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Fuel Cells as a Source of Green Energy

Rabea Q. Nafil and Munaf S. Majeed

Abstract

A fuel cell is an effective tool for extracting chemical energy from a special type of gaseous fuel other than fossil fuels. It is expected to be a replacement for thermal engines and rechargeable batteries within the next few years as they are emission-free and not subjected to Carnot restrictions. The fuel cell can be manufactured in different sizes depending on the amount of energy required, where it can be too small to be used in precision equipment or large enough to work as electrical stations. This proposal shows a demonstration of the principle of work involved in the fuel cells, structure components, and practice ideas to enhance the output power.

Keywords: energy extraction, fuel cell, green energy, zero emission, hydrogen energy

1. Introduction

Most of the power generators use conventional fuel and they obey the same operation principle that is transforming chemical energy to mechanical energy [1]. The heat engine (which is a very common conventional generator) burns or oxidizes the fuel in the air [2]. The chemical energy of fossil fuel is converted into thermal energy and this is the first step of its operation. The rising temperature and pressure lead to expanding engine gases. These excited gases rotate a crankshaft (conversion energy from thermal to mechanical energy step). Finally, the electricity is generated by the mechanical work done by the crankshaft [2]. Now it becomes clear that the production of electricity by heat engine passes through three stages. The overall conversion efficiency declines as the number of stages increases and this is one of the main disadvantages of heat engines [3].

Thermal engines have not been at the top of the list of energy sources despite their ability to provide high energy. This is due to several reasons, including that thermal engines cause increased global warming and environmental pollution by emitting carbon dioxide. Thermal engines often use fossil fuels which are originally threatened with depletion. Also, the sustainability of damaged mechanical parts adds an economic cost to the manufacture and operation of conventional engines. All these reasons prompted the search for new and sustainable energy sources that can compensate for the deficiencies in traditional sources of energy generation and storage. The solution embodies the use of fuel cells, which are not only a source of green energy but also fill the lack of advantages of both the thermal engines and rechargeable batteries. Their simple construction and non-use of fossil fuels gave them the ability to work for a long time without the need to replace their damaged parts. Fuel cells have unlimited operating time, higher power density and therefore greater storage capacity to outperform the advantages of a simple battery and rechargeable battery [4].

Fuel cells are zero pollution' power generators. They work as an electrochemical converter to chemically produce electrical energy from gas fuels. The conversion occurs directly by the chemical reactions and without burning of the fuel. Even better, they are not following the thermodynamic laws that limit most of the power plants. This chapter presents the operation principle of fuel cells, their main components, and finally the newer trends in developing these cells for commercial uses.

2. The fuel cells' principle of work

The main components of a fuel cell are two electrodes isolated from each other with a membrane (either solid or liquid electrolyte). The added parts are usually to improve the functioning of the cell. According to Eq. (1) [5], the gas fuel (hydrogen) oxidized at the anode to produces electrons and cations during entering of the oxidant from the cathode. These released electrons depart the anode through an external circuit and create an electric current before reaching the cathode. The electrons current can be utilized in working any load [5].



The positive hydrogen ions diffuse through the membrane and recombine with the exhausted electrons that reached at the cathode to reproduce H_2 gas. Finally, the produced hydrogen atoms combine with the oxygen atoms to generate water as the only waste of the complete reaction. Eqs. (2) and (3) show the reduction of oxygen and the fuel cell reaction, respectively [6, 7].



