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An Analytical Research on Hydrogen Fuel Cell Technology

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Abstract- this paper investigates fuel cell technology, an efficient and environmentally friendly method for generating electricity by harnessing the energy content of hydrogen or alternative fuels. Fuel cells produce electricity with water, heat, and power as the only by-products when hydrogen is used as fuel, making them a clean and sustainable energy option. Future applications in the hydrogen economy are expected to utilize fuel cells as safe, quiet, and reliable energy sources. Fuel cells exhibit superior efficiency compared to combustion engines, promptly converting fuel energy into electrical energy. Various types and sizes of fuel cells with distinct technological requirements have been developed by scientists and inventors to enhance efficiency. The choice of electrolyte is a critical factor influencing the possibilities available to fuel cell inventors.

Keywords*— Hydrogen Fuel Cell Technology, Generating Electricity, Water, Heat, Power, Sustainable Energy Option.*

INTRODUCTION

Presently there is an evolutionary change taking place in the world's electrical networks from traditional centralized to distributed generation technologies. Growing interest in microgrid systems worldwide can be attributed to this trend as well as the need to address energy constraint problems, guarantee energy security, and acknowledge environmental sustainability [1-2]. An electrochemical device with the ability to continually convert fuel and oxidant chemical energy into electrical energy using an electrode-electrolyte combination that is basically constant is the classic definition of a fuel cell. We all require energy to get by on a daily basis. Due to the world's population and personal income growing faster than in the past, there is an increasing demand for energy. With 8.7 billion people on the planet by 2035, 1.6 billion more people will need energy. The main obstacles are the world's expanding energy consumption and the finite availability of fossil fuels, in addition to worries about the usage of traditional fossil fuels and their potential harm to human health. Sustainable energy and environmentally friendly substitutes must take the place of the present non-renewable fossil fuels immediately [3-4]. Without question, the amount of renewable energy produced has increased globally. Approximately 1560 GW of renewable electricity capacity were used by the end of 2013, almost twice as much as the 895 GW recorded in the beginning of 2004. Vehicle propulsion, permanent electricity generation, portable power, and large electrical plants are just a few of the uses for fuel cells.

FUEL CELL DEVELOPMENT

External factors have played a major role in fuel cell development during the last century. At first, because of their incredibly low efficiency, fuel cells seemed like a highly appealing option for producing power. Water was electrolyzed to produce hydrogen and oxygen, as described by Anthony Carlisle and William Nicholson in 1800 [5]. Fuel cell demonstrations date back to 1839, and William Grove is credited as the pioneer. Grove later went over notes from Carlisle and Nicholson and managed to "recompose water" by wiring electrodes in series. What made this possible was an apparatus known as a "gas battery." In a diluted sulfuric acid electrolyte solution, it operated using individual platinum electrodes immersed in hydrogen and oxygen [6-10]. He saw

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that the sealed containers contained both water and gas as the stream ran and the water level in both tubes increased. The apparatus, known as the "Grove cell," consisted of two electrodes: one composed of zinc sulfate and the other of platinum submerged in nitric acid. When operating at 1.8 volts, it generated about 12 amps of capacity. Researchers Ludwig Mond and Charles Langer initially introduced the expression "fuel cell" in 1889 when they studied fuel cells that used coal gas as a fuel source. More efforts were undertaken to turn coal directly into electricity early in the twentieth century, but the method was largely unknown. Francis Bacon, the Cambridge engineering professor, did not demonstrate a working 5 kW fuel cell device until 1959, even though he had improved Mond and Langer's invention to establish the inaugural AFC in 1932. At the same time that he adapted a 15 kW Bacon cell, Harry Karl Ihrig mounted it on an Allis-Chalmers farm tractor. Later on, Allis-Chalmers worked with the US Air Force to build a variety of fuel cell-powered vehicles, such as a forklift truck, a golf cart, and a submersible boat [11-16].

