

OPTIMIZATION OF HYDROGEN FUEL CELL – REVIEW

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Abstract— A fuel cell is an electro-chemical instrument that generate's electricity by using Hydrogen and Oxygen. A catalyst is used in a fuel cell to divide hydrogen into electrons and protons, which are then sent via an external circuit to generate electricity.

The different types of fuel cell are:

- 1) PEMFC - Proton Exchange Membrane Fuel Cell
- 2) DMFC- Direct Methanol Fuel Cell
- 3) PAFC- Phosphoric Acid Fuel Cell
- 4) AFC- Alkaline Fuel Cell
- 5) MCFC- Molten Carbonate Fuel Cell
- 6) SOFC- Solid Oxide Fuel Cell

The fuel cell chosen for optimization, PEMFC, Proton Exchange Membrane Fuel Cell, is a future of forthcoming energy source due to its benefits of high energy output, low operating temperature, and zero pollution, which may be achieved by the following techniques. Increasing the electrode area, using catalysts, and boosting the temperature are all options.

As an electrolyte, the fuel cell employs a water-based acidic polymer membrane with a platinum electrode. This fuel cell operates at a low operating temperature (below 100 degrees Celsius) and may create electrical output based on power requirements. Because of the low operating temperature and the usage of noble metal electrodes, the fuel cells must run on pure hydrogen . PEMFC cell is the dominating technology for vehicle and material handling vehicle applications, but it is not widely employed in other applications.

The high temperature PEM fuel cell is a PEM fuel cell variation with a higher working temperature (HT PEM fuel cell). This fuel cell can run at temperatures up to 200 degrees Celsius by employing mineral acid-based electrolyte rather than water-based electrolyte. By implementing the following, the fuel cell is able to operate in the presence of larger levels of impurity in the fuel.

Keywords—Fuel cell, Types of Fuel cells, Solid oxide fuel cell, Alkaline Fuel cell

I. INTRODUCTION

The world's energy usage is gradually rising. According to the World Energy Technology and Climate Policy Outlook (WETO), global primary energy consumption would grow at a 1.8 percent yearly rate between 2000 and 2030. A major amount of demand is met by fossil fuel supplies, which emit greenhouse and other gases. These resources are dwindling and will become increasingly expensive.

Currently, developing economies release 20% more CO₂ per capita than large established economies. This will soar as developing countries industrialise [1-3]. Emerging-market CO₂ emissions might account for more than half of global CO₂ emissions by 2030. To overcome

this, industrialized nations should lead the way in the R&D of alternate energy system. The security of energy is a serious concern. Fossil fuels, particularly crude oil, are limited to a few regions in the world, and supply flow is monitored by political, financial and environmental factors [4-8]. These elements are combined to generate unpredictable and frequently high fuel prices, as well as environmental rules mandating reductions in global emissions and harmful pollutants.

It is necessary to develop an alternative energy strategy that addresses combining "energy supply and demand," considering the complete energy life cycle into consideration, covering fuel production, shipping, energy transfer, and the influence on energy apparatus makers and end consumers of the energy system [9,10]. The hydrogen-based commerce will have an effect on businesses in the long term. Car and parts maker, transportation, the energy sector, and even households is conducting substantial study into alternative energy and fuel sources and technologies as technology improves. Greener and more efficient - notably with regard to hydrogen and hydrogen fuel cells [1, 11-15].

A good quality, convenient, trustworthy, and stable energy supply is a vital requirement for a sustainably wellbeing across the world.

Energy systems must satisfy the following societal requirements at a reasonable price to guarantee a competitive economic environment:

- Mitigating the impacts of climate change
- Reducing pollutants toxic contamination
- Expected depletion of oil reserves.

Inability to satisfy these requirements will have dire repercussions for:

- The economy
- Environment
- Public health

The chemical element hydrogen has the nucleon one and the abbreviation H. It is the element with least weight in the table of elements, with an atomic mass of 1.008. The most prevalent chemical element in the Universe is hydrogen, which accounts for 75% of all ordinary (baryonic) matter (by mass) [16].

