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Review

A comprehensive review of alkaline fuel cells

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ABSTRACT

The alkaline fuel cell is known as the "bacon" fuel cell. It generates electricity through the chemical reaction without the emission of greenhouse gases. This will allow it to replace fossil fuels in the future. It produced only the water for the final product. It operates at a temperature of 25˚C to 250˚C, which is relatively low compared to the internal combustion engines. It has wide application in the modern industry. This is due to the system's high efficiency, reaching up to 60%. However, the alkaline fuel cell has several disadvantages, which affect to popularize. This paper contains a review of alkaline fuel cells, an extensive study of the components that make up the fuel cells, as well as the future applications and challenges of fuel cells. A comparison of alkaline fuel cells and other types of fuel cells has also been discussed in the paper. In addition to the research paper, future trends and forecasts will also be able to accurately predict the viability of implementing this technology in the near future.

1. Introduction

The alkaline fuel cell is called the 'bacon' fuel cell. Named after its British inventor, it is one of the most developed fuel cell technologies with a wide range of heat, electricity, and water production applications. With its numerous advantages, which include (but are not limited to) an abundance of hydrogen, non-hazardous by-products, and a quiet and clean source of energy that is more efficient at all levels of use, this technology shows great prospects in the gradual but inevitable replacement of fossil fuel. The ability of fuel cells to directly convert chemicals to electrical energy is what scientists believe will be a key component of future energy sources. Alkaline fuel cells are made up of an alkaline electrolyte. It is usually a Potassium hydroxide liquid in which hydroxide ions (OH-) travel from the cathode to the anode in water and are generally fueled with pure hydrogen. Catalysts also speed up reaction rates at the anode and cathode. Operating temperatures of these cells can range from 25˚C to 250˚C. Alkaline fuel cells are currently capable of producing 14% more electricity with 23% less emissions. Due to the high rate of reactions, efficiencies of up to 60% can be reached in some applications. Current drawbacks of this fuel cell technology are the cost of production, the small amounts of energy that can be stored at a time, and the diseconomies of large-scale application. Much research still must be done to determine the plausibility of wide-scale application, which researchers still call a "fairy tale". In this research, the team will perform an in-depth analysis of the current alkaline fuel cell technologies as well as their advantages and drawbacks. The team will also examine the current efforts by scientists to put this technology to wide-scale use. In addition, future trends and forecasts will be looked into to accurately forecast the viability of implementing this technology in our fast-changing and technologically driven world. The goal of the research on alkaline fuel cells is to investigate the application and mechanism of energy production of the fuel cell. Secondly, the possibility of alkaline fuel cells as a future source of energy supply will also be studied and analyzed. This research will discuss different aspects of the alkaline fuel cell, including its components, advantages and disadvantages, and importance. The research is more about experimental procedures, and a handful of simulations are involved as well. However, experiments are carried out in the laboratory. In addition, every member is exposed to hands-on experience when experiments are carried out in the laboratory. Moreover, results obtained in the laboratory can be compared with similar experiments that have been done for accuracy and improvement. For a better understanding of the benefits of alkaline fuel cells, there will be a comparative analysis done with the following types of fuel cells:

- Proton Exchange Membrane Fuel Cells
- Direct Methanol Fuel Cells
- Phosphoric Acid Fuel Cells
- Molten Carbonate Fuel Cells
- Solid Acid Fuel Cells

2. Background

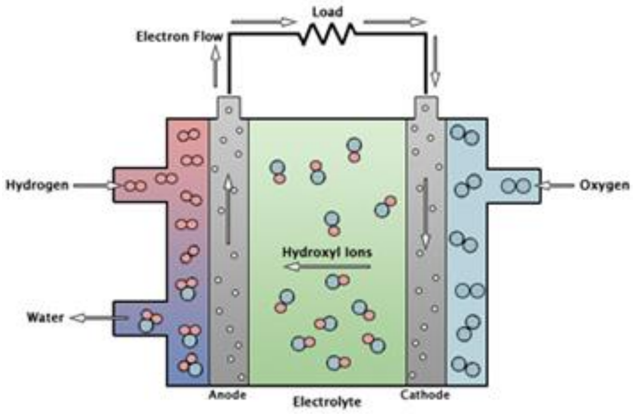
2.1 Alkaline fuel cells

2.1.1 Definition of alkaline fuel cells

Fossil fuel combustion, such as coal, jet fuel, and gasoline, falls under the non-renewable energy category. This releases harmful emissions into the environment and increases the greenhouse effect. On the other hand, many other environmentally friendly alternative energy sources, such as solar, wind, geothermal, and hydroelectric power, can be used only in particular environments. According to Viswanathan [1], fuel cells as a potential electrical energy conversion scheme are now being used worldwide. The reason for developing fuel cells is that they can have near-zero emissions while being quiet and efficient. Similarly, fuel cells use hydrogen and oxygen as reaction sources, which are abundant and environmentally friendly. A chemical reaction between the hydrogen ions with oxygen as an oxidizing agent. The reaction directly converts chemical energy into electrical energy [2]. Fuel cells are classified according to their electrolyte type. Thus, Alkaline Fuel Cells (AFC) use an alkaline electrolyte. In common practice, Alkaline Fuel Cells use liquid potassium hydroxide (KOH) as the electrolyte. In addition, Alkaline Fuel Cells are categorized as "low-temperature fuel cells" as their operating temperature ranges from 50 – 100 Degrees Celsius [3]. Similarly, the electrical efficiency of an alkaline fuel cell ranges between 60 – 70 percent. On the other hand, AFC systems have been said to have the advantage of good electrochemical stability [4].