HOW FUEL CELL WORKS

Fuel cells are currently the focus of further research since they have the potential to drastically alter the way that energy is generated. They ensure the potential for producing clean energy while preserving and even enhancing environmental aspects by using hydrogen as fuel. By definition, fuel cells are electric cells. Unlike battery cells, they may accept fuel continuously, enabling the production of electricity to last eternally [17-19]. Because hydrogen and oxygen electrochemically react, the fuel cell thus immediately transforms hydrogen or fuels based on hydrogen into energy and heat. Electrolysis is reversible via a process occurring within fuel cells. As seen in Figure 1, every fuel cell has the electrodes on either side of an electrolyte layer, the anode and cathode. A physical barrier called the electrolyte prevents the fuel and oxidant from mixing directly while also allowing ionic charge to move the dissolved reactants to the electrode and moving them between the electrodes. Porous electrode construction allows for maximum three-phase contact among the gas/liquid, the electrode, and the electrolyte while also separating the bulk gas phase from the electrolyte. Ionization or de-ionization of gas/liquid occurs on the three-phase contact, reactant ions are conducted into or out of the electrode surface [20-21].

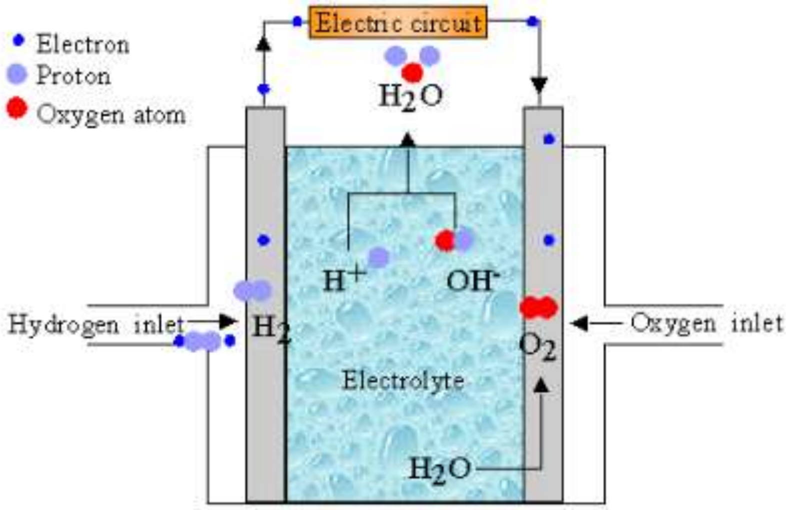

Figure 1- Hydrogen Fuel Cell

TYPE OF FUEL CELL TECHNOLOGY

Fuel cell categories are distinguished by the kind of The kind of electrolyte utilized and the operating temperature. Researchers are working on developing fuel cells capable of running at a variety of temperatures.

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The electrolyte's chemical properties, which serve as the cell's ionic conductor, are typically used to categorize fuel cells.

(i) Alkaline Fuel Cells (AFC)- Alkaline fuel cells, often known as alkaline FCs, run on pure hydrogen fuel and pure oxygen. Their electrolyte is diluted potassium hydroxide (KOH). To move hydroxyl (OH-) the electrolyte is in charge of transporting ions from the anode to the cathode. Numerous other fuel cell kindshave the opposite behaviour in terms of hydrogen ion conductivity between the cathode and the a node. The electrolyte, potassium hydroxide (KOH), is a malleable material. The mobile alkaline electrolyte fuel cells have a fluid electrolyte that is continuously pumped between the electrodes. The liquid electrolyte is heated and diluted by the waste heat and product water, which are then extracted from the cell when the electrolyte circulates. The electrolyte employed in immobile alkaline electrolyte fuel cells is a viscous paste contained within a matrix of permeable support, like asbestos, and held in place by capillary forces.

(ii) Molten Carbonate Fuel Cells (MCFC)- Molten Carbonate Fuel Cell (MCFC) technology provides an effective substitute for traditional coal-fired power plants in stationary power generation. G.H.J. Broers and J.A.A. Ketelaar, two Dutch scientists, began studying fused salt electrolytes in the late 1950s, which is when the molten carbonate fuel cell originated. As the name implies, Molten Carbonate Fuel Cell is built upon molten carbonate electrolyte. Fuel cells are often termed after the electrolyte used in the fuel cell. Since it runs at a temperature that is higher than that of polymer electrolyte fuel cells but lower than that of conventional solid oxide fuel cells (SOFC), usually at 650°C, it is referred to as an intermediate temperature fuel cell.

