Research on the Application and Development of Fuel Cells

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Abstract. Due to its high energy efficiency and low emission characteristics, fuel cells have received wide attention from all walks of life in the past two decades and have been developed rapidly. However, fuel cells are also facing some problems and challenges. This paper analyses and compares the performance, advantages and disadvantages of the major mainstream fuel cells, and puts forward the problems encountered in the current development by combining with their application examples. The results show that the cost of fuel cells is too high due to the limitations of electrodes and other key components, and some of the fuel cells have poor endurance, which is one of the major reasons hindering advancements in fuel cells, as the fuel cells are not able to achieve a balance between cost and performance. The practical application of fuel cells in various fields and the development status of fuel cells at home and abroad this year are introduced, and it is easy to see that in recent years, fuel cells have made breakthroughs to different degrees in different regions at different technical levels under the wide attention of all walks of life; fuel cell products are compared with traditional industries and the opportunities and challenges of the current development are put forward. However, despite the many advantages of fuel cells, there are still some challenges to their commercialisation, such as high cost, durability, storage and transportation of hydrogen. These problems are expected to be solved. It is crucial to research fuel cell development possibilities in order to advance the global energy transition, cut carbon emissions, and achieve sustainable development.

Keywords: Fuel cell, material Selection, application, development.

1. Introduction

As an emerging chemical power source, Fuel cells provide a high energy conversion efficiency and fewer emissions by running on H_2 (anode) and O_2/Air (cathode) supplies [1]. flexible fuel use and clean and noiseless site selection. It is an apparatus for electrochemical reactions changes the chemical energy of fuels and oxidisers directly into electrical energy. A fuel cell consists of an anode, a cathode and an electrolyte diaphragm. The fuel and oxidant in the battery carry out oxidation and reduction reactions at the anode and cathode respectively, thus completing the whole electrochemical reaction. The electrolyte diaphragm serves as a separator and ionic conductor for the fuel and oxidant.

The output voltage of a single fuel cell is about 0.5 to 1.3 V, but in practice, fuel cells usually exist in the form of a battery stack, in which an element used to connect a single cell is called a coupler or two-pole separator. It connects the anode of one single cell to the cathode of another. Depending on the use, the battery stack can be in series, parallel or a mixture of series and parallel.

Fuel cells have attracted much attention and developed rapidly in the last two decades due to their high energy efficiency and low emission characteristics. The advantages of direct methanol fuel cells have been greatly reflected in the power supply of electronic devices. The high temperature fuel cell technology represented by solid oxide fuel cell has also made great progress. The progress of diversified raw materials for power generation also provides certain possibilities for the sustainable development of energy economy. However, fuel cells are currently facing some problems and challenges, the high cost, the difficulty of commercialization as well as the longevity and reliability of the battery are still hot topics in the current research.

The main purpose of this paper is to analyse the nature of fuel cells, make a summary of the current development of fuel cells, and provide ideas to overcome the current difficulties. Firstly, the article classifies the current mainstream fuel cells and further elaborates on their development problems and respective advantages. Then, it analyses the shortcomings of the current development of fuel cells by comparing the actual application of fuel cells with the traditional industry and the domestic and international development respectively, and finally, it looks forward to the possible application scenarios in the future.

2. Classification of Fuel Cells

2.1. Alkaline Fuel Cells (AFC)

Alkaline fuel cells typically use a KOH solution as the electrolyte and direct hydrogen as the fuel, and operate at temperatures ranging from approximately 50 to 200 degrees Celsius. As one of the first fuel cell technologies discovered and developed, the specific advantages of alkaline fuel cells are low cost and high efficiency. And they are widely used in the aerospace construction business.

In AFC, the electrocatalysts at the cathode and anode as well as the choice of metal have a great influence on the overall reaction rate, and due to its own characteristics, the metals usually chosen at the two electrodes of alkaline fuel cells are mostly cheaper non-precious metals. As a cheap fuel cell, its disadvantages are also very obvious Because the hydroxide ions in the electrolyte are easy to react with carbon dioxide to form solid salts, thus reducing the reaction rate of the battery. This makes the range of alkaline fuel cells a major problem. But all in all, it's not a bad idea.