2.1.2 Energy production in alkaline fuel cells

An alkaline fuel cell comprises two electrodes: a cathode and an anode. They are separated by an electrolyte. As for the electrolyte solution, potassium hydroxide (KOH) solution is used as it can penetrate the porous electrode similar to the reaction gases. Since potassium hydroxide has a higher ionic conductivity and higher solubility than sodium hydroxide, it is feasible to use KOH as the electrolyte [5]. In addition, adjacent to the electrolytes, a porous coating of a catalyst is used. Since oxygen reduction reaction in alkaline media is easily achieved when compared with acidic media, the catalyst increases the electrical efficiency of the fuel cell [2]. The catalysts used in most common applications of fuel cells are Silver, Nickel, Metal oxides, or noble metals [6]. As shown in Figure 1, in an alkaline fuel cell, hydrogen gas is pumped into the anode, and oxygen is pumped into the cathode. The anode and cathode are electrically connected. When hydrogen gas hits the catalyst, the hydrogen atoms are oxidized. This triggers a reaction with oxygen whereby hydroxyl ions are produced at the cathode of the alkaline fuel cell [7]. These ions travel to the anode side of the fuel cell, where they react with hydrogen to form water continuously. Hydrogen gas combines with the hydroxyl ions at the anode to form water and electrons during the process. In the meantime, the water formed at the anode diffuses back to the cathode, where it interacts with oxygen while returning electrons to revive the hydroxyl ions [8]. The overall reaction of the fuel cell produces heat and water as by-products and generates four electrons per mol of oxygen. Since the four electrons are not capable of passing through the electrolyte, they are forced out at the anode, producing a current that flows through an electric circuit [2]. In contrast, an electrical current is produced when the flow of electronic charge within the circuit is balanced by the movement of ionic charge through the electrolyte [9]. On the other hand, the behavior of the cathode is directly related to the lifetime and power output of alkaline fuel cells. Since the oxygen reduction reaction at the cathode is a slower reaction when compared with the hydrogen oxidation reaction at the anode, losses are incurred [5]. Moreover, carbon dioxide affects the fuel cell, where the formation of carbonate species affects the performance of the alkaline electrolyte [10]. This carbonate is formed when carbon dioxide reacts with the electrolyte. The formation of carbonate decreases the ionic conductivity of the electrolyte and blocks the pores in the electrode. Ultimately, oxygen flow to the reacting sites is reduced as the pores are blocked, which causes the electrode to flood [9]. Hence, the oxygen solubility and electrode activity are vastly reduced. However, if an anion exchange membrane (AEM) is used as a solid electrolyte, the carbon dioxide issue is minimized greatly as there is a scarcity of mobile cations in the membrane [11].



Anode: $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

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

Figure 1. Schematic diagrams of an alkaline fuel cell

2.1.3 Alternate material for hydrogen in fuel cells

Methanol and Ethanol are some of the alternative materials used instead of hydrogen in alkaline fuel cells [12]. A direct alkaline methanol fuel cell is a type of alkaline fuel cell that uses methanol. Similarly, a direct alkaline ethanol fuel cell is another type of alkaline fuel cell whereby ethanol is used. Water management at the anode is caused by carbonation, where carbon dioxide is permanently produced during operation [13]. Regarding this, an anion exchange membrane is introduced as an electrolyte in the direct alkaline methanol fuel cell [14]. As for the catalysts used, a direct alkaline methanol fuel cell uses nickel as the anode catalyst for methanol oxidation in the alkaline media as a common practice [15]. In contrast, palladium, a pure metal, catalyzes the ethanol oxidation reaction in a direct alkaline ethanol fuel cell [16]. According to [15], because of the high overpotential for the electrochemical oxidation of the ethanol at low temperatures, direct alkaline ethanol fuel cells have a lower performance when compared to direct alkaline methanol fuel cells. However, when the energy densities of methanol and ethanol are compared, the energy density of ethanol is greater than that of methanol, provided a complete oxidation to carbon dioxide is attained. Moreover, ethanol and its oxidation products are less toxic than methanol and its oxidation products.

2.1.4 Review of cathode material

The efficiency and general overall performance of any fuel cell are largely due to the methods applied in fabricating the layer structures from carbon and PTFE of the gas diffusion electrode. All developed fuel cells utilize identical porous electrode structures, similar to the electrodes used in metal-air batteries. The overall power of the cell and the lifetime of the alkaline fuel cells are directly linked to cathode behavior, and an in-depth look into cathode development is necessary. Most of the AFC's polarization losses occur at the cathode, much more so than at the anode. This phenomenon can be explained by the speed of the oxygen reduction reaction, which takes place at the anode and is much slower and more limiting than the hydrogen oxidation reaction that takes place at the anode. Two types of designs exist for the AFC. They are the monopolar and bipolar stack designs. The monopolar stack design has several advantages, such as lower cost; it achieves this by avoiding the expensive materials needed for bipolar stack plates [17,18]. Furthermore, stack thickness decreases due to the presence of only one type of gas chamber between the two electrodes. Apart from these, the need for additional mechanical pressure is eliminated since the parts are mostly glued or welded together. Finally, the disconnection or interruption of a bad cell in this situation will facilitate the maintenance of the entire stack. However, some drawbacks are associated with this design. Currently, the monopolar design has a limited density of up to 100 mA cm^{-2}. This is due to current collection losses at each side of the electrode. The bipolar design shows a steadier current density throughout the entire surface of the electrode and even has a terminal voltage of higher value and less power limitation. This geometry will be preferred for high-power applications, but its cost is a major drawback [17].

2.1.5 Design of electrodes

Alkaline fuel cell electrodes are made up of many bonded polytetraflouraethylene (PTFE) carbon-black layers (Figure 2). These three-layer structures have many functions. They consist of an active layer, a gas diffusion layer, and a backing (support) material [19].