(iii) Proton Exchange Membrane Fuel Cells (PEMFC)- It is also known as the "Polymer" Exchange Membrane Fuel Cell, or proton exchange membrane fuel cell. As an electrolyte and divider of the cathode and anode, a solid polymer membrane is the basic structural component of a PEMFC, this membrane has been made from acidified Teflon. Hydrogen fuel travels via a system pathway to the cathode across the membrane after splitting into protons at the anode. By connecting the two electrodes with an external circuit, electrons are gathered as electrical current. Here, protons passing through the electrolyte membrane and electrons from the external electrical circuit mix with airborne oxygen, the oxidant, via a network of channels that resembles a cathode to produce heat and water.

(iv) Direct Fuel Cells (DMFC)- Direct methanol is a fuel substitute for hydrogen that can be used in proton exchange membrane fuel cells, or PEMFCs. Despite releasing less energy than using pure hydrogen, this reaction does not involve the synthesis of hydrogen. Consequently, this simplifies the fuel storage mechanism. A variant of the hydrogen polymer electrolyte membrane fuel cell (PEMFC) that is particularly well-suited for usage in automobiles and portable electronics is the direct methanol fuel cell (DMFC) technology. This process uses methanol as one of its energy sources. In a DMFC, at the cathode, oxygen typically air is reduced to water or steam, while at the anode, methanol is electro-oxidized to CO_2.

(v) Solid Oxide Fuel Cells (SOFC)- Since they are not constrained by the Carnot cycle of a heat engine, solid oxide fuel cells (SOFCs) provide an environmentally acceptable and low-pollution means of electrochemically producing energy at high efficiency. These fuel cells are superior to conventional energy conversion systems in a number of ways, including extremely low NOx and SOx emissions, high efficiency, reliability, flexibility, and fuel adaptability. Because SOFCs operate silently and without vibration, they also eliminate the noise that is frequently associated with conventional power production systems. SOFCs intended for operation in the 900–1000oC temperature range have been under development over the past six years or so. They have the capacity to internally reform hydrocarbon fuels like natural gas and supply cogeneration with high-quality exhaust heat. It is also possible to combine these high-temperature SOFCs with a gas turbine under pressure to increase the power system's overall efficiency. Even so, when the SOFC's operating temperature is lowered by 200oC or more, a wider range of materials can be used, the strain on the seals and other plant parts is reduced, thermal management is made simpler, starting and cooling times are shortened, and degradation of the cell and stack components is reduced.

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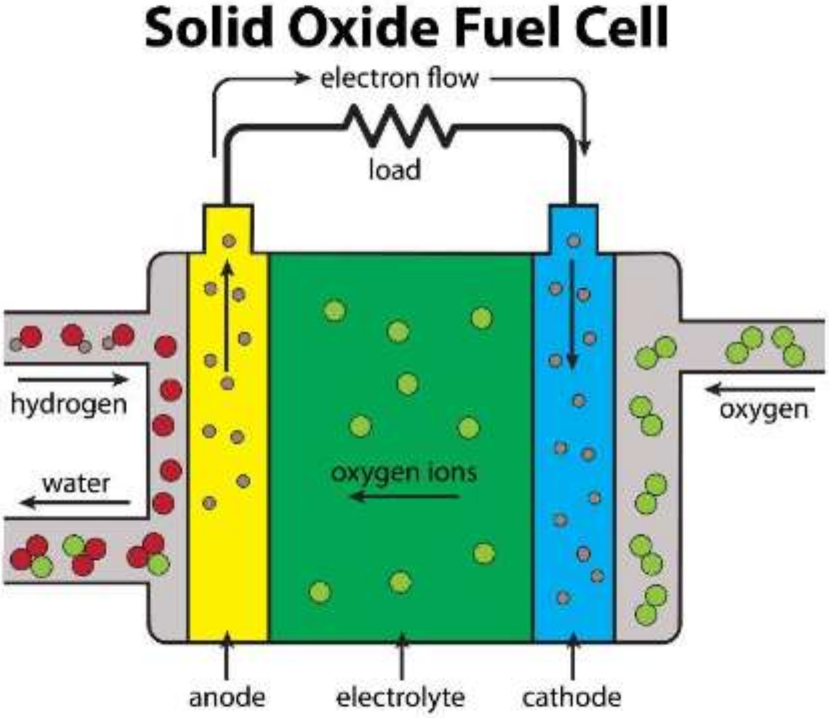

