Various Well-Designed Hydrogen Fuel Cells: Structure, Principle, and Advantages

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Abstract. Nowadays, with the increasing use of fossil fuels, more and more environmental problems appear, like global warming and air quality degradation. In different industries that use fossil fuels as fuel, the harmful greenhouse gases emitted by car engines account for a large proportion. This paper will discuss the hydrogen fuel cells used for vehicles nowadays, which consist of three different kinds. These hydrogen fuel cells have similar structures, only different in some specific sectors. They have many advantages over traditional fossil fuels, like higher efficiency and lower carbon dioxide emissions. The basic structure, development process, principle, and catalysts needed for reaction will be introduced. Also, the advantages of each of the fuel cells will be discussed compared to others. The study of hydrogen cells in this paper can help understand its benefits. By promoting the development of hydrogen fuel cells, there will be more clean and efficient energy options in the future.

Keywords: Hydrogen fuel cell; principle; catalysis; vehicle.

1. Introduction

The choice of energy sources is a point of great concern in all parts of history. As human society continues to advance, people's preferences for fuel are no longer just based on how much heat it releases; they are also starting to consider how fuel affects efficiency, safety, and the environment. At present, dependence on fossil fuels has led to many environmental problems. For example, climate change and ecological harm caused by environmental pollution, the acceleration of global warming, the tension between various regions caused by the uneven distribution of fossil fuels, and so on [1]. Therefore, to find suitable alternative energy sources to meet the growing demand for energy, hydrogen and hydrogen carriers have become a good choice.

Recently, based on the situation, many countries have already made some progress in the field of fuel cells. In the electrochemical reaction, hydrogen can react with oxygen to produce electricity in the fuel cell. The resulting clean, efficient energy can be used for different purposes such as lighting, transportation, and so on. Alkaline fuel cells (AFC) and proton and anion exchange membrane fuel cells (PEMFC and AEMFC) are three types of hydrogen fuel cells that will be discussed in this paper. It will also give a brief rundown of how hydrogen fuel cells work. Since hydrogen is an unstable fuel, the way of storage becomes a really important factor affecting the safety of vehicles using hydrogen fuel cells. The choice of catalysts in the cell will also be discussed with their impact on the efficiency. However, compared with other mainstream fuels, hydrogen fuel cells still have some problems to solve, and in the future, there may be improvements in the catalyst or structure to make hydrogen cells more practical and reduce the cost of hydrogen energy vehicles to increase production.

2. Problems with Fossil Fuels for Traditional Vehicles

Although fossil fuels are still the dominant part of fuel use today, their negative effects are also increasing. There are fewer fossil fuels accessible, and greenhouse gas emissions, such as carbon dioxide emissions, are rising. The major issues that cause urban air pollution are because of road transportation and the production of fuels, especially in growing megacities [2]. Fig. 1 shows the forecasted fossil fuel surplus in 2020. Although this prediction is not accurate at present, it is also a reminder of the shortage of fossil fuels. Fig. 2 shows the increasing trend of carbon dioxide year by year in different countries. Human beings are facing the dilemma of increasing demand for fossil energy and the greenhouse effect brought about by the extensive use of fossil energy. To solve this contradiction, human beings have been actively exploring new energy sources to replace fossil energy sources and control greenhouse gas emissions, which means that cleaner fuels should be used to replace coal in traditional thermal power and oil in the power industry.

Fig. 1 Year of fossil fuel reserves left, 2020 [3]