The bulk of stars are made up mostly of hydrogen. One proton orbits one electron in the most common hydrogen isotope. Hydrogen's principal application is in the petroleum industry, where it is used to transform heavy petroleum fractions into lighter, more usable fractions. It is also used in the manufacture of ammonia (Figure 1). A smaller proportion is utilised as fuel. The combination of natural gas and water vapour produces the vast majority of hydrogen [17-20]

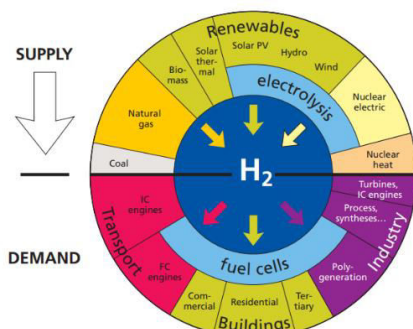


Figure 1. Various applications of hydrogen

Water electrolysis utilizes electricity to separate water into hydrogen and oxygen. When hydrogen is burnt, it reacts with oxygen to produce vapour (pure water vapor). Fuel cells fuse hydrogen and oxygen molecules, releasing an electron in the form of energy. Because of these considerations, many people believe that hydrogen will eventually replace other synthetic fuels [1].

Hydrogen may also power steam turbines and internal combustion engines. Hydrogen, like other synthetic fuels, may be produced from natural fuels ie coal or bio-gases, or from electricity, and so constitutes a valuable addition to the grid; it performs the same role as natural gas as a network and infrastructure with fuel cell automobiles.

2. Fuel Cell

A fuel cell is an electrochemical apparatus that electricity through a chemical process. Each fuel cell is made up of two electrodes, an anode and cathode. The activities that develop electricity take place on these electrode [6].

Every fuel cell usually contain an electrolyte that conducts charge carriers through one electrode toward the next, a catalyst that fastens the rate of chemical reaction at the electrodes. Despite the fact that hydrogen is the most fundamental fuel, fuel cells also need oxygen (Figure 2). One significant advantage of fuel cells is that they emit minute pollution; most of the hydrogen and oxygen required to develop power ultimately merge to give a by-product known as water.

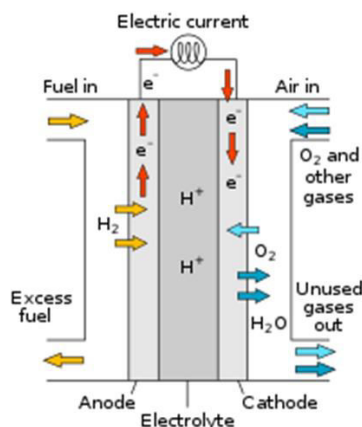
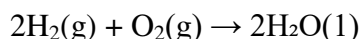


Figure 2. Hydrogen-Oxygen fuel cell



(Hydrogen) Fuel + oxygen = water

A. How fuel cells works

Aim of a fuel cell is to create an electrical charge that may be used by an external appliance, according to the way electricity works, it may drive a dynamo or metropolis. This current, due to the characteristics of electron, it reverts to the fuel cell to complete an electrical circuit. Fuel cells come in a variety of shapes and sizes, each with its unique set of features. Hydrogen atoms, on the other hand, normally enter a fuel cell at the anode, where a catalyst breaks down atoms into subatomic particles (Figure 3). The hydrogen atoms have been "ionised," which means they now have a net positive charge. Delocalised electrons transmit electricity across wires, allowing work to be done.

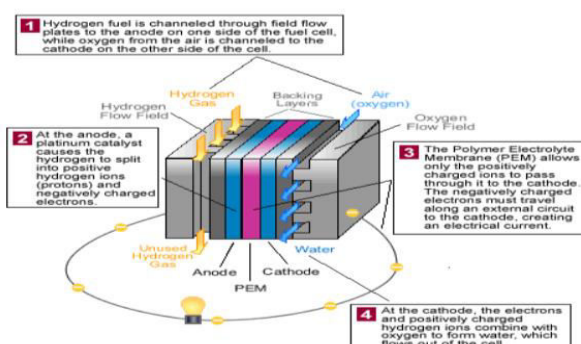


Figure 3. Schematic representation for the working of H₂-O₂ fuel cell

1. Types of fuel cell

AFC - Alkaline Fuel Cell.

MCFC - Molten Carbonate Fuel Cell.

DMFC -Direct Methanol Fuel Cell.

PAFC - Phosphoric Acid Fuel Cell.