Figure 2- Solid Oxide Fuel Cell

APPLICATION OF HYDROGEN FUEL CELL

Hydrogen fuel cells have emerged as a groundbreaking technology with the potential to revolutionize various industries, presenting a compelling case for their positive impact on the environment. Particularly in the areas of transportation, stationary power generation, and general energy resilience, hydrogen fuel cells are making a substantial contribution to the mitigation of environmental concerns as a clean and efficient energy source. As an environmentally benign substitute for conventional internal combustion engine vehicles, hydrogen fuel cell vehicles, or FCVs, have gained attention in the transportation sector. The underlying idea is the electrochemical conversion of oxygen and hydrogen into electricity, which powers the car and produces only water vapor as waste. This feature of zero emissions tackles air pollution issues head-on and is essential in lowering greenhouse gas emissions. By reducing air pollution and advancing the cause of climate change mitigation, fuel cell vehicles (FCVs) present hydrogen-powered mobility as a viable long-term alternative. The advantages for the environment do not stop with transportation; stationary power generation is another area where hydrogen fuel cells present a viable option. Fuel cells are a dependable source of electricity with no environmental impact that can be used in residences, workplaces, and industrial settings. Fuel cells generate power using electrochemical processes instead of using fossil fuels, which prevents the discharge of hazardous pollutants. This use of hydrogen fuel cells in stationary applications contributes to the reduction of overall carbon emissions and is in line with global efforts to move toward a low-carbon and sustainable energy system. Hydrogen fuel cells are also advancing in the aerospace sector to mitigate the environmental impact of flight. Fuel cell-powered aircraft are a game-changer because of the high energy density of hydrogen, which allows for longer flying ranges with lower emissions. This invention has the power to completely reshape the aviation industry, addressing worries about the sector's role in climate change and representing a significant step toward environmentally friendly aircraft. Hydrogen fuel cells have an influence that goes beyond traditional uses; they are essential for improving energy decentralization and resilience. Hydrogen fuel cells

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provide a dependable and ecologically beneficial way to generate electricity for the development of microgrids and off-grid power solutions. This is especially helpful in isolated or disaster-affected places where traditional power infrastructure can be nonexistent or damaged. An important step toward sustainable energy practices is thus taken, as it removes the environmental impact of the extraction and use of conventional fuels.

CONCLUSION

This paper explore the diverse fuel cell technologies highlights their dynamic developmental trajectories and potential contributions to sustainable energy landscapes. Notably, the imminent release and technological preparedness of direct methanol and molten carbonate fuel cells signal advancements propelling them toward commercial viability. Projections for the next five to ten years envision molten carbonate fuel cells evolving into second-generation systems, showcasing their promising growth. Similarly, solid oxide fuel cells, positioned as third-generation systems, are anticipated to enter the market within the same timeframe, following the strides of phosphoric acid and molten carbonate fuel cells.

The paper introduces a categorization into low-temperature (alkaline, direct methanol, proton exchange membrane, phosphoric acid) and high-temperature (solid oxide, molten carbonate) technology groups, offering a nuanced analysis of power density, efficiency, and operational aspects. Alkaline fuel cells, particularly notable for their utilization of potassium hydroxide as an electrolyte, exhibit a power density range of 0.1–0.3 W cm^{-2}, finding applications in spacecraft despite their reliance on nearly pure hydrogen as fuel.

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