Comparative Study of Different Fuel Cell Technologies

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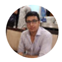
2 authors:


Mohammad Rahat Rahman
Rajshahi University of Engineering and Technology


Md Mashrur Islam
Walton Hi-tech Industries PLC.

Comparative Study of Different Fuel Cell Technologies

Md. Ziaur Rahaman and Md. Mashrur Islam

***Abstract*— A fuel cell is a technology that converts chemical energy into electric energy through electrochemical reaction which happens between oxygen and hydrogen to form of water. This is a big improvement over internal combustion engines, coal burning power plants, and nuclear power plants, all of which produce harmful by-products. Fuel cell technology is a promising way to provide energy for rural areas where there is no access to the public grid or where there is a huge cost of wiring and transferring electricity. There are several types of fuel cells currently under development, each with its own advantages, limitations and potential applications. The current paper includes a comparative study of basic design, working principle, applications, advantages and disadvantages of various technologies available for fuel cells. In addition, techno-economic features of hydrogen fuel cell vehicles (FCV) and internal combustion engine vehicles (ICEV) are compared.**

***Index Terms*— Fuel Cell, Emission, Fuel, Engine Technology, Power.**

I. INTRODUCTION

THIS Fuel cells are basically open thermodynamic systems. They operate based on electrochemical reactions and consume reactant from an external source [1] – [4]. The fuel cells are the noticeable alternatives of combustion engines for mobile and stationary applications due both to their high efficiency and to the fact that they do not release polluting agents and have not environmental effects. Since fuel cells do not use combustion, their efficiency is not linked to their maximum operating temperature. As a result, the efficiency of the power conversion step (the actual electrochemical reaction as opposed to the actual combustion reaction) can be significantly higher. The electrochemical reaction efficiency is not the same as overall system efficiency. The efficiency characteristics of fuel cells compared with other electric power generating systems are shown in Figure 1.

In addition to having higher specific thermal efficiency than heat engines, fuel cells also exhibit higher part-load efficiency and do not display a sharp drop in efficiency as the power plant size decreases. Heat engines operate with highest efficiency when run at their design speed and exhibit a rapid decrease in efficiency at part load. There are various types of fuel cells which are currently under research and development. Each of them has their own advantages, limitations and potential applications [6].

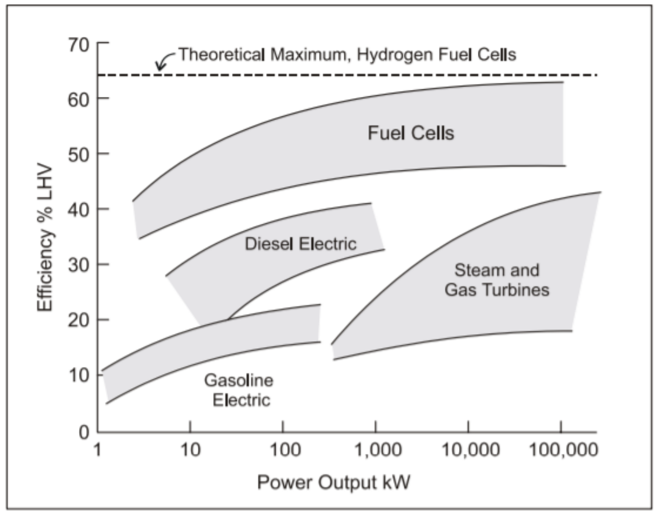


Figure 1. Power Generating Systems Efficiency Comparison [5].

II. LITERATURE SURVEY

The concept of a fuel cell had effectively been demonstrated in the early nineteenth century by Humphry Davy. This was followed by pioneering work on what were to become fuel cells by the scientist Christian Friedrich Schönbein in 1838. William Grove, a chemist, physicist and lawyer, is generally credited with inventing the fuel cell in 1839 [2, 4] Fuel cell was used firstly by Ludwig Mond and Langer in 1889 while trying to provide a practical fuel cell included coal gases such as mixture of carbon monoxide, hydrogen, carbon dioxide, nitrogen oxygen and air [6]. In 1932, Cambridge engineering professor Francis Bacon modified Mond's and Langer's equipment to develop the first AFC, but it was not until 1959 that Bacon demonstrated a practical 5 kW fuel cell system. At around the same time, Harry Karl Ihrig fitted a modified 15 kW Bacon cell to an Allis-Chalmers agricultural tractor [7]. Allis-Chalmers, in partnership with the US Air Force, subsequently developed a few fuel cells powered vehicles including a forklift truck, a golf cart and a submersible vessel [2, 7].

