The Working Principle, Applications, And Prospects of Hydrogen-Oxygen Fuel Cells

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Abstract. Currently, owing to the growing demand for energy, the decreasing quantity of traditional fossil fuels such as coal natural gas is rapidly arousing the attention of the public. Among the various alternatives to traditional fossil fuels, hydrogen fuel cells have obtained significant attention due to their environmental friendliness and the capability of converting energy with higher efficiency. With regard to hydrogen-oxygen fuel cells, this article not only explores their working principle and primary applications, but also discusses and analyzes them, so that hydrogen-oxygen fuel cells can be maximally utilized. Despite of the fact that the large-scale use of hydrogen fuel cells is still facing challenges including significant safety risks, the superior difficulty in storage and transportation, and high costs, technological advancements, which lead to the corresponding reduction of cost, could contribute to the extended range of potential applications in construction, vessels and other regions in addition to more prospects in aerospace which has already been applied.

Keywords: Hydrogen-oxygen fuel cells; energy conversion; environmentally friendly energy; potential applications.

1. Introduction

Based on the content of the Working Principles and Classifications of Hydrogen-Oxygen Fuel Cells, along with the increasing amount of population, the exponential growth of economics on a global scale, and the rapid advancement of technology, the process of industrialization is gradually accelerating worldwide. As a result, traditional fossil fuels including coal, natural gas, petroleum and other types of fuels are being significantly consumed at a fast speed, and at the same time, both humans' escalating demands for energy and the consumption of energy are also continuously increasing dramatically, which further indicates that, exploring alternatives to traditional fossil fuels is gradually turning into one of the most essential and urgent issues under the current circumstance [1]. Among all kinds of alternatives, fuel cells have been instantly focused on both the domestic market and the international market, on account of their inherent edges. By way of example, fuel cells are capable of converting energy with higher efficiency, releasing much less contaminated substances during operation and have a higher value of safety factor compared with other types of cells. When it comes to applications, hydrogen-oxygen fuel cells have already stood out and have been utilized in aerospace, electric vehicles and other real-life scenarios as one prominent type of fuel cell. All of this being said, several drawbacks can still be found in hydrogen-oxygen fuel cells despite their prospects, which can be better exemplified by those limitations, including the high cost, the high safety factor, the highly demanding technology and equipment, and the scarcity of natural resources. In the following context, based on the working principle and current applications of hydrogen-oxygen fuel cells, the ultimate goal of utilizing this material as a new energy resource can be more likely to be achieved by forecasting its potential applications as well as discussing and analyzing the competitive edges and the current adversity of hydrogen-oxygen fossil fuel, instead of shying away from admitting those downsides and merely focusing on the plus points of this new energy material.

2. The Working Principle of Hydrogen-Oxygen Fuel Cells

The energy, which motivates the chemical energy to be converted into electrical energy, is dependent on the operating electrochemical device based on the electrochemical theory. Since the process of burning is not required for fossil fuels, the efficiency of conversion is not restricted by the Carnot cycle when producing electrical energy, which indicates that the efficiency of conversion is inclined to reach at least 80% theoretically [1].

Regarding the raw materials, fossil fuels could be divided into 2 categories, including the type using liquid and the other type using gas [1]. Advantages and disadvantages can be located in these 2 types at the same time: prevalent raw materials of the former are methanol, ethanol, etc., which can be significantly deteriorated by environmental factors such as pressure (P) and the temperature (T); while raw materials of the latter one normally acquire the higher energy density, which implies that extra costs and demanding technologies are required to compress the gas when storing this type of fossil fuels.

In spite of the fact that both drawbacks and plus points exist in these 2 categories of fossil fuels, what is still in need is the type of fossil fuel with higher efficiency of energy conversion and less contamination. Under this circumstance, the fossil fuel whose raw material is hydrogen becomes the prior option since hydrogen has a higher density of energy and releases no contaminated gas compared with other raw materials.