PEMFC - Proton Exchange Membrane Fuel Cell

3.1. Alkaline Fuel cell

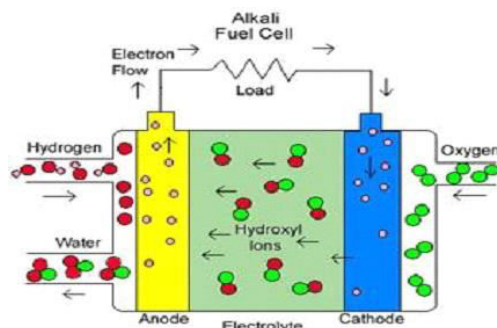


Figure 4. Schematic representation of AFC

They are powered by pressurized hydrogen and oxygen. As the electrolyte, they generally employ a hydroxide to form in water. The efficiency is roughly 70%, and the working temperature is between 150 and 200 degrees Celsius (about 300 to 400 degrees Fahrenheit). The cell's output varies from 300 watts (W) to 5 kilowatts (KW) (kW). In the Apollo program, alkaline cells were utilised to produce both electricity and potable water. They do, however, require clean hydrogen, and its platinum electrode accelerators are overpriced. They may also leak, just like any other liquid-containing container.

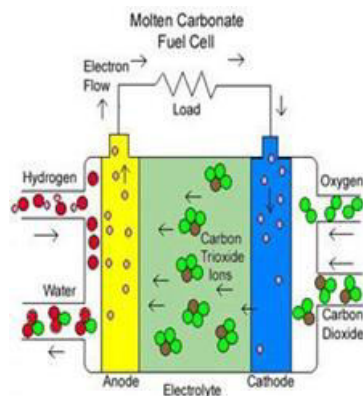


Figure 5. Schematic diagram of MCFC

3.2. Molten Carbonate Fuel cell

As the electrolyte, they employ high-temperature salt compounds such as sodium and magnesium carbonate (chemically, CO_3). With working temperatures of around 650 degrees Celsius (1,200 degrees Fahrenheit), the efficiency varies between 60 and 80 percent. Systems with capacities of up to 2 megawatts (MW) have been built, whilst units having capacities up to 100 MW are now under construction.

Cells are protected from the 'poisons' of carbon monoxide and waste at high temperatures. Heat may be collected and used to generate extra energy. Their nickel electrocatalysts are less expensive than be collected and used to generate extra energy. Their nickel electrocatalysts are less expensive than platinum, which is employed in other cells. High temperatures, on the other hand, limit the contents and ethical usage of MCFCs, making them too harsh for home use. Furthermore, carbonate ions in the electrolyte are utilized in practices that need the input of carbon dioxide to compensate (Figure 5.).

3.3 Direct Methanol Fuel cell

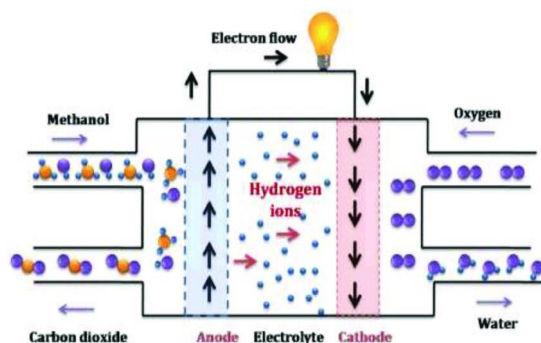
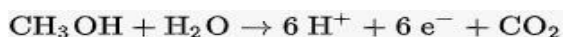


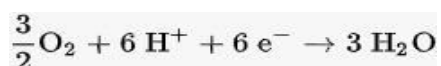
Figure 6. Schematic diagram of Methanol fuel cell

Anodic reaction (oxidation):

Researchers have been exploring the direct electrochemistry of methanol in fuel cells for more than three decades. Early cell designs used a sulfuric acid electrolyte in water at roughly 60°C at the anode and carbon dioxide at the cathode.

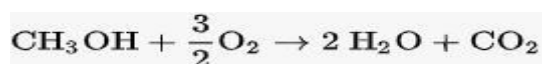


Cathode reaction (reduction):



The thermodynamic potential (E₀) for SHE calculated from the standard chemical potential at 25°C is 0.03 V. Gaseous oxygen interacts with subatomic particles protons and electrons to create water at the cathode.[20] For reaction (2), the thermodynamic potential (E_{c0}) is 1.23 V. (vs. SHE). As a result, the net cell reaction is

Overall reaction:



