Development status and prospect of hydrogen fuel cell

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Abstract. Hydrogen fuel cell is the largest application scenario of hydrogen in the world. Its working principle is to generate electric energy by electrochemical reaction of hydrogen and oxygen. The advantages of hydrogen fuel cell are very obvious, which not only has high energy conversion efficiency, but also realizes zero emission, low noise during operation and high safety. However, at present, it also has some shortcomings, such as great difficulties in the storage and transportation of hydrogen, relatively high cost compared with traditional energy sources, and imperfect related infrastructure. However, with the continuous development and progress of technology, it is expected that in the future, the application of hydrogen fuel cells in new energy vehicles and aircraft industries will be greatly improved and expanded, and energy storage and related issues are also expected to achieve important breakthroughs. Despite many obstacles, hydrogen fuel cells still show great development potential and broad space.

Keywords: hydrogen fuel cell, catalysts, proton exchange membrane.

1. Introduction

The progress of human society is inseparable from the support and development of energy, and the change of energy type usually means a leap in human production level. The importance of energy in the development of human society has been reflected from the early society when humans learned to use fire, the use of branches and weeds as fuel and the extensive use of traditional fossil energy in modern society[1].

With the development of world economy and the increase of population, the demand for energy is increasing. At the same time, the extensive use of traditional fossil energy will also bring a series of problems: the burning of fossil fuels will produce a lot of carbon dioxide and other greenhouse gases, which will lead to global warming. In addition, pollutants such as nitrogen oxides and sulfur oxides will be discharged, causing environmental disasters such as acid rain and smog, endangering human health and ecological balance. Therefore, with the development of human science and technology and technological progress, all countries have actively laid out the development strategy of new energy [2]. Under the background of human pursuit of sustainable development and environmental protection, the research and application of new energy technology has become a hot spot in the global science and technology field. Among them, hydrogen fuel cell, as an efficient and clean energy conversion device, is regarded as an important development object in the future energy system with its advantages of high energy density, zero emission and wide fuel sources.

Hydrogen fuel cell is composed of cathode, anode, catalyst and proton exchange membrane. The hydrogen raw material battery generates electricity and water through the hydrogen oxidation reaction on the anode and the oxygen reduction reaction on the cathode, and realizes the direct conversion from chemical energy to electric energy. In this process, proton exchange membrane (PEM), as a key component, not only effectively isolates hydrogen and oxygen, but also allows protons to pass through, thus maintaining the electrochemical reaction. The selection and performance optimization of catalyst is the key to improve the efficiency and reduce the cost of hydrogen raw material battery. In recent years, with the rapid development of technology, remarkable progress has been made in the research and development of new catalysts, which provides new possibilities for improving the performance of hydrogen raw material batteries.

However, despite many breakthroughs in hydrogen raw material battery technology, its commercialization process still faces many challenges. First of all, the preparation, storage and transportation of hydrogen is the main bottleneck restricting the wide application of hydrogen raw material batteries. Traditional hydrogen preparation methods, such as fossil fuel reforming, will produce greenhouse gases, while the water electrolysis law depends on a large amount of power input, and the storage and transportation costs are high. Secondly, the cost of hydrogen-based battery system is also one of the key factors restricting its popularization, including the manufacturing and maintenance costs of proton exchange membrane, electrode materials and the whole battery system. In addition, infrastructure construction, especially the construction and operation of hydrogen refueling stations, is also an urgent problem to be solved in the process of commercialization of hydrogen raw material batteries. In this paper, the electrode materials, catalysts, proton exchange membranes, advantages and disadvantages of hydrogen fuel cells will be briefly discussed.

2. Working principle and classification of fuel cells

2.1. Definition and Overview of Fuel Cell

Fuel cell is a kind of power generation device that directly converts chemical energy existing in fuel and oxidant into electric energy. It converts the chemical energy of fuel into electric energy through electrochemical reaction, which is not limited by Carnot cycle effect, so it has high energy conversion efficiency. Fuel cells use fuel (such as hydrogen) and oxygen as raw materials, which does not involve the combustion process, so they emit very few harmful gases and have a long service life. As shown in Table 1, Fuel cells can be divided into different types according to the electrolyte used and the manufacturing process[3].