Fuel cell' efficiency is greatly influenced by the quality of the electrolyte. It increases with increasing the membrane ability to block electrons generated from the oxidation of the anode from reaching the cathode. Therefore, the electrolyte must be chosen with caution as it acts as a filter that allows only positive ions to pass

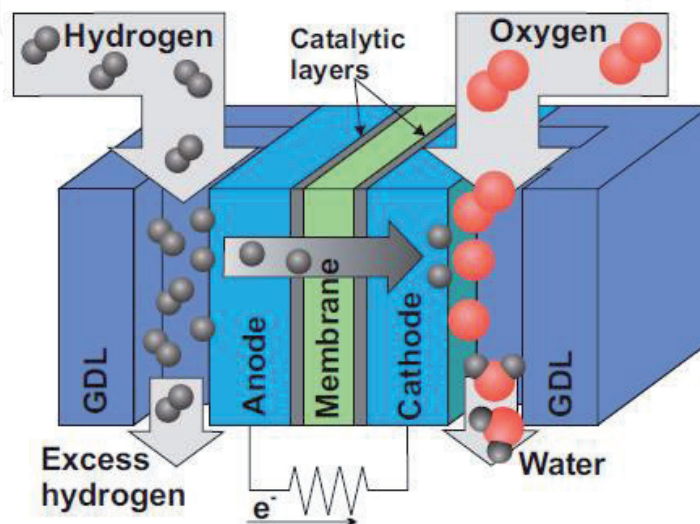


Figure 1.
The components of fuel cell [11].

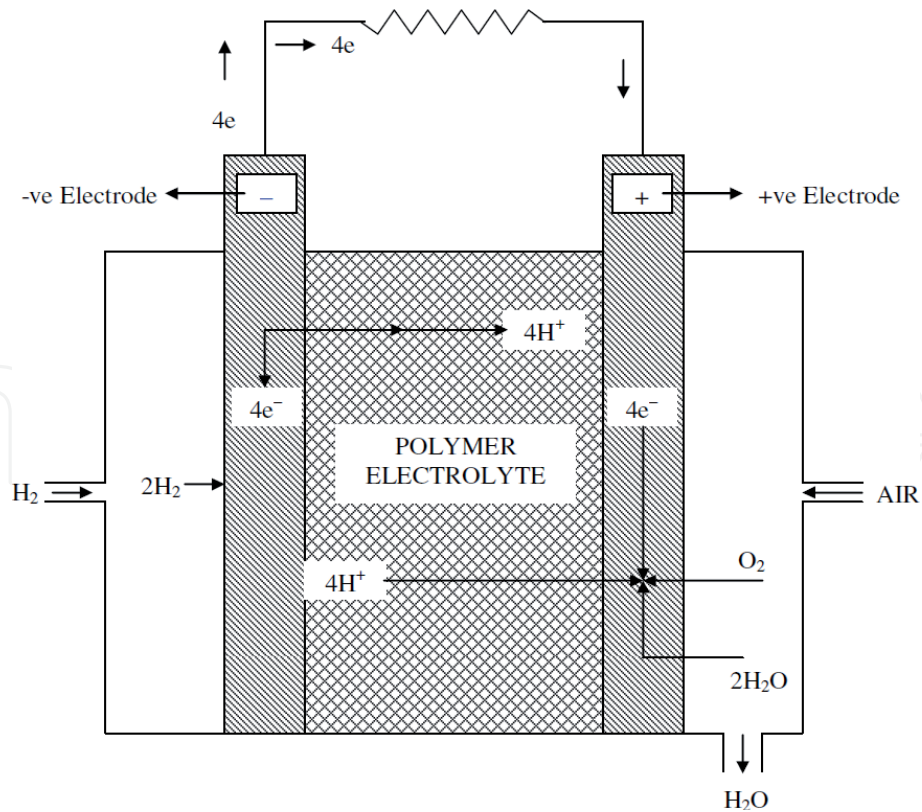


Figure 2.
 A scheme of oxidization processes at the electrodes [13].

through it in one direction only which is the direction of the cathode [8]. To reduce the reaction energy on the two electrodes, a catalyst is added [9, 10]. The structure of the fuel cell is displayed in **Figure 1**.