3.4. Phosphoric Acid Fuel cell

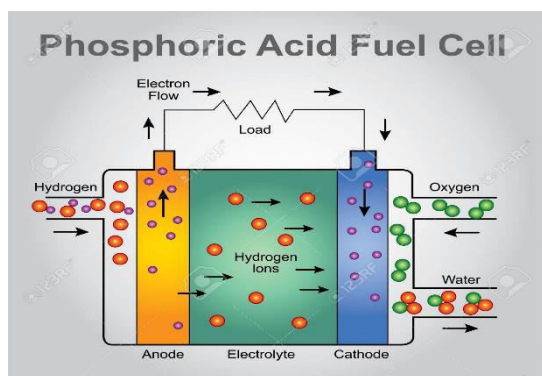


Figure 7. Diagram of Phosphoric acid fuel cell

Because they use an acidic electrolyte, phosphoric acid fuel cells (PAFCs) are carbon dioxide insensitive. They can work at temperatures between 160°C to 200°C. (Figure 7.) Because of their acidic electrolyte and high working temperature, PAFCs are insensitive to the majority of contaminants. Both in the fuel and in the reaction air. Because of the combination of phosphoric acid with platinum catalyst, the power-density attained by PAFC

is lower than that of polymer electrolyte membrane fuel cell. PAFC has shown to work successfully with both in-situ reformation hydrogen and pure hydrogen.

3.5. Proton Exchange Membrane Fuel Cell (PEM)

In PEM fuel cells, the electrolyte is a proton-conducting composite membrane ('Polymer Electrolyte Membrane') or PEM ('Proton Exchange Membrane') is an acronym for Polymer Electrolyte Membrane or Proton Exchange Membrane, respectively. Another term for them is polymeric membrane fuel cells, or simply cells membrane fuels. The electrolyte of a fuel cell (SPE). This concept has received the greatest attraction because to its easiness, practicality, and rapid start-up, and it has been proved in nearly every application imaginable, from powering mobile phones to diesel. The PEM fuel cell is driven by a polymer membrane with distinct characteristics. It is gastight while simultaneously transporting protons (thus the name Proton Exchange membrane). The electrolyte membrane is made up of 2 permeable conducting electrodes (Figure 8). Carbon cloth or carbon fibre paper is widely used to make these electrodes. A layer of catalyst, normally, is present at the interface between the porous electrode and the polymer sheet, platinum is aided by carbon. The cell structure and its importance functioning principles are depicted in a schematic figure.

At the point of contact between the electrolyte and the membrane, electrochemical reactions occur on the catalyst surface. Hydrogen dissociates into protons and electrons when given at one intermembrane space. One electron and one proton make up each hydrogen gen atom. Protons pass out through membrane, while electrons return to the other side through active electrodes, a current collector, and an external circuit. They come into touch with protons that have gone through the membrane at the catalytic sites among the membrane and the other electrode, and oxygen is delivered to this semi - permeable membrane. Water is created during the electrochemical process and subsequently expelled from the cell by an excess of electricity. The sum of these simultaneous reactions is the flow of electrons over the external load, which is known as direct current.

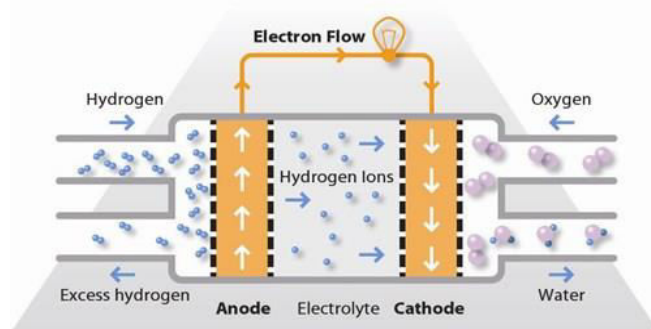
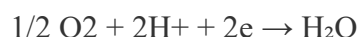


Figure 8. Diagram of Proton Exchange membrane Fuel cell

At the anode:



At the cathode:



Overall reaction: $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$

Literature survey

As the data sheets in this analysis reveal, the growth rate in fuel cell exports has grown over the last 5 years as new applications have become commercial. This really commercial marketplace has generated cash for a few organisations, allowing them to conduct research in broader transportation and stationary applications. Shipments of APU goods to the recreational market also stimulate the wearables sector. The introduction of Toshiba's Dynario fuel cell charger in 2009 boosted the use of fuel cells in the portable industry. With just 3000 units produced, this fuel cell charger's supply could not keep up with demand. With the deployment of Japan's EneFarm project, the usage of static fuel cells has increased, and uninterrupted power (UPS) fuel cells have been used in North America.