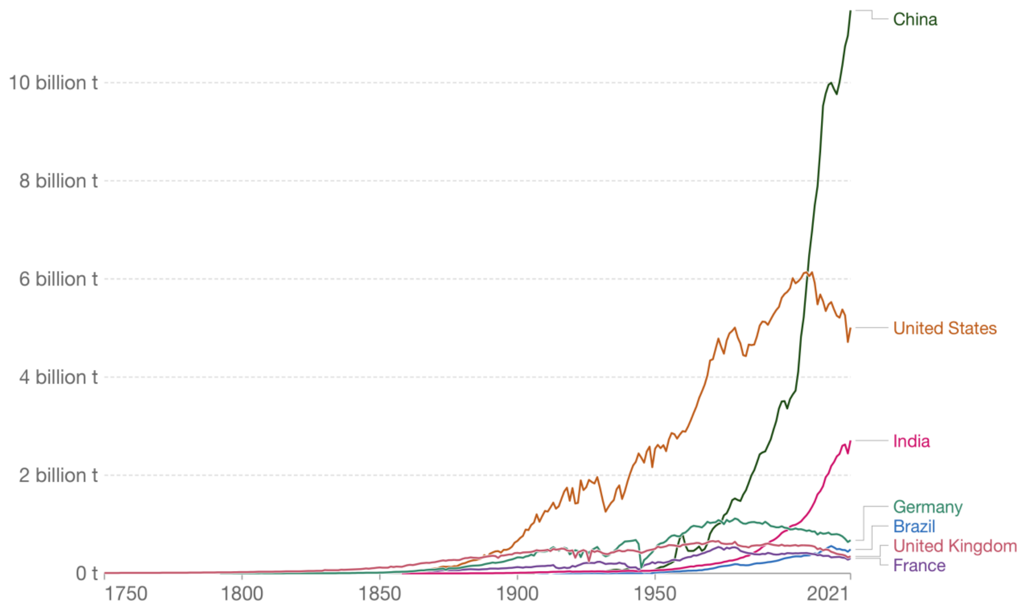

Fig. 2 Annual CO_2 emissions [4]

3. Hydrogen Cell

A fuel cell is a power generation device, but it keeps adding fuel to retain power rather than being discarded like a standard non-rechargeable battery or recharged like a rechargeable battery. Fuel for hydrogen fuel cells is hydrogen. In the hydrogen fuel cell, chemical energy is converted into electrical energy. Fuel cells come in a wide variety of forms, but they always operate on the same fundamental principle: the anode, electrolyte, and cathode are three neighboring components. Although there are many different types of fuel cells, they all work on the same basic idea: the anode, electrolyte, and cathode are three adjacent parts. Similar to this, oxygen is reduced to water by cations and electrons at the cathode in a reduction process [5].

Depending on the electrolyte, hydrogen fuel cells have a variety of groups. Three different types of hydrogen fuel cells will be covered in the section that follows. Although the primary fuel for these various hydrogen fuel cell types is hydrogen, they all have different environmental specifications and purposes.

3.1. AFC

AFCs, which are mainly used in drinking water, space shuttles, and other applications, are the newest and most rapidly developing type of fuel cell technology. It was used during the Apollo missions to the moon. This technology was invented in 1939, widely used, and further developed in the 1950s and 1960s because of its technological advances; however, because of its intolerance to carbon dioxide and other problems like difficulties in the management of electrolytes. This has led to increased funding requirements. After that, firms started to move their funding to other fuel cells like phosphoric acid fuel cells (PAFC) [6].

The fundamental workings of regular fuel cells and AFC are relatively similar. Water and electricity are produced by the fuel reacting at the anode and the oxide reacting at the cathode. The primary distinction is in how electrolytes are used. The use of electrolytes in the AFC is usually hydroxide ions, which are mostly gained from potassium hydroxide (KOH) since it can provide a high pH value of about 15 and concentration in a range of 30-45 wt.%. The operation temperature is typically 70-250 ℃ [7]. To continue with a reduction process known as an oxygen reduction reaction (ORR), oxygen is supplied with water in the cathode sector.

Comparable to this, the hydrogen oxidation reaction, or HOR, takes place in the anode when incoming hydrogen reacts with the electrolyte's hydroxide ions to form water and electrons. Heat, water, and four electrons per oxygen are the only byproducts of combining cathode and anode. [6]. Compared with the anode, the cathode has been studied more since most power output and efficiency depend on the performance in the anode since most polarization happens there. Also, ORR has an operating current density of around 20 mV, compared to HOR, which only exhibits slight overpotentials [8].

Because of the importance of the cathode in the battery, the choice of different catalysts can improve the power output and life of the battery, so more diverse cathode catalyst materials are constantly being studied. Pt is a poly-crystalline metal that is suitable to be the catalyst of the AFC. However, since platinum is expensive, to cut expenses, people are trying to find more methods to increase its utilization. Among these approaches, some are modified platinum-based catalysts that use Pt as the shell and other cheaper metals as the core.

3.2. PEMFC

PEMFC has drawn much attention lately because of its great efficiency and lack of pollutants. PEMFC uses a conductive ion polymer film as an electrolyte. It has a low operating temperature and easy scale-up, which make it a worth developing fuel cell in the future. PEM fuel cells only gained attention and development a few decades ago, starting with the discovery at Los Alamos National Laboratory (LANL) that reduced the Pt required for the battery. To create an assembly with a membrane and electrodes, LANL developed a crucial method that involves applying a solution containing Nafion® material to the porous electrode's surface, pressing the electrode onto the membrane, and then waiting for it to dry. It was later improved to directly use hydrogen-rich streams of hydrocarbons as fuel for the PEM cell [9].

