMFC

Due to various advantages of proton exchange membrane fuel cell such as a low operating temperature, low weight, compactness, the potential for low cost and fast start-ups and suitability for discontinuous operation [29-30]. Because of all these features PEMFCs becomes the most promising technology for a wide variety of power applications such as portable/micro power and transportation to large-scale stationary power systems for buildings and distributed generation. The major application of PEM fuel cells focuses on transportation primarily because of their potential impact on the control of emission of the greenhouse gases (GHG). Other applications comprise distributed/stationary and portable power generation. Most of the motor companies work exclusively on PEM fuel cells due to their high power density and outstanding dynamic characteristics as compared with other types of fuel cells. Due to their light weight, PEMFCs are mostly suitable for transportation applications. PEMFCs for buses, which use compressed hydrogen for fuel, can operate at up to 40% efficiency. Updating energy system & incorporation of PEMS are the Technical matters for transportation. Full fuel cell vehicles are not advantageous if H_2 is sourced from fossil fuels; however, they become advantageous when implemented as hybrids. Therefore, PEMFCs are best for small scale systems until pure hydrogen is available.. [31-36]

3.1 Transportation

In today's era the means of transport plays an important role. The current technologies are not environmentally sustaining in nature. So there is need to alter the technology. The scientists have realized that they will demonstrate the vehicles with PEMFC technology. This technology can switch the older complex technology. PEMFCs having advantage of low operating temperature range. The PEM techniques are appropriate for the transporting devices. The main favoring point to consider is these technologies don't require pure hydrogen used as fuel, can be operated without any rotating parts. Also, it doesn't exhibit any significant poisoning systems. There are benefits known recently in several companies like BMW, Delphi automotive systems, etc. They have developed SOFCs as auxiliary power unit and companies implementing PEM fuel cells replacing hydrogen combustion engine. [37]

3.2 Portable Devices

This will be the widely used major applications of fuel cell in the equipment's such as portable computers, mobile phones, telephones and one of the important applications is military application. This area will include sustainability in terms of expansion. [38-39]

3.3 Stationary power Generation

India is facing a huge power shortage which affects the growth of economy. Use of PEMFC technology for power generation can tackle this shortage issue. Important markets for fuel cell technology in India, as per the reading conducted by the TERI- Delhi, are telecommunication sector, chlor-alkali industry, dairy industry and paper pulp industry [40]. The conventional centralized large-scale power plants have many benefits such as high efficiency, yet there are power loses due to long distance transmission which affects the efficiency. The way to undertake this drawback is a decentralized power generation which generates heat and energy for local

usage. The back-up power generation is also a potential area for adoption of PEM fuel cells as power generating unit. Organizations such as banks, hospitals and telecom sector require uninterrupted power supply (UPS) to avoid unexpected power breakdowns and thus are potential customers of back-up power supply by PEMFCs. Recently RelianceJio has ordered fuel cells from Ballard power systems for their back up power deployment.

3.4 Portable power generation

As the demand of portable electronic devices such as laptops and mobile phones is growing day by day there is a high demand of power for use in portable devices. Conventional batteries used for this purpose doesn't produce satisfactory results due to their low power outputs and long charging durations. Micro PEMFCs can handle down these problems efficiently because of their high power efficiency and short charging duration. Area of portable power in today's world is not only confined to laptops and mobile phones but also used in robot and power toys, boats, radio control cars and emergency lighting is also encouraged these days. In addition to this, fuel celled portable radios and other electronic devices are being used for military expeditions [41].

IV. Conclusion

Today environmental pollution & energy crises has turned into a great problem for human. For solving these problem great efforts have been taken for replacing the conventional fuels with other environmental friendly energy sources. Fuel cells are simple, environmentally clean, efficient device. Fuel cell have potential to qualify as technology from which electricity can be generated with harmless byproduct. There are various types of fuel cells. Among all the types proton exchange membrane fuel cell is widely used due to its compactness, quick start up & clean byproduct. There is a need to have good understanding of each proton exchange membrane component to get better performance of cell. This paper represents concept of fuel cell, proton exchange membrane fuel cell working & application areas of PEMFC.

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