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Md. Ziaur Rahaman is with the Dept. of Mechanical Engineering, DUET, BD (e-mail: ziaros.28marine@gmail.com).
Md. Mashrur Islam was with the Department of Electrical & Electronic Engineering, RUET, BD (e-mail: mashrur.samit@gmail.com).
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III. TYPES OF FUEL CELL TECHNOLOGY

- Polymer Electrolyte Membrane (PEM) Fuel Cell Technology
- Direct Methanol Fuel Cell (DMFCs) Technology
- Alkaline Fuel Cell (AFC) Technology
- Phosphoric Acid Fuel Cells (PAFC) Technology
- Molten Carbonate Fuel Cell (MCFC) Technology

IV. STUDY OF POLYMER ELECTROLYTE MEMBRANE (PEM) FUEL CELL TECHNOLOGY

Polymer Electrolyte Membrane (PEM) Fuel Cell Technology is also known as proton exchange membrane cell. This deliver high power density and offer the advantages of low weight and volume compared with other fuel cells. This type of cell technology uses hydrogen and oxygen gases as fuels. As a result of electrochemical reaction between hydrogen and oxygen in the cell, electricity, water and heat is produced. As Oxygen is found in air at a large number, we only need to produce hydrogen to run the cell. Hydrogen is produced through electrolysis process. PEM fuel cell uses a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. This catalyst facilitates the reaction between oxygen and hydrogen. PEM fuel cells operate at relatively low temperatures, around 80°C (176°F) [8]. Low temperature helps to start fast and results in less wear on system components, resulting in better durability.

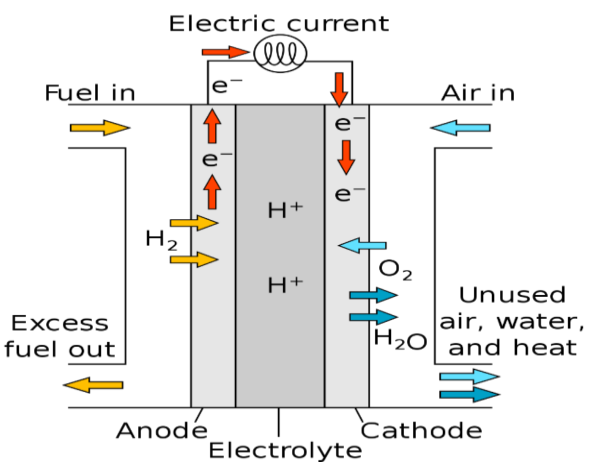

Figure 2. Diagram of a PEM Fuel Cell [9].

As the name implies, the main operational part of the cell is the proton exchange membrane. It excites protons to pass through, while electrons are blocked. So, when H_2 hits the platinum catalyst and splits into protons and electrons, the proton moves directly to the cathode side, while the electrons are bound to move through an external circuit [7]. Pressurized hydrogen gas entering the fuel cell on the anode side. This gas is to move through the platinum core by pressure. When an H_2 molecule meets the platinum on the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode, where they make their way through the anode where they make their way through the cathode side of the fuel cell. Meanwhile on the cathode side of the fuel cell, oxygen gas (O_2) is being forced through the catalyst, where it forms two atoms of oxygen. Each of these atoms has a strong negative charge which attracts the H^+ ions and form the molecule of water.

V. STUDY OF DIRECT METHANOL FUEL CELL (DMFCS) TECHNOLOGY

Direct methanol fuel cell (DMFC) is considered a promising power source for the next-generation portable electronics, owing to its characteristic s such as high energy density, green emission, convenient refueling of liquid fuel, and ambient operation conditions [10]. However, there remain several critical problems to be overcome to commercialize the DMF C system a s a rea l power source. Among the technical issues, increasing the catalytic activities of electrode catalyst s is one of the most important issues. In this regard, recently, nanostructured carbons, including carbo n nanotubes, carbon nanofibers and ordered mesoporous carbon s (OMC) , were exploited a s new carbo n supports for DMFC catalysts , to enhance the catalytic activities in electrode reactions . Amon g a variety of nanostructure d carbons, in particular, the OMC s are highly intriguing a s support material s for DMFC, du e to their high surface area, uniform mesopore, and high thermal an d chemical stabilities. Consequently, recent report s demonstrate d that the promising catalytic activities were obtained using OMC-supported catalysts [11-15]. 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.