Table 1. Classification and basic characteristics of fuel cells

Battery type	PEMFC	PAFC	AFC	MCFC	SOFC
electrolytic	Proton exchange membrane	phosphoric acid	Alkaline electrolyte	Molten carbonate	Solid oxide
Working temperature	-100	100-200	50-200	600-700	650-1000
superiority	Efficient, energy-saving, environment-friendly, quick start.	Cogeneration has high efficiency and is suitable for various scenarios.	High efficiency, low pollution, low cost and fuel flexibility.	Low cost, high efficiency and flexible fuel.	High efficiency, wide fuel adaptability, environmental protection and long service life.
disadvantaged	High cost, complex technology and high temperature control requirements.	High cost, long start-up time and sensitivity to sulfur-containing impurities.	Catalysts are expensive and electrolytes are corrosive.	High temperature management is difficult, the start-up time is long and corrosive.	High cost and immature technology
Commonly used catalyst	platinum	platinum	Nickel/silver	nickel	platinum
application area	Vehicles, distributed power stations and various electronic products.	Emergency power supply in hospitals and military.	Aerospace military equipment, electric vehicles, civil power generation devices	Chemical industry, electric vehicles	Distributed power generation, industrial standby energy, transportation

2.2. Definition and Working principle of Hydrogen Fuel Cell

Hydrogen Fuel Cell is a power generation device that directly converts the chemical energy of hydrogen and oxygen into electric energy. Its working principle is the reverse reaction of electrolytic water[4]. Hydrogen and oxygen are supplied to the anode and cathode respectively. Hydrogen reacts with electrolyte on the anode to generate hydrogen ions and electrons. Electrons reach the cathode through external loads, while hydrogen ions reach the cathode through the electrolyte membrane and combine with oxygen to generate water. This process does not produce nitrogen and sulfur oxides that pollute the environment, so it is clean.

2.3. The Difference between Hydrogen Fuel Cells and Traditional Batteries

2.3.1. Environmental Protection Aspects

In the working process of hydrogen fuel cell, electric energy and water are generated by electrochemical reaction of hydrogen and oxygen, realizing real zero emission. Compared with the traditional internal combustion engine, this characteristic makes the hydrogen fuel cell greatly reduce the emission of greenhouse gases and various toxic and harmful gases in the working process, and has obvious advantages in improving air quality and realizing carbon neutrality and peak carbon dioxide emissions in China.

In addition, the renewability of hydrogen is also an important aspect of environmental protection. As a fuel, the sources of hydrogen can be varied, including hydrogen production from renewable energy (such as hydrogen production from electrolyzed water). When hydrogen can be produced by renewable energy, the whole hydrogen energy production chain will be clean from production to use, forming a green closed loop. This will help promote the transformation of energy structure and reduce dependence on fossil energy.

2.3.2. Efficient Aspects

Hydrogen fuel cell has high energy conversion efficiency, which can directly convert the chemical energy of fuel into electric energy without intermediate links such as combustion, which also directly eliminates the problem of carbon deposition in traditional internal combustion engines, thus reducing the maintenance Chen Ben. This efficient conversion method not only reduces the waste of energy, but also improves the energy efficiency of the whole system. According to relevant data, the power generation efficiency of hydrogen fuel cells can be as high as 40-60%, which is much higher than that of traditional internal combustion engines by 20-30%.

2.3.3. Mute Aspects

The noise generated by hydrogen fuel cells is low, usually only about 55dB, which is equivalent to the level of normal conversation. This low noise makes hydrogen fuel cells have obvious advantages in places that need quiet environment (such as hospitals and libraries), which is incomparable with traditional batteries. In addition, vehicles using hydrogen fuel cells can also effectively reduce noise pollution and improve the quality of life of urban residents.

2.3.4. Disadvantage

High cost: At present, a major factor that puzzles the development of hydrogen fuel cells is the high manufacturing cost. In the world, proton exchange membrane hydrogen fuel cells (PEMFC) are mainly used for hydrogen fuel cells. The cost of hydrogen fuel cell mainly depends on catalyst, electrolyte membrane and bipolar plate. At present, the catalyst of most batteries is mainly platinum catalyst, and metallic platinum is a high-cost precious metal material, which leads to a significant increase in the price of batteries. Exchange membrane is a big vacancy in the technical field of our country, and our country mainly relies on imports for exchange membrane, which increases the production cost of hydrogen fuel cells.

Difficulty in transportation: The transportation of hydrogen has always been a fatal problem. The main transportation modes of hydrogen are gaseous transportation, liquid transportation and solid transportation, among which the high-pressure gaseous long-tube trailer is a relatively mature transportation mode at present. However, the flammable and explosive characteristics of hydrogen still make the risks in the transportation process exist, and the density of hydrogen is low, and the energy density per unit volume is relatively low, which leads to a much larger transportation volume than that of traditional energy sources. If liquid hydrogen transportation or solid transportation is used, the ensuing safety problems will also increase. Therefore, solving the problem of transportation difficulty is also an important development direction of hydrogen fuel cells.