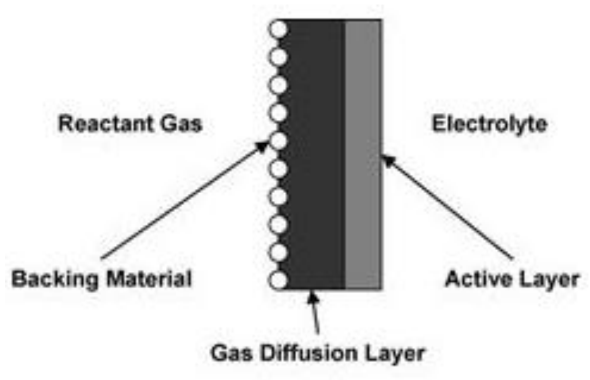


Figure 2. Design of a double-layer electrode in a bipolar stack design

This design is used more often than a single-layer electrode, although more complex designs are currently in use depending on the scope of the application. A good double-layer electrode should have a backing material that easily allows gases to permeate it, as well as good electrical conductivity and high strength. Due to the nature of the monopolar design, backing materials also play the role of the current collector, and as such, metal screens and meshes that are comprised mainly of nickel are used. In the case of bipolar designs, the backing material comes in direct contact with the bipolar plate. This implies that carbon cloth or porous carbon paper can be used for it [20]. The gas diffusion layer plays a very important role. It supplies gases that undergo the reactions to the active layer. In addition to this, it prevents electrolytes from passing through the electrode. A phenomenon termed ‘flooding’. Most monopolar designs use a PTFE gas diffusion layer. Bipolar designs require a gas diffusion layer that is capable of electronic conduction. Ideally, a gas diffusion layer should be completely hydrophobic and have satisfactory metal conductivity [21].

2.1.6 Materials used in the fabrication of electrodes

A wide variety of materials is used to make alkaline fuel cell electrodes. Recently, most alkaline fuel cell electrodes used carbon-supported catalysts with a large surface area for PTFE to obtain the necessary three-phase boundary elaborated on earlier in the report. The key parameter here in electrode performance and catalytic activity is the surface area of the catalysts used on the electrode rather than its weight [22]. PTFE has been a very popular binding agent since its introduction. Some other alternatives include wax and polyethylene. It is present as globular particles or porous substrates with thin films and fibrils. When combined with carbon black, it permeates the carbon subsurface. Sintering, which involves melting PTFE to provide a thin covering over the carbon black, is usually necessary [17]. Carbon black has some particular chemical and electrical properties that make it ideal for AFC electrode use. Carbon black consists of carbon in the form of globular particles obtained through decomposing carbon by heat application. Its high surface area characteristic is achieved by treating it with steam at high temperatures as the steam passes through the carbon black’s inner core, which has more entropy than the outside; a large number of pores form while the particle does not completely disintegrate [23].

2.1.7 Operational mechanism

By altering or adjusting the various input layers and structures, scientists can control the electrochemical behavior of the AFC. Control can be achieved if the ratio of hydrophobic and hydrophilic pores inside the carbon structure is altered. Two structures in the electrode play vital roles in its operation. The first is the macrostructure created due to the incomplete covering of the carbon particles by PTFE. This is responsible for the skeletal structure and ensures electrical conductivity and mechanical support [24]. The secondary microstructure is a result of the pore system inside the carbon black particle, and this is also dependent on the nature of the pore, its structure, and the surface area of the carbon used. Micro pores are hydrophilic, while macro pores are hydrophobic. Hydrophobic micropores are essential in gas mass transport because they mimic the behavior of gas supply channels. On the other hand, oxygen reduction reaction mechanisms occur in hydrophilic pores and are filled with electrolytes.

2.1.8 Cathode catalyst materials

A variety and range of materials exist and can be considered for use as the cathode catalyst. These include, but are not limited to, non-noble metals, noble metals, perovskites, spinels, etc. In evaluating the catalyst chosen, it is necessary to factor in the effect that the type of carbon used has on the catalyst. The supporting carbon particle, which has a range of physical and chemical characteristics, directly impacts the catalyst support system [19]. If we plan on building and sustaining a pollution-free world in the future, the world will have to bank on Low-temperature fuel cells like Polymer electrolyte fuel cells and alkaline fuel cells. In addition to its relatively cheaper cost, the system has advantages in its working principle; no gas humidification is required, in the case of PEFC. In addition to this, the temperature of the AFC can be managed with only its electrolyte. It will be established in the course of this report that AFCs are a promising alternative to polymer electrolyte fuel cells (PEFC) and other forms of energy generation and storage [22]. The key aspect of this attractiveness goes down to the cathode part of the electrode, which is used in the oxidation-reduction reaction, as has been established previously. To use AFCs in the long term will require a long-term behavioral analysis of these components. The lifetime of the entire cell is based on the degradation of the electrodes. Since the cathode in a fuel cell can be easily replaced, most of the focus will be on it. For this research, a few variations will be considered, described in detail below.

2.1.9 Silver cathodes in alkaline fuel cells

This cathode consists of catalysts made of silver and Polytetraflouraethylene as a binder roll-formed into a metal web-like structure. Silver can be used in this situation because of the less corrosive nature of the alkaline fuel cells compared to the acid fuel cell environments. This presents a big cost advantage over other types of cells and also a much higher commercial use potential [25]. The solubility of silver in a completely alkaline fuel cell can affect the overall performance if it gets dissolved and transferred to the anode part. This resulting plating of the anode component may destroy the catalysts present at the anode. A study investigated this degradation during the oxygen reduction reaction (ORR) at a constant load. According to a study performed on silver electrodes in alkaline cells, the electrodes were investigated by observing the structure and the changes that electrochemical stressing induces. This was achieved using a scanning electron microscope. Measurements were performed with a TOPCON DS130 and a Zeiss Gemini LEO microscope. This device was equipped with a NORAN VOYAGER 3000 EDX system. In addition, a variation of the microscopic beam energy in the range of 1-40 keV was performed. The results showed that the performance of the silver cathode used decreased during operation time at a constant rate. Also, because of the declining roughness of the surface, the surface area of the catalysts decreases, and the pore system is altered. During the ORR, a reduction in electrochemical performance is observed. A direct implication is that in an operating period of about 5000 hours, the total voltage loss will be about 100mV [22]. This result will be more suitable for mobile than stationary applications.