Xuan Cheng et.al His research provided a thorough account of the effect of contamination on PEM fuel cells. Contaminants include fuel impurities (CO-carbon monoxide, CO₂-carbon dioxide, H₂S, and NH₃-Ammonia), ambient pollutants (nitrides, sulphides), and corrosion of fuel cell stack components owing to the presence of ferric and cupric cations. This review focuses on three areas: the influence of pollution on fuel cell capabilities, the model examines the creation of mitigation measures, and the model explores the development of mitigation measures. Some of the projected future work on fuel cell pollution studies to aid with the transition to capitalization.

Hydrogen energy systems: A critical review of technologies Meiling Yue et al research.'s also points out that the cost of hydrogen generation is expensive and not competitive enough for widespread use of hydrogen in industries and the use of water and raw materials. Material scarcity has hampered progress from a sustainability standpoint. The electrolytic and fuel cell systems' performance and durability are not satisfied, resulting in significant operating and maintenance expenses. Cost-cutting measures must be implemented while enhancing system efficiency and sustainability.

Ramchandra Bhandari reviewed the value chain of solar photovoltaic hydrogen generation by adjusting the essential input values, the study gives a straightforward method for system size and levelized cost of heat computation globally. This research may be used to determine the system size and economic indicators needed to promote "electrical energy," as well as to aid enhance hydrogen production by developing business models..

Materials for hydrogen-based energy storage – The past, recent development, and the prognosis for the future. This document summarises the work done under the auspices of the Hydrogen-based energy storage from 2013 to 2018, giving the most recent research findings, views from experienced professionals in the area, and laying the groundwork for future R&D in the field. Each chapter presents a summary of the research's latest findings.

Hydrogen based systems for integration of renewable energy in power systems: Torbjørn Egeland Eriksen et al. assessed roughly 15 initiatives that were constructed and tested in their achievements and views. Several studies on electronics, control, and energy management systems for hydrogen storage have been examined. The goal of the exam is to provide an

overview of current advancements and the state of technology in hydrogen-based systems, as well as to illustrate the benefits and problems of applying them. Hydrogen mining as a solution for energy storage.

5. Optimization of hydrogen fuel cell

The PEM fuel cell employs an acidic water-based membrane as its electrolyte and platinum as its electrode. PEM fuel cells function at low operating temperatures (100°C). PEM fuel cell batteries are presently mostly employed in light automobiles and are less commonly used in heavier vehicles and other applications. Hydrogen fuel is handled at the positive electrode (anode), where electrons are separated from protons in the presence of a platinum catalyst. The membrane that separates the cathode and anode is selectively permeable, allowing only protons to pass through. There is an external circuit through which electrons travel, and this passage of electrons creates electricity. A metal electrode on the cathode side joins protons and electrons with oxygen to give water as a by-product fuel cell receives pure oxygen directly from the air.

The improved version of the PEM fuel cell runs at a higher working temperature by employing a mineral acid electrolyte rather than an aqueous electrolyte high temperature PEM fuel cell with a working temperature of 200 degree C. The constraints of the PEM, such as fuel impurity and other restrictions, can be overcome by making the following changes. High temperature PEM fuel cell is not superior to low temperature PEM fuel cell; both of these fuel cells have applications where their benefits outweigh their disadvantages. The differences between the two PEM fuel cell versions are summarized in the Table 1 below.

Table 1. Comparison table for Low temperature PEM Fuel cell and High temperature Fuel cell

	Low Temperature PEM Fuel Cell	High Temperature PEM Fuel Cell
Working temperature	80-100 °C	Up to 200 °C
Electrolyte	Water-based	Mineral acid-based
Pt loading	0.2-0.8mg/cm ²	1.0-2.0 mg/cm ²
CO tolerance	<50 parts per million	1-5% by Volume
Other impurity tolerance	Low	Higher
Power density	Higher	Lower
Cold start	Yes	No
Water management	Complex	None

6. Conclusion

We optimized a PEM fuel cell by increasing the working temperature and then using mineral acid-based electrolyte instead of water-based electrolyte. By making the following changes, the fuel cell can deliver the same level of performance while containing higher levels of impurities such as ammonia, formic acid, formaldehyde, carbon monoxide, and carbon dioxide. This is done because pure hydrogen is difficult to reform using existing production processes. Both varieties of fuel cells have no significant advantages or disadvantages, but each has its own set of advantages and favoured applications.

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