3. Key Technologies of Hydrogen Fuel Cell

3.1. Catalyst

The catalyst acts on hydrogen to make electrons leave hydrogen atoms, and the catalytic layers are located on both sides of the proton exchange membrane to promote the redox process and improve the reaction rate. Commonly used catalysts for hydrogen fuel cells mainly includePlatinum-based catalyst, Low platinum catalystandNon-platinum catalyst

3.1.1. Platinum-based Catalyst

Platinum (Pt) is the most commonly used catalyst material in hydrogen fuel cells at present, especiallyProton exchange membrane fuel cell(PEMFC). Platinum-based catalysts have high catalytic activity for hydrogen oxidation (HOR) and oxygen reduction (ORR). However, due to the low platinum reserves and high price, and the intrinsic activity, stability and platinum utilization rate of commercial platinum-carbon catalysts can not meet the increasing performance requirements, it is an inevitable trend to develop catalysts with low platinum loading, high catalytic activity and stability [5].

3.1.2. Low Platinum Catalyst

Because of the scarcity and high cost of platinum, scientists prepare low-platinum catalysts by alloying with other metals, such as Pt-Co,Pt-Ni, etc. These alloy catalysts not only improve the stability and activity of the catalyst, but also reduce the cost.

3.1.3. Non-Platinum Catalyst

In order to further reduce costs, researchers have explored non-platinum-based catalysts as alternatives, mainly includingTransition metal-based catalyst(such as iron, cobalt, nickel, etc.) andCarbon-based catalyst(such as carbon nanotubes, graphene, etc.). These catalysts have lower cost and are powerful substitutes for platinum-based catalysts, but their stability and durability still need to be further improved.

3.1.4. Other types of Catalyst

In addition to the above main types, there are some special catalysts, such asBifunctional catalystandComposite catalyst. The bifunctional catalyst can catalyze the oxidation reaction of hydrogen and the reduction reaction of oxygen at the same time, simplify the structure of the fuel cell and improve the energy conversion efficiency. The composite catalyst is composed of many materials, and the performance of the catalyst is improved through the interaction between the materials. In addition, there areEnzymatic catalystUsing biological enzyme as catalyst has the advantages of biocompatibility and environmental friendliness.

3.2. Proton Exchange Membrane

As one of the key components of hydrogen fuel cell, proton exchange membrane should have high proton conductivity, which can effectively transport hydrogen protons from the negative electrode to the positive electrode. In addition, in the working environment of hydrogen-oxygen battery, proton exchange membrane needs to have high acid and alkali resistance, high temperature resistance and gas corrosion resistance to ensure the long-term stable operation of the battery[6].

The performance improvement of proton exchange membrane can significantly improve the efficiency, life and reliability of hydrogen fuel cells, and promote the application of hydrogen energy technology in the field of sustainable energy. The commonly used proton exchange membrane material is polytetrafluoroethylene (PTFE) modified polymer membrane, which has good proton conductivity, high chemical stability and high temperature resistance.

3.2.1. Preparation method of Proton Exchange Membrane

Melt film forming, also known as melt extrusion, is the earliest method used to prepare proton exchange membranes. In this method, the molten resin is extruded, cast or calendered into a film, and the final product is obtained after transformation treatment. The film prepared by this method has uniform thickness, good performance and high production efficiency, and is suitable for mass production of thick films. However, the melt film forming method can not be used to produce thin films, and it is difficult to keep the film flat during the production process, so its research and application are decreasing[7].

Solution film forming is the mainstream method used in scientific research and commercial products at present. The method comprises the following steps: dissolving polymers and modifiers in a solvent, casting or casting, and finally removing the solvent and drying to form a film. Solution film-forming method is suitable for most resin systems, which is easy to realize hybrid modification and microstructure design, and can be used to prepare ultra-thin films. According to the different processes in the latter stage, the solution film forming method can be further subdivided into solution casting method, solution casting method and sol-gel method.

3.3. Bipolar Plate

3.3.1. Bipolar Plate Materials

At present, the bipolar plates of hydrogen batteries are mainly made of nickel-based bipolar plates, stainless steel bipolar plates, composite bipolar plates, coating materials and composite bipolar plates. Among them, the composite bipolar plate is mainly composed of Lu Fucai and amorphous alloy. The coating material has the advantages of corrosion resistance, high thermal conductivity and low contact resistance.

3.3.2. Performance of Bipolar Plate

Bipolar plates can be classified into high-temperature resistant bipolar plates, high-strength bipolar plates and lightweight low-cost bipolar plates according to their properties. High temperature resistant bipolar plates are represented by niobium carbide and high temperature thermoplastic materials. The representative of high strength bipolar plate is carbon-based high strength polymer.