2.2. Proton Exchange Membrane Fuel Cell (PEMFC)

In PEMFC, the key component is the membrane electrode (MEA) which is used to conduct protons between the electrodes. The main working principle is the directional movement of protons by the combination of insulator special materials and water. For catalysts, PEMFCs mostly use platinum metal particles. Platinum has good chemical properties and a large specific surface area that allows it to provide a larger catalytic reaction site. However, the inexpensive cost of precious metals is also known as the common problem of a number of fuel cells, including PEMFC; although the current development of single-atom catalysts and non-precious metal catalysts for PEMFC to get rid of the possibility of precious metals, due to its poor electrical conductivity, the preparation of harsh conditions and other issues, for the time being, platinum metal is still the best choice to catalyse the PEMFC [2].

2.3. Phosphoric Acid Fuel Cell (PAFC)

Phosphoric acid-based fuel cell, PAFC for short, takes phosphoric acid as the core medium, and shows its potential in the medium-temperature operating range, generally in the range of 190 ℃ to 220℃.

Its operating temperature characteristics give PAFC a series of unique features. In terms of fuel, it is able to reconcile a wide range of options, whether it is pure hydrogen or a gas mixture after coal gasification, all of which can be accommodated by the PAFC. This affinity with multiple forms of energy bodes well for its potential to integrate with traditional energy networks and creates opportunities for fuel cell technology to move towards commercialization. In addition, the mesophilic environment means that the erosive effect on metallic materials is minimal, which means that the stability and longevity of the cell is enhanced.

But as with all technologies, PAFC is not perfect. In this particular temperature range, certain chemical reactions are not as good as they should be, which negatively affects the efficiency of the cell. Therefore, research in the field of PAFC has focused on how to improve the catalytic properties of the electrodes.

In summary, PAFCs are unique in the fuel cell family in that they exhibit robust performance and good durability. However, technological innovation and continuous research efforts are still needed to take it to the next level.

2.4. Molten Carbonate Fuel Cell (MCFC)

Belong to the high-temperature fuel cell classification, and their operating temperature generally exceeds 650°C. The temperature of the fuel cell is over 650°C. Such temperature brings a series of advantages and technical difficulties. In terms of advantages, MCFCs can directly consume natural gas, biogas, and a variety of other fuels, avoiding the need for a complex fuel conversion process. This direct utilization provides opportunities for system architecture simplification and efficiency gains. Further, such high operating temperatures benefit the electrochemical processes, further enhancing the performance output of the battery.

However, such high operating temperatures put the stability and durability of materials to the test. The components inside the battery have to operate stably under these high temperature and highly corrosive conditions. To accommodate these characteristics, the MCFC was developed using a number of innovative materials and construction techniques.

The characteristic of carbonate as an electrolyte is that it does not use electrons as the main charge carrier, but rather carbonate ions (CO_3^{2-}). Therefore, the selection and optimization of electrode materials for MCFCs has become the focus of its research.

Overall, molten carbonate fuel cells are favored by researchers and industries for their efficacy, diverse fuel options and solid performance. However, its high-temperature characteristics also make it necessary to pay close attention to the components of material and design.

2.5. Solid Electrolyte Fuel Cell (SOFC)

Solid electrolyte fuel cell (SOFC) is a kind of convinience energy conversion technology that has attracted extensive research interest. [3] It is used in many fields like energy storage, industrial heating, renewable energy integration, etc. Using solid oxide as electrolyte, it is characterised by excellent thermal effect and fuel flexibility. The electrochemical interaction of hydrogen and oxygen is the basic working principle of SOFC in which the solid oxide electrolyte acts as a channel for ion transport. Hydrogen combines with the oxide electrolyte at the anode, generating oxygen ions and electrons in the process, as shown in equation (1). In the cathodic direction, oxygen ions pass through the solid oxide electrolyte. To complete the current loop, electrons also move through the external circuit at the same time. Oxygen combines with oxygen ions and electrons at the cathode to form an oxide as shown in equation (2).

$$H_2 + O^2- \rightarrow H_2O + 2e^- \quad (1)$$

$$O^2- + 1/2O_2 \rightarrow O^{2-} \quad (2)$$

The electricity and water produced by the SOFC throughout the process also provides excess heat energy that can be reused, thus increasing thermal efficiency, Solid state electrolyte fuel cells operate in a high temperature environment, typically between 600 degrees and 1000 degrees.

Solid-state electrolyte fuel cells have excellent prospects and application potential in sustainable energy, energy conversion and hydrogen economy, and with the increase of application demand, its development in energy conversion, energy storage and sustainable chemical production is increasingly important, but at present, due to the stability of the material, high temperature environment and the cost of the problem, want to further commercialisation still need to be in the research and technology breakthroughs.