An electrolyte membrane that separates the two electrodes in the PEM fuel cell permits only protons to flow through instead of electrons. On both sides of the membrane, the catalyst is the site of the reaction. In the catalyst's anode, hydrogen is first split into a proton and an electron. The electron is then sent to the cathode side via a membrane, while the proton travels to the cathode side to produce electricity. On the cathode side, proton and electron recombine to form hydrogen and react with the air or pure oxygen to form water and heat, which is around 60-80 ℃. Platinum is also the main catalyst used in PEM fuel cells. Water in the battery is a key factor affecting the performance of the battery. The excess water generated at the cathode will cover the active catalyst site, thus forming a water column in the smooth channel and blocking the gas flow [10]. In the cell, preventing excess water and maintaining the membrane adequately hydrated is necessary [11].

3.3. AEMFC

The structure of AEMFC and PEMFC is similar, with the exception of the electrolyte, which regulates the operating temperature. Utilizing anion exchange membranes (AEMs) provides more benefits than using an anion flow cell (AFC), which employs aqueous KOH as the electrolyte. AEMFC provides numerous advantages over PEMFC, including faster electrochemical kinetics, lower catalyst costs, and less erosion. The AEMFC allows the employment of some non-precious metals, which expands the opportunities for company development. [12].

Hardware for preventing gas leakage, AEM, catalyst layers for the anode and cathode, and cathode gas diffusion layers (GDL) make up a single AEMFC. An alkaline state is formed in a fuel cell, where OH is transported as an anion through the membrane to the anode, where the fuel comes into contact with the electrocatalyst and oxidizes to form water molecules. Water occurs simultaneously at the cathode and anode ends and acts as a reactant and a product, respectively. The fundamental framework of the entire electrode is provided by the cathode and anode GDL. GDL is the transmission channel of the reactants and products. It can be shaped to resemble the porous structure of carbon fiber paper or a woven carbon fiber material with a microporous layer (MPL). The catalyst is located at the place where a chemical reaction occurs. Although the AEMFC structure is special to use non-Pt catalysts, in the condition of use of hydrogen fuel, it is proved to be insufficient. Nonetheless, since it is feasible to oxidize complex fuels directly, AEMFC still has the advantage in alkaline conditions [12].

4. Unique Benefits

In the future automotive industry, the use of clean energy, such as hydrogen fuel cells, will gradually be valued and developed because its benefits to the environment are beyond doubt. The entire system is an electrochemical reaction and is fueled by hydrogen. Only water and heat are produced. If hydrogen is also produced through renewable energy sources, the process cannot produce harmful substances.

Zero pollution is not the only benefit of hydrogen fuel cells [13]. High efficiency and nosiness are also the main features. The power generation efficiency of hydrogen energy batteries can reach more than 50% because its unique energy conversion process is directly converted from chemical energy to electrical energy without intermediate changes in mechanical energy.

5. Conclusion

In conclusion, this paper compares hydrogen fuel cell with formal fossil fuels and present an introduction of three hydrogen fuel cell that have different electrolyte or structure. These cells include AFC, PEMFC, and AEMFC. The paper begins by presenting the background information on the environmental effects nowadays because of the use of fossil fuels nowadays. Then, the paper introduces the basic principle of hydrogen fuel cells and their advantages in different aspects, like efficiency and environmental effects. In the future, PEMFC and AEMFC may be used and developed more since they use a membrane. They are low-corrosive and low-cost on the use of catalyst.

As more catalysts or structures are found that are suitable for fuel cells, old fuel cells will be phased out, and new ones that perform better in all aspects will follow. However, fuel cells always have some problems that make them not fully applied in reality, such as the need to add fuel and high costs repeatedly. In summary, hydrogen fuel cells may be developed and widely used in the future because of their zero pollution and high efficiency. But there's still something that needs to improve. For example, on the economic side, the cost of producing hydrogen fuel can still be reduced, although the current pollution-free electrolysis method is expensive, and the low-cost hydrogen production method will produce some pollutants. So, more efficient hydrogen production methods still need to be studied. On the social side, there is a need to increase the general acceptance of hydrogen fuel cells. In the future, this kind of energy has a good prospect for development and will get the attention of government personnel to achieve sustainable development concept.

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