4. Application Status and Scenarios of Hydrogen Fuel Cell

4.1. UAV

With the continuous advancement and development of the times, the use of drones is increasingly extensive and diverse. For example, in the field of topographic mapping, geographic information can be accurately drawn; In the aspect of crop monitoring, the growth status of crops can be detected in time; In the field of material transportation, it can efficiently complete the transportation task; In the emergency rescue work, it plays a vital role and so on. In today's market, there are many kinds of UAV batteries, such as common lithium batteries, lead-acid batteries, and emerging hydrogen fuel cells. It is precisely because of the variety of batteries that the shortcomings of all kinds of batteries are gradually perceived by people. Compared with lithium batteries, hydrogen fuel cells have significant advantages. Its energy density is quite high, which enables the drone to fly continuously for several hours or even longer, which is far beyond the traditional lithium battery drone. Moreover, in terms of energy supplement, hydrogen fuel cells are faster, which can effectively reduce the downtime of drones and greatly improve the working efficiency. Comparing the hydrogen fuel cell with the lead-acid battery, the hydrogen fuel cell can still maintain stable performance output under extreme low temperature or high temperature conditions. However, in low temperature environment, the performance of lead-acid battery will be significantly reduced, the battery life will be seriously affected, and there may even be some safety hazards. In terms of energy replenishment, compared with lithium batteries and lead-acid batteries, hydrogen fuel cells have the fastest energy replenishment speed, and it only takes 10 seconds to hydrogenate or replace the fuel tank, which greatly improves the work efficiency. In addition, the hydrogen fuel cell UAV only produces water when working, and there is no carbon emission and other pollutants, which fully meets the current environmental protection requirements. Moreover, compared with other types of batteries, the safety of hydrogen fuel cells is better, and the excellent escape of hydrogen provides a great guarantee for safety.

4.2. Cars

The development of hydrogen energy vehicles in China has begun to take shape. Under the policy background of the Medium and Long-term Plan for the Development of Hydrogen Energy Industry (2021-2035) jointly promulgated by the National Development and Reform Commission and the National Energy Administration, domestic automobile companies such as SAIC, Changan and Hongqi have begun to lay out the development of hydrogen energy vehicles, and launched models such as Deep Blue SL03 and Hongqi H5-FCEV. However, the development of hydrogen energy vehicles in China still faces several major problems. One is that the manufacturing cost is too high, and the other is that the popularization rate of supporting infrastructure construction is low, but no matter how much suffering it faces, the development of hydrogen energy vehicles is still the general trend.

4.3. Microgrid

In the island region, the unique geographical conditions and relatively isolated environment make the power supply face many challenges. These islands are far away from the mainland, so the construction of power facilities is difficult and the traditional power supply methods are limited. For example, relying on long-distance transmission lines to transmit electricity from the mainland is not only costly to build, but also vulnerable to damage in bad weather or natural disasters, resulting in power interruption; However, oil-fired power generation has some problems such as high transportation cost, inconvenient storage and environmental pollution[8]. In this dilemma, hydrogen fuel cells provide an innovative and effective solution strategy for island microgrid. Hydrogen fuel cell is widely used in island microgrid, which can be used as the main power supply to meet the daily electricity demand of residents, such as lighting and household appliances[9]. In fishery, it provides stable power for refrigeration equipment and processing machinery, and helps industrial development. At the same time, it can also provide continuous and reliable energy for island communication facilities and monitoring equipment. The development potential of hydrogen fuel cell in island microgrid is huge. With the technological progress, its energy conversion efficiency will be improved and its cost will be reduced, which will make hydrogen fuel cell more widely used in island areas and reduce the dependence on oil-fired power generation[10]. In addition, it will be more closely integrated with renewable energy sources such as solar energy and wind energy to build a more efficient and stable energy system. Infrastructure construction, including hydrogen preparation, storage and transportation, will also be continuously improved, creating favorable conditions for the large-scale application of hydrogen fuel cells. It can be predicted that hydrogen fuel cells will bring revolutionary changes to the development of island microgrid, and improve the island's energy self-sufficiency and residents' quality of life.

5. Conclusion

This paper mainly relates to the principle, advantages and disadvantages of hydrogen fuel cells, as well as the contemporary development status and future development direction of proton exchange membranes, electrodes and catalysts. As a device for converting hydrogen into electric energy, hydrogen fuel cell should have outstanding advantages such as no pollution, low noise and regeneration. Although there are a lot of challenges to be overcome in the development process, its excellent characteristics have always been regarded as the hot spot of new energy development. In the future development, in order to promote the formal landing of the hydrogen energy battery project, it is necessary for the government, enterprises and scientific research institutions to make joint efforts and do a good job in policy, capital and technology support. With the continuous progress of science and technology, hydrogen fuel cells are expected to play an important role in the field of new energy.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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