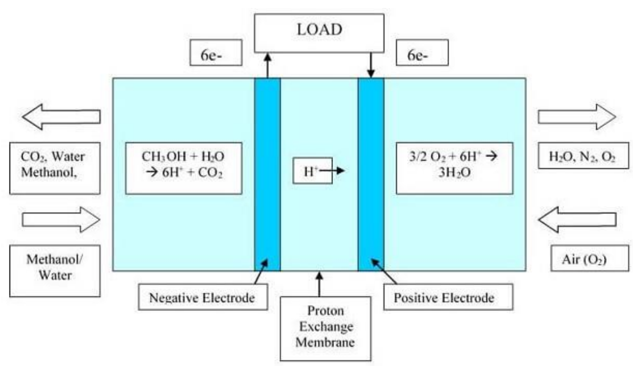

Figure 3. Direct Methanol Fuel Cell Technology [16].

VI. STUDY OF ALKALINE FUEL CELL (AFC) TECHNOLOGY

Alkaline fuel cells (AFC's) 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 [8, 12]. The chemical reactions that take place in an alkaline fuel cell are:

Anode: $2H_2 (g) + 4OH^- (aq) \rightarrow 4H_2O (liq) + 4e^-$

Cathode: $O_2 (g) + 2H2O (liq) + 4e^- \rightarrow 4OH- (aq)$

Overall Reaction: $2H_2 (g) + O_2 (g) \rightarrow 2H_2O (liq)$

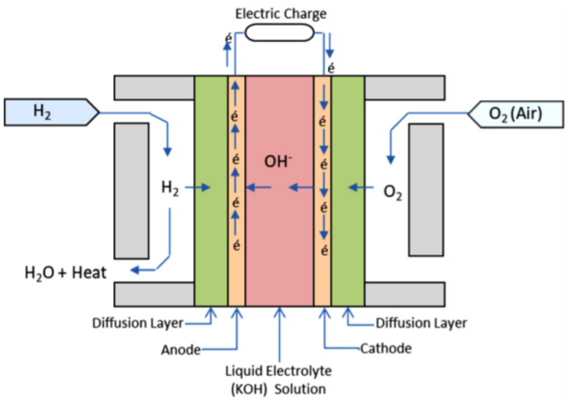

Figure 5. Operating principle of an AFC [17].

An alkaline fuel cell consists of an alkaline electrolyte, typically potassium hydroxide (KOH), sandwiched between an anode (negatively charged electrode) and a cathode (positively charged electrode). The processes that take place in the fuel cell are as follows:

1. Hydrogen fuel is channeled through field flow plates to the anode on one side of the fuel cell, while oxygen from the air is channeled to the cathode on the other side of the cell.
2. At the anode, a platinum catalyst causes the hydrogen to split into positive hydrogen ions (protons) and negatively charged electrons.
3. The positively charged hydrogen ions react with hydroxyl (OH^-) ions in the electrolyte to form water.
4. The negatively charged electrons cannot flow through the electrolyte to reach the positively charged cathode, so they must flow through an external circuit, forming an electrical current.
5. At the cathode, the electrons combine with oxygen and water to form the hydroxyl ions that move across the electrolyte toward the anode to continue the process.

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, High-temperature AFCs operate at temperatures between 1000 ºC and 2500 ºC. However, a newer AFC designs operate at lower temperatures of roughly 23ºC to 27 ºC [18].

VII. Study of Phosphoric Acid Fuel Cells (PAFC) Technology

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 catalyst8. The phosphoric acid fuel cell (PAFC) is one of the few commercially available batteries. Hundreds of these batteries have been installed around the world. Most of these provide power ranging from 50 to 200 kW, and 1 MW and 5 MW power plants have been built. The largest plant installed to date provides 11 MW of alternating current (AC), corresponding to a distribution network [19]. PAFCs have power generation efficiencies of 40%. Their operating temperature is between 150-300°C. PAFCs are poor ion conductors at low temperatures, and carbon monoxide (CO) tends to severely poison platinum in the catalyst. The chemical reactions that occur in PAFCs are:

Anode: $H_2(g) \longrightarrow 2H+ (aq) + 2e-$

Cathode: $½ O_2 (g) + 2H+ (aq) + 2e- \longrightarrow H2O (liq)$

Overall Reaction: $½ O_2 (g) + H_2(g) + CO_2 \rightarrow H_2O (liq) + CO_2$

The operating temperature is between 180°C and 210°C. At low temperatures, the electrolyte is not a good conductor and solidifies around 40°C. PAFC battery technology is the most mature in terms of development and commercialization. Indeed, stationary installations, up to 50 MW, have been set up. About 200 test facilities have been in operation worldwide, the main application of these batteries is cogeneration; the power range of PAFC batteries is between 200 kW and 50 MW [17].