Theoretically, the anodic substance could be any material that gives up electrons such as hydrogen, methane, kerosene, or even carbon. But among all, hydrogen is preferred due to its availability, has a high energy density, and good reactivity with catalysts [12]. Also, the best choice of oxidant agent is oxygen gas because it is easily subjected to a reduction reaction and is much available in the air. **Figure 2** illustrates the oxidization reaction schematically.

3. The main components of fuel cells

In addition to the two electrodes and their separator electrolyte, other additional parts are required for specific tasks such as gases flow and electrical insulation or connection. These parts are shown in **Figure 3**.

3.1 The end plates

The outer sides of the anode and the cathode are supported mechanically by plastic plates which are called the endplates. Their main jobs are to save the fuel cell component and to prevent the reacting gasses from leaking [15].

3.2 The bipolar plates

A fuel cell has two bipolar plates each one consists of a current collector and separator plate. They are manufactured from a metal or a carbon-filled composite (conductive polymer) [16]. Researchers suggested several designs of

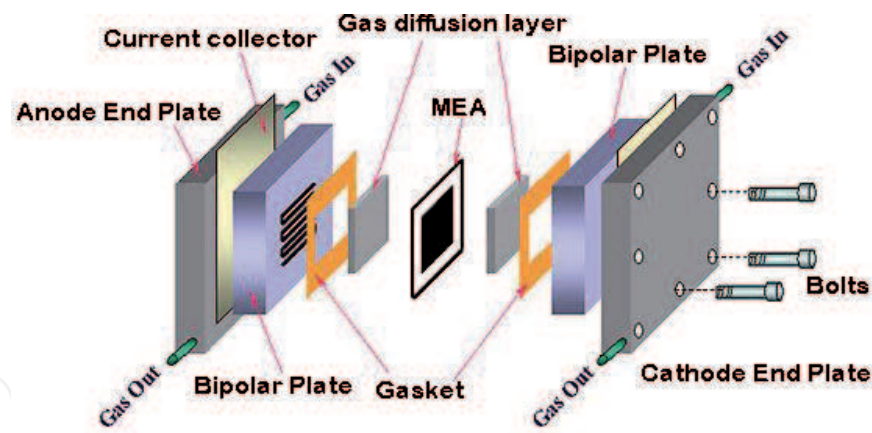


Figure 3.
The component of fuel cell [14].