2.1.10 Bipolar gas diffusion layer: Polytetraflouraethylene bonded carbon black layer

As per a study on this bipolar electrode, nickel was selected as the conductor because it is a cheap alternative and has good characteristics of mechanical strength, high porosity, specific surface area, corrosion resistance, low density, and electrical conductivity. New electrode designs are also possible due to its three-dimensional structure. The diagnostic technique used to test the efficiency and source of losses of the cathode is called electrochemical impedance spectroscopy (EIS). The nickel used in this experiment had 99.9% pure, 110 pores per inch, a thickness of 1.7 mm, and an average pore size of 590nm [24]. In the preparation of each electrode, the gas diffusion layer mixture was rolled and formed into a thickness of 0.5mm with a calendaring machine, and it was done on top of the glass-proof paper. Excess liquid is finally removed by pressing at constant pressure, and then the resultant cathode coalesced in the air at 255 C for 30 minutes. The liquid electrolyte utilized in this study was strong potassium hydroxide synthesized from deionized water and potassium hydroxide pallets. Trapped air was avoided in the cell throughout the experiment by properly circulating the electrolyte from top to bottom. This new cathode design that had been developed over time for the oxygen reduction cathode reaction in an alkaline fuel cell showed promising results from the experiment conducted. Based on the study, cathode performance was significantly improved, especially at high potentials of 130 mA cm^2 at 25 C and 0.8 v. This is compared to about 35 mA cm^2 of previous designs in the same testing conditions. This insight will allow us to relate the micro and macrostructure of the electrode to its kinetics, which offers exciting opportunities for further cathode evolution and development [26].

2.2 Future innovations for alkaline fuel cells

Technological change does not just happen from nothing. It evolves, and therefore, the history of its evolution matters. Early scientists discovered that just as electricity could be used to split water into its component elements, the reversal process can be done to generate electricity. Originally, platinum was used as the electrode, while sulphuric acid was used as the electrolyte. This was very expensive and impractical; hence the idea was shelved temporarily [27]. Further attempts by other scientists to revive this idea will involve them changing the acidic sulphuric acid electrolyte to an alkaline fluid to reduce the cost. For this new fuel cell, nickel could be used as an electrode much cheaper than platinum. Energy systems around the world are trying to switch to cleaner energy sources to reduce the rate of CO_2 emissions. This unilateral action is necessitated by the fact that climate change, scarcity of fossil fuels, and uneven distribution of traditional energy sources are becoming a growing concern [1]. Although it is expected that this change will be costly and technically difficult, the burden of innovation will lie in the hands of government institutions and industry entrepreneurs. Analyzing the trends in innovation will serve as a means of evaluating the success so far and predicting the pace at which future innovations will take place [2]. A study focused on technological innovations in practice explained that the United States is currently one of the world's largest energy consumers. Though its government is sluggish in implementing radical climate and energy policies, it has introduced two changes in the energy sector to enhance the country's competitiveness in the energy sector and encourage innovation. The Energy Policy Act of 2005 and the Energy Security and Independence Act of 2007 are the two policies and significant reasons behind the country's massive investment in fuel cell technology research [4]. Despite these investments, commercialization of this relatively new technology has been slow. At this stage, it is uncertain how much public acceptance this technology will gain in the future. Currently, fuel cell technology firms are developing many prototypes and pre-commercialization products at fast speeds to try and ease the technology into the very aggressive energy market. A few innovations, however, show good prospects [27].

2.2.1 Nano gold hybrid materials for oxygen reduction reaction

A review by Umsa et al. [29] investigated the use of novel Nano gold hybrid materials for use in the oxygen reduction reaction of an alkaline fuel cell. The study highlighted that the successful application of these materials would rely on parameters such as the size and crystallographic orientations of Nanogold materials in the electrodes. This parameter is very critical and determines, to a large extent, the overall performance of the fuel cell [28]. While this gold technology might not be up to standards yet with the more expensive platinum electrode, it proved from the study that it could be a reliable and reasonable alternative. It has been discovered that Nano particulate gold has good catalytic activity for oxidation-reduction reactions [29]. The performance of Nanoparticulate catalysts is directly influenced by their size and support. Although catalytic activity usually cannot be observed at characteristic sizes more than 5 nm. The unique structure and properties of these Au Nanoparticle hybrid materials are responsible for their current and growing applications in the field of fuel cells. Despite all the prospects and successes recorded by the Nanoparticle gold electrode, fuel cells based on this technology have still not been fully understood by scientists. Their surface chemistry is still somewhat elusive; hence, they have still not yet been able to replace the traditional fuel cells. These nanoparticle fuel cells have many possible permutations; this, combined with the dynamic surface chemistry, makes them an attractive option for future study and application [30].

2.2.2 Alkaline direct ethylene glycol fuel cells

Alkaline direct ethylene glycol cells represent what can be said to be the most promising source of power for portable stationary and mobile applications. This is because this fuel cell stack runs on sustainable fuel, and the key components that make up the overall design are relatively inexpensive [31]. Ethanol is very suitable for alkaline cell use because it is a carbon-neutral transportation fuel. However, an issue exists with difficulty in breaking down its bonds at temperatures lower than 100^{o} C.

2.3 Advantages of alkaline fuel cell

2.3.1 Environmentally friendly characteristics

Hydrogen is a sustainable green energy. The final product of hydrogen combustion is the water, which is the cleanest energy and pollution-free [32]. Hydrogen combustion will not emit greenhouse gases. Hydrogen can be produced through a different process. Hydrogen can be obtained from fuel processing, biomass, and water. The fuel processing of methane is the primary hydrogen production method used in factories today [33]. Only 2%-6% of commercial hydrogen production is from electrolysis, and over 95% is from fossil fuel conversion [32]. Nowadays, more research is being done to obtain hydrogen through a cleaner process from biomass and water. Biomass used for the production can be obtained from different types of organic resources such as agricultural wastes, sawdust, corn, and others.

2.3.2 High energy efficiency

Besides that, the alkaline fuel cell is used as an essential energy storage for the spacecraft. It converts the excess electrical energy into storage through electrolysis. Hydrogen and oxygen are stored in a tank and supplied to the fuel cell when needed. The fuel cell will not be affected by the Carnot factor, which will allow it to have high efficiency [34]. A fuel cell is more efficient than the combustion of fuel, which produces heat and electricity [35]. This is because a fuel cell is not a heat engine. Conventional combustion power plants usually have an efficiency of 33% to 35%, whereas the fuel cell is able to reach an efficiency of 65% [36].