3. Practical Application

3.1. Fuel Cell Vehicles

Compared with traditional cars, the benefits of fuel cell vehicles are low energy usage, great efficiency, and environmental preservation., which is of great strategic significance for solving the environmental problems in recent years. Therefore, with the increasing seriousness of the environment and energy problems, new energy cars represented by fuel cell cars have become the research hotspot of automobile manufacturers all over the world nowadays. After nearly a decade of continuous research and development worldwide, automotive fuel cells have made breakthroughs in energy efficiency, volume and mass power density, low-temperature start-up and other functional characteristics, and a new wave of fuel cell vehicle industrialisation is approaching [4].

3.1.1. Status of fuel vell vehicle development in north america

The primary fields of fuel cell development, research, and demonstration include, the United States and Canada have made great progress in fuel cell technology with the support of relevant government departments, and cultivated world-renowned fuel cell manufacturing and research and development companies, such as UTC in the United States (United Technologies Corporation) and Ballad in Canada [5]. 14% of the annual liquid hydrogen market demand in the United States comes from the use of liquid hydrogen in fuel cell vehicles, Plug Power is the largest fuel cell forklift company in the United States, currently has more than 20,000 fuel cell forklifts, more than 6 million hydrogen refuelling operations. This shows that fuel cells are widely used in the U.S. automotive industry.

3.1.2. Current development of fuel vehicles in Europe, Japan and Korea

Hydrogen energy as an important element of Europe's energy transition, which has made a great contribution to fuel cell vehicles, hydrogen can overcome the technical difficulties of battery fuel transport, but also play a role in carbon emission reduction in Europe. In recent years, Europe has also broken through a series of demonstration programmes to develop some of the difficulties in the development of hydrogen fuel cells. For instance, the deployment of the STEP project and the CHIC (Clean Hydrogen in European Cities) initiative has effectively addressed the issues with fuel cell car cost and dependability in Europe [5].

Due to the shortage of resources in Japan and South Korea, the research and development level of fuel cell technology is among the best in the world, and a number of automobile companies, such as Nissan and Toyota, have gradually surpassed Europe and the United States in terms of the service life and cost control of fuel cell vehicles. In terms of hydrogen refuelling stations, the Korean government plans to increase the cumulative production of hydrogen fuel cell vehicles to 6.2 million by 2040.

3.1.3. Domestic fuel vell vehicle development status

Currently, China's hydrogen energy industry is in the government's introduction period and small-scale commercialisation stage, with the investment in fuel cells heating up in recent years, China's Yangtze River Delta, the Pearl River Delta and other coastal areas have gradually gathered a large number of new energy automotive enterprises, of which SAIC Group's contribution is particularly prominent, and in 2017, it released the country's first commercially available fuel cell light buses - the -Datsun V80 [6]. Fuel forklifts may now employ China's fuel cell technology more broadly as the market for hydrogen energy continues to grow.

In the construction of hydrogen refuelling stations, due to the difficulty of achieving independent production of some key components related to hydrogen production has led to the difficulty of cost downward pressure, China's current hydrogen refuelling station construction number can not be compared with fuel cell technology developed in other places and the pressure standard of hydrogen refuelling has yet to be upgraded and popularised. The first patent for a hydrogen fuel cell invention appeared only in 1998, and the number of relevant core patents now accounts for only about 1 per cent of the world's patents [7]. 2016, the National Institute of Standardization Resources and Environment Branch and the China Electrical Appliance Manufacturers Association released the

"China Hydrogen Energy Industry Infrastructure Development Blue Book (2016) for the first time put forward the Chinese industry's hydrogen energy development plan, as shown in Table (1) [8].

Table 1. Roadmap for the development of China's hydrogen energy industry.

Time	Overall goal	Functional goal	Development focus
2020	The number of hydrogens refueling stations reached 100; The number of fuel cell vehicles reached 10,000	The cold starting temperature reaches -30 degrees Celsius to optimize the structure of the power system and reduce the cost of the model	Common key technologies such as fuel cell pairs, basic materials, control technology and hydrogen storage technology; Key components; Hydrogen, hydrogen transportation, hydrogen refueling stations and other infrastructure
2025	Fuel cell vehicles reached the scale of 100,000	The cold start temperature reaches -40 degrees Celsius, which reduces the cost of the vehicle by mass, and is comparable to the hybrid of the same class	
2030	1,000 hydrogen refueling stations have been built; The number of fuel cell vehicles reached 1 million	The overall performance is comparable to that of traditional cars, with product competitive advantages	

3.2. Aerospace

The aerospace industry is just one of many potential uses for fuel cells. As batteries they are often installed on spacecraft to generate electricity and heat where solar panels are not available or applicable. To provide a reliable source of power for spacecraft. At the same time systems applying fuel cells can support the development of multiple space endeavours such as lunar/Mars transport, reusable launch vehicles (RLVs), emergency power for space stations and/or future energy storage applications and various portable applications [9].