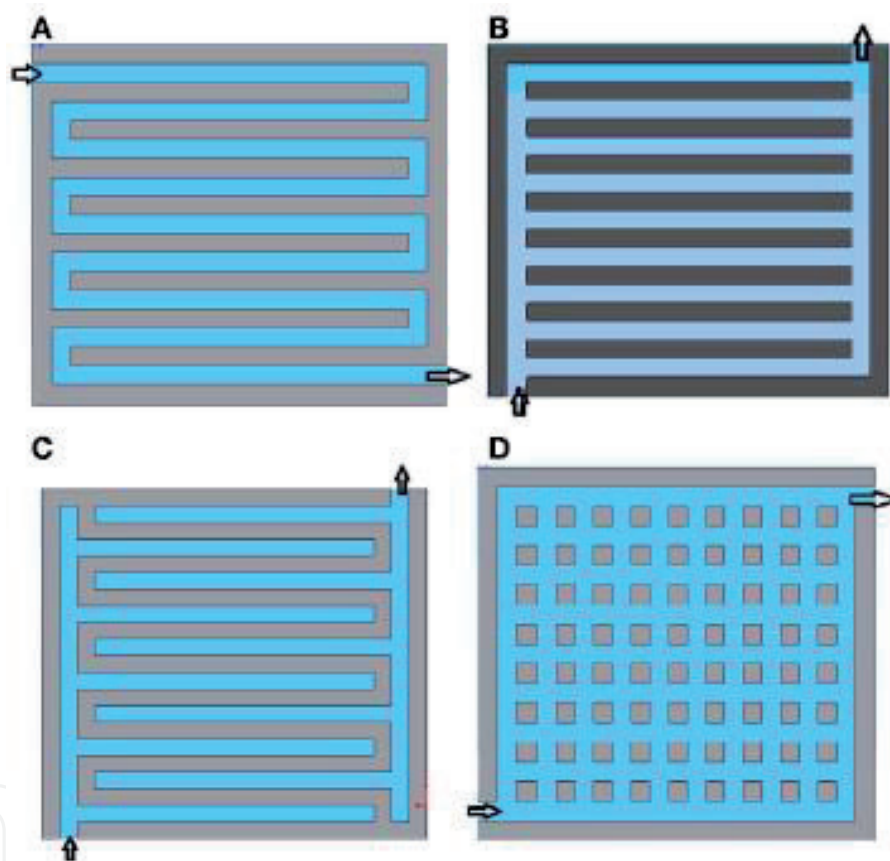


Figure 4.
Various designs of bipolar plates [17].

the bipolar plate to feed the gaseous fuel to the electrodes uniformly as shown in **Figure 4**. Their designs differ by the shape and the distributions of the gas flow channels.

When many cells are connected in one stack, the bipolar plates conduct current between the adjacent cells. Another function of the bipolar plate is to dissipate the generated heat during the chemical reactions [18, 19].

3.3 Gaskets

Gaskets are sheets of rubbery polymer used to prevent leaking of reactant gases and coolant. They are carefully selected to be able to withstand the propellant of gaseous fuels, resist operating temperature up to 100°C, not affected by ambient

air humidity or moisture of reaction gases, non-corrosive by liquid acids, and also withstand mechanical pressures resulting from prolonged operation [20].

3.4 The gas diffusion layers

Two pieces of a conductive material and they are representing important parts of the fuel cell. They are manufactured in a porous form using carbon fibers weaved into carbon papers or clothes [21]. Their major works are to transfer the reactants between the bipolar plates and the catalyst layers, assist the dissipation of the produced water and heat from the catalysts and protect them from corrosion [22].

3.5 Membrane electrodes assemble (MEA)

A compact unit which is responsible for producing the output power of the fuel cells. Its thickness approaches a few hundred microns and consists of; the electrolyte, the two electrodes with their catalysts, with/without GDL [23]. These components are:

3.5.1 The electrodes

As in any electric cell, the fuel cell has two electrodes that are cathode and anode. At these parts of fuel cell the chemical reactions which produce electricity occur. Therefore, the catalyst is required for each electrode. When hydrogen atoms enter a fuel cell at the anode, the catalyst strips them of their electrons in the oxidation process. The oxygen reduction occurs at the cathode. The electrodes that have a large active surface area of electrode to catalyst are regarded as a good electrode. The overall performance of the electrode should be stable during operation time, and this can be satisfied by choosing a suitable catalyst for the specific electrode material, distribution the catalyst over the electrode uniformly, remove the produced excess heat and water, and most importantly for the best connection with the external electrical circuit.

3.5.2 The electrolyte (membrane)

The electrolytes are thin plastic-like or solid polymer membranes. Their main function is to pass the hydrogen positive ions from the anode to the cathode while completely block the free electrons from moving in this direction [18]. If the free electrons could pass through the electrolyte, they would hold up the chemical reaction. The filtration process is based on the semi-permeability of the membrane. There are several mechanisms of ions permeability through the membrane including absorption and adsorption, distillation, extraction, physical filtration, and stripping.

The compositions of the electrolytes are perfluorosulfonic acids, which are Teflon-like fluorocarbon polymers that have side chains ending in sulfonic acid groups ($-\text{SO}_3^-$). Such acidic polymer electrolytes require water to conduct hydrogen ions. Therefore, the reaction gas (H_2) in contact with the electrolyte must be saturated with water. The commercial name of Teflon based polymer electrolyte is Nafion [20]. It has a high ionic conductivity at 80°C , good thermal and chemical stability [24–27], and high chemical resistance. Its chemical chain is shown in **Figure 5** [28].