2.3.3 Low maintenance cost

The alkaline fuel cell has proven that the maintenance cost is cheaper than the conventional diesel energy generator, which allows it to be used in remote areas [37]. The initial cost of the alkaline fuel cell is higher, but the alkaline fuel has a low maintenance cost. A fuel cell is used in the vehicle as the fuel cell's energy source. Fuel cell vehicles can be considered zero-emission vehicles [38]. Alkaline fuel cells run at lower temperatures compared to the normal engine, which deals less damage to the engine. The alkaline fuel cell operated at 60 °C to 140 °C with the highest efficiency [34]. Conventional engines will operate at high temperatures, so a cooling system is needed. More operating parts means higher maintenance costs.

2.3.4 Non-toxic

Hydrogen is a non-toxic substance that is uncommon for a fuel source. Unlike nuclear energy, the power plant's failure is catastrophic and will harm human beings. In the various accidents that occurred, radioactive substances released caused the death of thousands of people, and the area around it was quarantined. This can be seen in the various nuclear power plant accidents: the Three Mile Island, Chornobyl, and Fukushima [39]. Hydrogen is unique compared to other fluids, which have high solubility and are easily diffused with other materials at room temperature [40]. This reduced the chance of affecting the health of the human body.

2.4 Disadvantages of Alkaline fuel cells

2.4.1 High difficulty in storage

Storage of the hydrogen for the alkaline fuel cell is an issue. The hydrogen is stored in three types: compressed gas, adsorbed gas, and cryogenic liquid gas [41]. Commonly, hydrogen is stored using compressed gas and cryogenic liquid gas. The high pressure of the hydrogen storage caused the design of the cylinder storage tank to be bulky. Besides that, metals will become brittle when consistently in contact with hydrogen gas. This is known as the hydrogen embrittlement [42].

2.4.2 Fossil fuel still needed

Hydrogen production commercially nowadays mainly uses fossil fuels, including natural gas, petroleum, and carbon [43]. Hydrogen is not considered renewable energy when it is produced from fossil fuels. Hydrogen gas production will still cause the emission of greenhouse gases and the depletion of fossil fuels. This production method is not the long-term production method for hydrogen. Although hydrogen can be produced through water electrolysis, only 4% of the total production of hydrogen gas is produced by water electrolysis [44].

2.4.3 Flammable

Oxygen gas and hydrogen gas may not be toxic, but they are flammable. The pure hydrogen will not explode, but it will burn if not handled with care. Hydrogen flame is almost invisible under daylight. This is because the wavelength of the flame is similar to ultraviolet, which is about 311nm [41]. The hydrogen can produce more than 2,000 degree Celsius when burning in the air which is considered low in the combustion of the fuel.

2.4.4 Costly to use

The fuel cell contains no moving parts and should have a lower production cost. However, the materials, catalysts, and sealing of the alkaline fuel cell are the main costs of the fuel cell, which will be extremely expensive to achieve high efficiency [45]. More research needs to be done to increase the performance, reliability, and durability, which means more cost for the research. This will increase the cost to produce the fuel cell. Various problems are faced during the scaling-up of the fuel cell, including degradation, uneven chemical reaction, reduction of active area, and others [46]. The lifecycle cost of the fuel cell is higher than the internal combustion engine and hybrid engine due to the high initial cost [47]. Therefore, large production is needed to reduce the cost of the fuel cell.

2.5 Comparison with other fuel cells

Alkaline fuel cells are fuel cells with an alkaline electrolyte that consumes hydrogen and pure oxygen and produces water, heat, and electricity (Figure 3). They are among the most efficient fuel cells, reaching 70% [48]. In the last decade, energy-related problems are on the rise. One of the means of renewable energy conversion is via alkaline fuel cells. These fuel cells are used to produce electrical energy [49]. Alkaline fuel cells can be compared with a number of other fuel cells some of those fuel cells are mentioned as follows:

- Direct methanol fuel cells (DMFC)
- Molten carbonate fuel cells (MCFC)
- Phosphoric acid fuel cells (PAF)
- Proton exchange membrane fuel cells (PEMFC)
- Reversible fuel cells (RFC)
- Solid oxide fuel cells (SOFC)

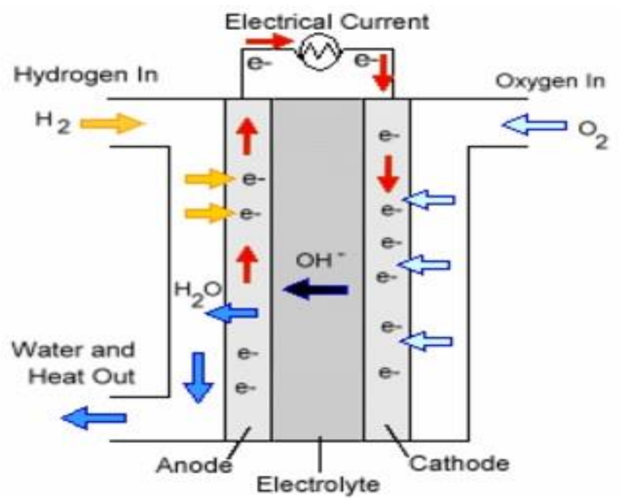


Figure 3. Process of alkaline fuel cells

2.5.1 Direct methanol fuel cells

DMFC is a promising alternative for reinforcement control frameworks and the power supply of convenient gadgets. Although DMFC has complex electrochemistry, it is promising as a power hotspot for compact and uninterruptable power supply applications. It is attractive in terms of high energy density liquid fuel, quick recharging by refilling, and low operating temperature [50]. During the process, both methanol and water can undergo a phase transition from liquid to gas phase, as shown in Figure 4.