3.2.1. Rocket motor boost

Fuel cells are used in the propulsion system of rockets to improve the launch efficiency of satellites and probes, assist in orbit adjustment and attitude control, etc. These cells are capable of providing a large energy output during the launch phase, thus enhancing the rocket propulsion. Consequently, this leads to an increase in launch capacity and orbit adjustment capability. The ability to launch a payload into a designated orbit or to steer it to a target planet is critical. The oxidation of fuel (usually hydrogen) on the anode side of the rocket fuel cell produces electricity and hydrogen ions. In addition, water is produced by a reduction process involving an oxidiser (usually oxygen) at the cathode, which involves the oxidiser accepting electrons and hydrogen ions. These electrons can flow through the circuit and be used for purposes outside the system, such as generating electricity. Thrust can be generated by discharging the hydrogen and oxygen produced by these reactions into a single nozzle and igniting them.

A fuel cell system, a DC/DC converter, a lithium-ion battery, a DC motor, and a propeller make up an aircraft fuel cell propulsion system [10]. Fig. 1 displays a schematic representation of the fuel cell-powered aircraft propulsion system.

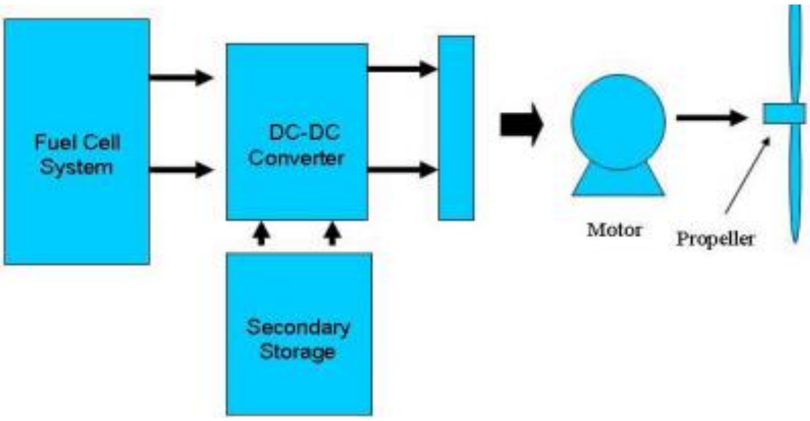

Figure 1. Aerospace fuel cell propulsion system. https://ieeexplore.ieee.org/document/4677772

3.2.2. Deep space mission

Deep space exploration missions face the challenge of declining solar panel efficiency. In these missions, fuel cells have advantages to address the lack of light on the surface of Mars. For example, the Mars Rover uses fuel cells as a source of energy and ensures a continuous supply of power even when far from the sun, allowing for a smooth mission. Spacecraft on deep space missions may encounter environments such as radiation, vacuum and extreme temperatures. Unlike other batteries, fuel cells can maintain smooth operation in these harsh environments. Fuel cells generate heat as a by-product, and this heat can be used to prevent sensitive instruments and equipment from overheating or freezing in extremely cold or hot conditions.

4. Conclusion

Fuel cell technology, as a high-efficiency and low-pollution energy conversion technology, has received widespread attention in recent years. The principle of fuel cell is to use hydrogen and oxygen to have a reaction under the use of a catalyst to create energy and water. Compared with traditional fossil fuel power generation, fuel cells not only have the advantages of high efficiency, low noise, and no carbon dioxide emission, but also can realise the application of distributed energy. The development of fuel cells will be more rapid as the access to hydrogen continues to be abundant. From transport, household electricity to industrial applications, fuel cells will be widely used in various fields. However, despite the many advantages of fuel cells, they still face some challenges in commercialisation. Such as high cost, durability, storage and transport of hydrogen. With the advancement of technology and policy support, these problems are expected to be solved. With the development and globalisation of hydrogen technology, fuel cells will become an important part of the future energy sector. It is believed that in the near future, fuel cells will be more widely used worldwide and become an important representative of the new generation of clean energy. This paper analyses the current development status of fuel cells and their characteristics to provide a reference for understanding the application and development of fuel cells.

Authors Contribution

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

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