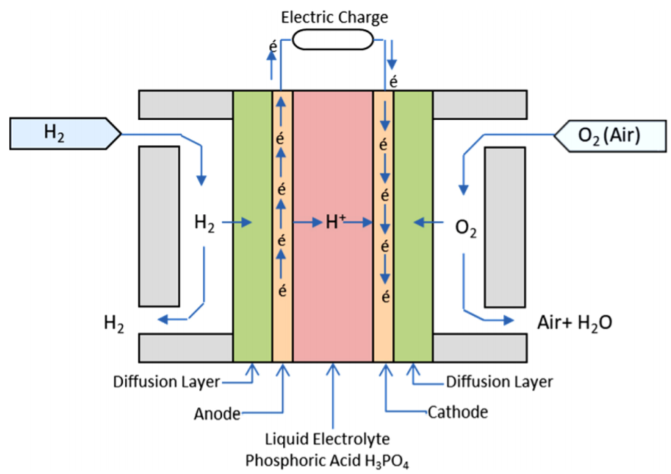

Figure 6: Operating Principle of PAFC [17].

VIII. Study of Molten Carbonate Fuel Cell (MCFC) Technology

The electrolyte in the molten carbonate fuel cell (MCFC) is usually a combination of alkali carbonates, retained in a ceramic $LiAlO_2$ matrix. The temperature of operation is 600–700ºC, where the alkali carbonates form a highly conducting molten salt, with carbonate ions providing the means for ionic conduction. The increased temperature of operation means that precious metal electro catalysts are not needed, and generally nickel anodes and nickel oxide cathodes are used. A design constraint with the MCFC is the need for CO_2 recirculation, meaning that it is difficult to operate below the 100 kWe scale. Avoiding degradation of the electrodes by reaction with the corrosive molten salt electrolyte is also a challenge. The sole developer of the technology is US based Fuel Cell Energy (FCE), who have made roll outs in the US and the Democratic Republic of Korea. Interest in MCFCs has increased through their potential role as a carbon capture and storage technology (CCS), where CO_2 recirculation is replaced by the dilute exhaust gas stream of a conventional coal fired power station. The dilute gas stream can then be used in an MCFC to produce a concentrated exhaust gas, which can be stored [20].

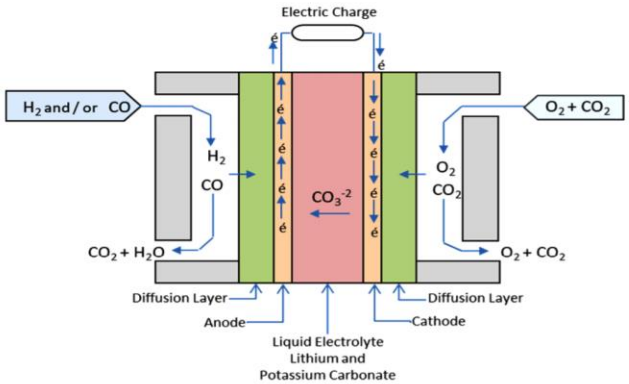

Figure 7. Operating Principle of MCFC [17].

MCFCs are mainly used in stationary applications. An example is a 2 MW natural gas mini plant in the United States that has been operating close to 4,000 hours. The power range is between 500 kW and 10 MW.

IX. Conclusion

Various sorts of energy units are contemplated to explain the best application for each kind. It was talked about that albeit a wide range of energy components work on a comparable premise; Alkaline is the most proficient (60%), trailed by Polymer electrolyte film (58%) and Molten carbonate (47%) as far as power productivity. While AFCs are the most productive, the PEMFC is perfect for transportation applications like car and transports. DMFC and PAFC are financially productive; notwithstanding, they experience the ill effects of low proficiency. SOFC and MCFC perform high CHP effectiveness. Correlation of the evaluated capital expenses among ICEV and FCEVs demonstrates that despite the fact that the last is progressively costly because of costs associated with hydrogen framework adjustments and dispersion foundation, the operational expenses during the vehicle's lifetime are all the more persuading. Current inventive and present-day power device innovations need to meet the prudent highlights and surpasses the upsides of the current advances to be satisfactory for large scale manufacturing. So as to improve the attainability and to expand the productivity of FCEVs, more R&D ought to be led by research establishments and enterprises. Energy components offer various significant favorable circumstances over interior burning motor (ICE) and other current power generator frameworks.

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