$$H_2O\ (gas) \leftrightarrow H_2O\ (liquid) \quad (1)$$

$$CH_3OH\ (gas) \leftrightarrow CH_3OH\ (liquid) \quad (2)$$

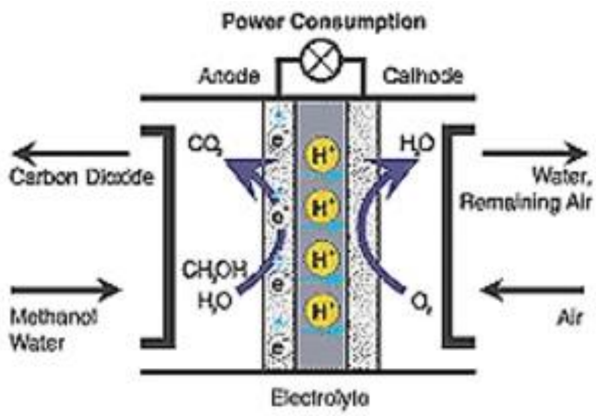


Figure 4. The schematic process diagram of direct methanol fuel cells

2.5.2 Molten carbonate fuel cells

MCFC utilizes liquid salts as fuel for energy devices (Figure 5). Electrolyte membrane constituted by a liquid carbonate eutectic and a lithium aluminate solid support attractive. Liquid carbonates are non-toxic and very conductive salts. At a regular working temperature of 650°C, heat and electrical power are generated. The liquid carbonate goes about as whatever other dissolvable, for example, water [51]. The separation produces acidic-fundamental properties, which control the conduction. The condition of equilibrium is written below:

$$M_2CO_3 (l) \leftrightarrow M_2O (s) + CO_2 (g) \quad (3)$$

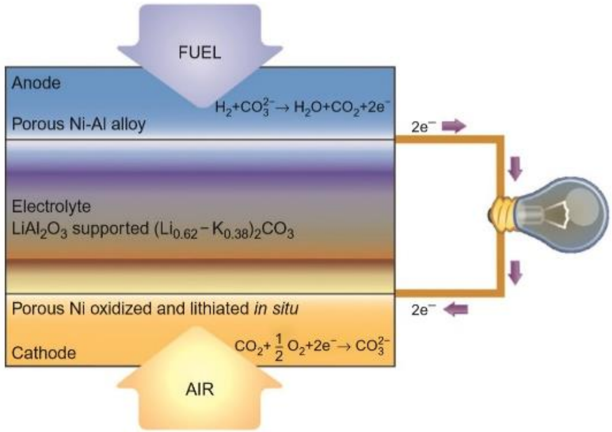


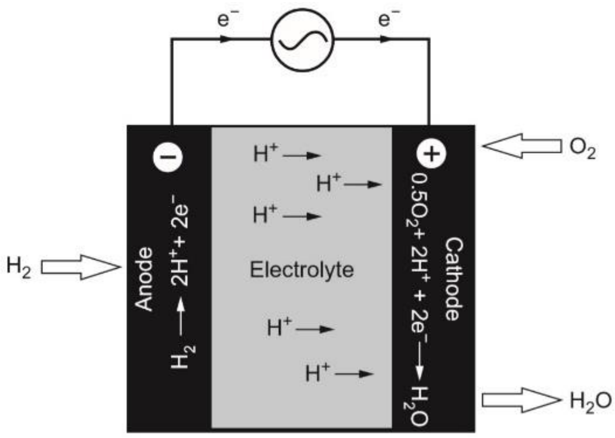
Figure 5. Process of molten carbonate fuel cells

2.5.3 Phosphoric acid fuel cells

PAFC is the most industrially propelled innovation among the hydrogen-oxygen fuel cells (Figure 6). PAFC is distinct from the other energy conversion systems because the electrolyte operates at 160-220°C. CO poisoning of the platinum catalyst is additionally diminished. PAFC is discovered to be valuable in stationary power distribution, defense, and military applications. Because of the utilization of valuable metal electrocatalysts, it is expensive. The chemical energy of the reaction is converted into electrical energy [52]. The equations of the process at the electrodes are shown below:

Anode: $H_2 \rightarrow 2H^+ + 2e^-$ (4)

Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (5)



Overall: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ (6)

Figure 6. Process of phosphoric acid fuel cells

2.5.4 Proton exchange membrane fuel cells

PEMFCs are the cells where electrochemical reactions occur to produce electrical power (Figure 7). Proton conducting film comprises catalyst layers and gas diffusion layers. These segments are manufactured independently and, after that, squeezed together at high temperatures and pressure. The equations of the electrodes are shown below:

Anode: $\frac{1}{2} O_2 + 2H+ + 2e- \rightarrow H_2O$ (7)

Cathode: $H_2 \rightarrow 2H+ + 2e-$ (8)

The flow of ionic charge through the electrolyte must be balanced by the flow of electronic charge through an outside circuit, and this balance produces electrical energy [53].

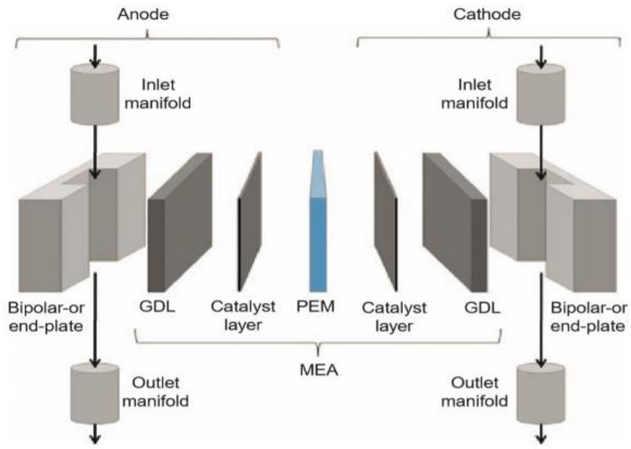


Figure 7. Process of proton exchange membrane fuel cells

2.5.5 Reversible fuel cells

RFC offers an answer for creating fuel using surplus power and reconverting this into power utilizing a similar device (Figure 8). RFC system in electrolysis mode can be utilized to make hydrogen and oxygen, which are put away in tanks. On the off chance that there is an absence of vitality, then the put away hydrogen and oxygen are utilized as working fuel to produce power. Hydrogen and oxygen are both naturally well-disposed and economical [54]. The overall reaction of water electrolysis is expressed as:

$H2O$ (g/l) + electrical energy + heat $\rightarrow \frac{1}{2} O_2 + H_2$ (9)

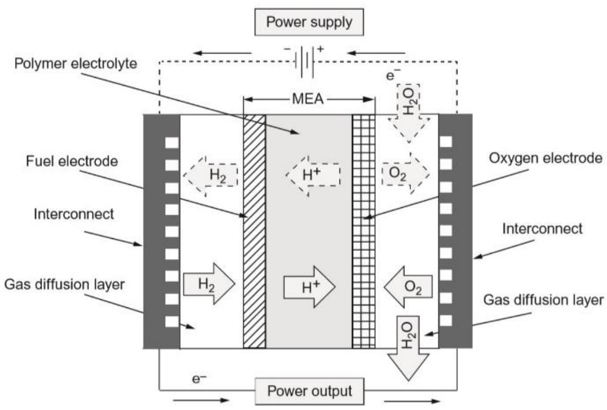


Figure 8. Process of reversible fuel cells

2.5.6 Solid oxide fuel cells

SOFC is a device that allows the prompt change of substance vitality into electrical vitality at high temperatures, using an all-strong state cell equipped with ceramic materials (Figure 9). These frameworks can, on a basic level, accomplish productivity levels higher than customary advancements used to make power. The responses included are fundamental and undefined to those incorporated into the interior burning engine. SOFC includes three segments gathered together to shape like a sandwich. A thick electrolyte is sandwiched between two penetrable terminals, the cathode and anode [55]. The following equations are involved in the anode and cathode, as shown below:

Anode: O_2- (s) + H_2 (g) = H_2O (g) + 2e- (10)

4O_2- (s) + CH_4 (g) = 2H_2O (g) + CO_2 (g) + 8e- (11)

Cathode: ½ O_2 (g) + 2e- = O_2- (s) (12)

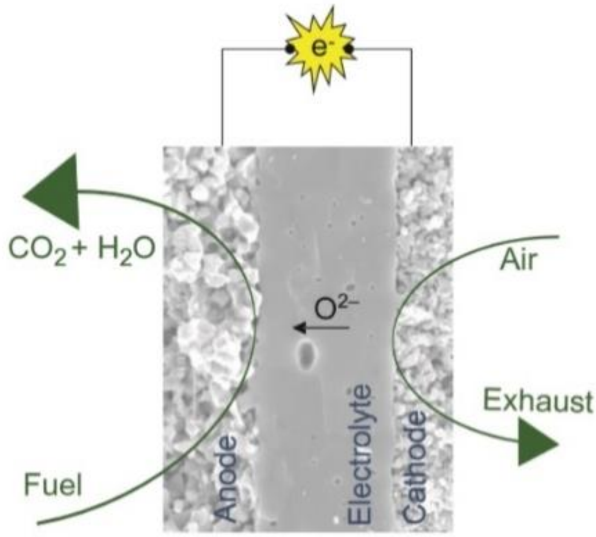


Figure 9. Process of solid oxide fuel cells

2.6 Fuel cell applications

2.6.1 Maritime activities

Shipping is a significant activity that contributes massively to the global emissions of greenhouse gases, volatile organic compounds, particulate matter, hazardous air pollutants, and oxides of Nitrogen and Sulphur. 3.5% of CO_2 emissions and over 5% of SO_x emissions worldwide are the result of shipping activities. Despite introducing modern propulsion technology, the shipping industry has failed to reduce emissions. This puts them behind the road transport. The absence of strict environmental regulations at sea can also be a major factor in why shipping has a poor environmental emissions record [56]. Fuel cells have the potential to be of use onboard ships. Application of fuel cells in different vessels includes emergency power supply, electric energy generation, especially in waters and harbors prescribing environmental regulations; small-scale power output for propulsion at unique operating modes (e.g., very quiet run); and generation of electrical power to satisfy the needs of the ship. The fuel cell is used in submarines to achieve air-independent propulsion, and the Proton Exchange Membrane Fuel Cell system was utilized on German Navy submarines [57].

2.6.2 Stationary power generation

Molten carbonate fuel cell (MCFC) is the most promising high-efficiency and sustainable power generation technology, as demonstrated by the current availability of several commercial units in the market. Stationary power generation utilizing MCFC technology offers an efficient alternative to power plants fueled by coal. MCFCs have emerged as the preferred technology for commercialized stationary power generation. Various companies around the globe are conducting tests on big-scale power generation systems that consist of kilowatt to megawatt-class systems. Some companies are expanding their systems to hospitals, hotels, data centers, and other industries with lower power demands, including wastewater treatment plants [58].

2.6.3 Space programs

The alkaline fuel cells (AFC) utilized in space shuttle programs of the United States are unable to withstand CO2. The polymer electrolyte fuel cell (PEFC) was developed initially for use in space and was used for quite some time until its sensitivity to CO was discovered. In terrestrial applications, fuels that contain hydrocarbon compounds had to be used in various applications, and the presence of carbon monoxide and dioxide was detrimental to the systems. In order to overcome this hurdle, the phosphoric acid fuel cell (PAFC), the molten carbonate fuel cell (MCFC), and the solid oxide fuel cell (SOFC) were developed [59].

2.6.4 Transportation and portable energy

Polymer electrolyte fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs) have been seen as compatible sources of power generation for electric cars. In theory, methanol possesses greater specific energy density (6000 Wh/kg) when compared to the best rechargeable battery in the market, lithium polymer, and lithium-ion polymer (theoretical, 600 Wh/kg) systems. This advantageous efficiency trait can be utilized to enable longer battery life in cell phones, laptop computers, and other consumer electronics. These fuel cells can also increase the battery's lifetime, thereby giving longer hours before replacement [60].