Fuel cells performances improve largely with increasing temperature to 90°C due to the decline in ohmic resistance of their electrolytes [29]. But at higher temperatures, the fuel cell will dry. Since Nafion ionic conductivity is strongly dependent on water content, the Nafion membranes will have an osmotic swelling problem and maybe potentially dissolve in methanol solution when increasing methanol concentration and temperature.

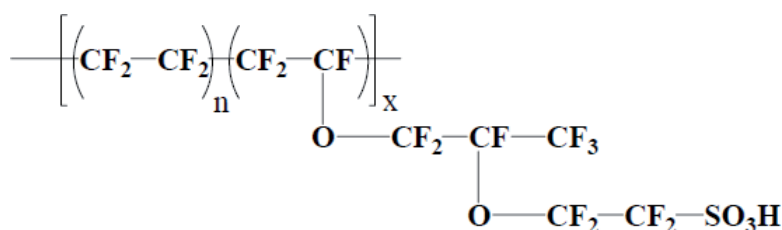


Figure 5.
Nafion chemical chain [28].

3.5.3 The catalysts

The catalysts are special chemical materials used to increase the rate of reactions without being consumed. The main condition of the material to be used as a catalyst is to stay unchanged after reactions. Therefore, they could be recovered from the reaction mixture chemically. The existing of catalysts reduces the reaction energy barrier and thus speeds up the reaction at low temperatures [30]. Most types of fuel cells used platinum (Pt) and its group as a catalyst at the two electrodes. At the anode, the Pt catalyst helps in splitting the hydrogen molecules into free electrons and positive cations. While at the cathode, it enables oxygen reduction [31]. A perfect catalyst for a fuel cell is the one with high electric conductivity, stable during contact with the reactant gases and the electrolyte.

4. The new trend in enhancement fuel cell performance

All types of fuel cells are a good source of green energy, but none is yet suitable enough to replace traditional sources. That leads the designers to spend their efforts on improving efficiency, size, weight, and cost. Some new trends to enhance fuel cell performance are explained as the following:

A single fuel cell generates a little electrical current, so a group of cells is connected in a geometrical form called a stack. The bipolar plates in any fuel cell stack cause most of the weight and participate in the cost. Hence, the dimensions and manufacturing cost of the stack can be significantly reduced if the bipolar plate is removed. Some designers used laser ablation to sculpture microchannels on the cell electrodes to increase the gas flow rate. They found that by this simple idea the bipolar plates could be excluded [32].

Oxidation and reduction process occurs on the surface of the catalyst, which necessitates an increase in the reaction space between the catalyst and the reaction gases. But this contradicts the continuous tendencies to lower the cost of fuel cell since Platinum is very expensive. Although platinum is preferred as a catalyst in most fuel cell types because it is a stable and active substance, a less expensive alternative should be found. So it was replaced by palladium. One way to increase the active surface areas of the catalysts is to reduce particles size. For this, nanotechnology had been used in many research works to manufacture porous nanocatalyst to exclude bulk catalyst and gas diffusion layer [32].

5. Conclusions

According to the explanations given in the previous syllabuses of the chapter, the following conclusions can be reached.

1. Energy extraction by the burning of fossil fuels goes through three stages and in each stage is spent energy to complete the process. Therefore, the efficiency

of internal combustion generators is low. Whereas in fuel cells, production is direct and not subject to Carnot limitations, which increases fuel cell efficiency.

2. Fuel cells use hydrogen gas, which is available in air and can be produced in secondary ways such as the electrolysis of water. Therefore, fuel cells are economical and there are no difficulties in manufacturing them in countries which have not petroleum.
3. It does not cause harmful gas emissions and thus it is considered environmentally friendly.
4. Using laser and nanotechnology, fuel cells can be manufactured in very small sizes that can be included in micro devices such as mobile phones and medical devices.

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