2.6.5 Automotive applications

In the automobile market, carmakers have made significant efforts to switch to more efficient and sustainable fuels to power vehicles. Various laws have been enforced on automobile manufacturers that force them to adhere to strict emission standards as well as fuel consumption margins. Hence, there are continuous efforts in this industry to develop technology that meets these requirements. Fuel cell technology can be the answer as it gives the manufacturers what they need: environmental compatibility, consumer profit, costs of maintenance, and efficiency [20]. Alkaline fuel cells can be used in the automotive industry and have high power density requirements. However, when compared to the PEFC, the simplicity of AFC technology enables the utilization of affordable materials for catalysts, electrolytes, and other parts needed for the cell and the system. PEFCs could be the future of automotive applications, but only after implementing a method of reducing the costs significantly. This puts AFCs at a big advantage compared to the PEFC [61].

2.7 The Future of fuel cells

2.7.1 Direct methanol fuel cells

To reduce greenhouse gases and avoid the violation of current environmental rules and regulations, a system with high efficiency combined with economic feasibility must be created. This energy conversion system with the abovementioned benefits is seen in DMFCs [60].

2.7.2 Hybrid systems

Solar and wind energy are the types of energy sources preferred these days due to their natural abundance and unlimited supply. However, due to the various geographical limitations, such as the need for low cloud cover for solar energy and high-speed wind areas for windmills, harnessing energy consistently has been a challenge. Results from various experiments showed that by combining solar energy, wind energy, and fuel cells, a hybrid system can be designed that will prove to be a plausible solution for applications hindered by geographical limitations. These systems, known as hybrid power systems, will considerably increase the energy supply [62]. Studies conducted in the past support using a fuel cell as another energy source to overcome such problems.

2.7.3 Direct oxidation of alkaline fuel cells

Direct oxidation alkaline fuel cells (DOAFCs) have recently gained attention due to their potential to solve problems encountered in the Proton Exchange Membrane fuel cells. A polymer electrolyte made up of an anion exchange membrane has been found to reduce carbonate build-up from the CO_2 released. The electro-oxidation of fuels enables the utilization of cheaper metals such as palladium, silver, and nickel as well as perovskite-type oxides in alkaline fuel cells, which will decrease the catalyst cost considerably compared to catalysts made of platinum [63].

2.7.4 Electric vehicles

The benefits of running electric vehicles on fuel cell power plants are an established technological fact. PEM and PAFC systems are tested, their results are studied, and viability is assessed. A significant factor in deciding the use of a fuel cell type is the economics associated with that cell. Similarly, the fuel needed to power these cells is also significant in automotive applications. Ammonia is a key ingredient in most fuel cells as it is available all around the globe and has the added use of being a gasoline additive to clear the presence of nitrogen oxide from exhaust gases, as suggested by Renault [64].

3. Results analysis

3.1 Challenges

The challenges facing fuel cells are quite simply that of efficiency and costs associated with the manufacturing and running of those fuel cells. Future research will focus on these aspects, and once plausible solutions have been found, fuel cells can finally answer energy requirements in particular industries [65]. Solid oxide fuel cells (SOECs) are operable on natural gas and gasoline fuels. They are also compatible with alternative or green fuels such as hydrogen and biofuels. The only obstacles facing it are reduced operating temperature and cost [66]. PEMFCs are believed to have great potential for use in the transportation sector. High cost is a significant factor slowing down the progress and entry into commercial use [67]. A low-power system constructed using AFCs will compete with a PEMFC system regarding running costs. AFCs are cost-efficient and hence preferable over PEMFC systems [68].

3.2 Importance of alkaline fuel cells in the future

A fuel cell system is an advanced power device for the future that is sustainable, environmentally friendly, and clean. Fossil fuel storage is limited and will be replaced in 70-150 years. Persistent utilization of non-renewable energy sources will produce greenhouse gases, prompting environmental change and an Earth-wide temperature increase. Alkaline fuel cells produced the power for NASA's Gemini and Apollo space containers, giving the group drinking water. The technology of the alkaline fuel cells will contribute essentially to a reduction in environmental impacts, improved vitality security, and the formation of new vitality businesses. Basic energy components can be used in transportation, distributed heat and power generation, and energy storage systems [69]. Technical improvements are dependable on increments in overall car advertising. Dramatic restrictions on emissions as well as the regiment of fuel consumption by legislation. The technology of fuel cells offers the likelihood to exceed expectations as far as environmental compatibility, consumer benefit, cost of maintenance, and efficiency. The alkaline hydrogen energy components framework with flowing KOH electrolyte and minimal effort-catalyzed carbon cathodes could be a promising alternative [70]. Alkaline direct methanol fuel cells are a type of alkaline fuel cell that converts the chemical energy stored in ethanol directly into electricity. This produced electricity can be utilized in automobiles because these alkaline fuel cell components keep running on carbon-neutral, sustainable fuel, and the electro-catalyst and membrane materials that constitute the cell are relatively inexpensive [3]. Daihatsu is a big name when it comes to automobiles. They are one of the biggest automobile names in Japan. Daihatsu Motor Company developed a fuel cell that eliminates the need for platinum. This alkaline fuel cell runs on easily handled hydrazine hydrate. It is safe to use as polymer technology developed by the company [71]. Electricity generation is another significant factor in the future of alkaline fuel cell components. Electricity generation from macro-algae utilizing alkaline fuel cells. This renewable power source innovation can relieve the energy crisis emergency and significantly reduce global warming emissions [72]. Algae stand out amongst the most encouraging supportable wellsprings of sustainable power sources since they have higher growth rates, require less earth's surface, and don't contend with other food productions [73]. Electricity is additionally generated from refillable glucose alkaline fuel cells with methyl viologen-immobilized activated carbon-nickel anode. The electricity produced by alkaline fuel cells has a lot of advantages, such as less pollution, high efficiency, and adaptability to deal with various fuel sorts. Glucose is abundant, cheap, nonpoisonous, simple to get and store, and convenient to transport; it is a potential positive fuel for energy components. The only issue confronted is the high cost [74, 75].

4. Conclusion

Research on Alkaline Fuel Cells is conducted by only a few segments of researchers based primarily in Europe. The most common problems hindering the use of AFCs have been solved, and new and innovative ideas for developing systems have been developed. Overcoming the challenges of cost and efficiency will make fuel cells the answer to the global population's demanding and increasing energy requirements.

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Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The author declares no potential conflict of interest.

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