Reactions of oxidation and reduction can respectively occur when hydrogen and oxygen are on electrodes. After hydrogen loses electrons, oxygen gains electrons subsequently. As a result, a current is generated due to the directional movement of electrons, which helps to convert the chemical energy into electrical energy [1].

Components of hydrogen-oxygen fossil fuels basically include an electrolyte (ion conductor), graphite electrodes (positive and negative electrode materials), hydrogen (negative reactant), oxygen (positive reactant), and conductors (electron conductors) [2]. Additionally, reactions at the positive and negative electrodes are correlated to the pH value of the electrolyte [1]. In the following content, the working principle of hydrogen-oxygen fossil fuels is illustrated:

When the electrolyte solution is acidic:

$$\text{reaction equation at the positive electrode: } O_2 + 4e^- + 4H^+ = 2H_2O \tag{1}$$

$$\text{reaction equation at the negative electrode: } 2H_2 - 4e^- = 4H^+ \tag{2}$$

When the electrolyte solution is saline or alkaline:

$$\text{reaction equation at the positive electrode: } O_2 + 2H_2O + 4e^- = 4OH^- \tag{3}$$

$$\text{reaction equation at the negative electrode: } 2H_2 + 4OH^- - 4e^- = 4H_2O \tag{4}$$

$$\text{The overall reaction equation: } 2H_2 + O_2 = 2H_2O \tag{5}$$

The overall reaction equation can be approximately regarded as the composition of the forward process and the reverse process. When these 2 processes are combined, the chemical energy in the fuel can be continuously converted into electrical energy to better supply the power source [1]:

$$\text{forward process: } 2H_2 + O_2 = 2H_2O + \text{electrical energy} \tag{6}$$

$$\text{reverse process: } 2H_2O + \text{electrical energy} = 2H_2 + O_2 \tag{7}$$

Consequently, when the hydrogen and oxygen are capable of supplying the device with electrical energy continuously, the battery can obtain a continuous flow of electricity as a result.

3. Applications of Hydrogen-Oxygen Fuel Cells

3.1. Hydrogen-Oxygen Fuel Cells and Transportation

Hydrogen-oxygen fuel cells have been extensively utilized in transportation systems like cars, buses, trains, and ships, and additionally, they are also prioritized as potential replacements for traditional generators and internal combustion engines in the United States, Japan, and other developed countries [3].

In the field involving transportation, hydrogen fuel cell vehicles stand as a typical example in this point. Hydrogen fuel cell vehicles combine hydrogen and oxygen to generate electricity, which is then converted into electrical energy, operating generators to achieve zero pollution goals, such as the Toyota Mirai fuel cell vehicle (FCV) [4]. This fuel cell vehicle uses a smaller, lighter, and more powerful new type of fuel cell - the next-generation fuel cell stack with a maximum output power of 114 kW, mass energy density of 2.0 kW/kg, and uses a single-cell channel of 3D fine mesh compared to the first-generation fuel cell stack introduced in 2008 with a maximum output power of only 90 kW, a mass energy density of 0.83 kW/kg, and used a single-cell channel of a direct channel [4].

3.2. Hydrogen-Oxygen Fuel Cells and Aerospace

Owing to their high density of energy, long-term usability, and cleanliness, hydrogen-oxygen fuel cells have gained widespread attention in the aerospace field, and are applied in air taxis, aerospace power generators, and aerial port drones [5].

Take manned space missions as an example, on account of their regenerative energy systems, hydrogen-oxygen fossil fuels are capable of offering longer mileage and have shorter charging times compared to rechargeable batteries like lithium batteries. For example, under the same 500 km range, hydrogen-oxygen fuel cells only require 3 minutes for a full charge, while super-fast charging in regular lithium batteries takes about an hour and a half [6]. Additionally, concerning the adaptability of future manned space missions, the reaction of hydrogen-oxygen fuel cells consuming hydrogen and oxygen to produce water allows integration with propulsion, thermal control, and environmental control subsystems, enhancing resource utilization efficiency.

Therefore, hydrogen-oxygen fuel cells hold significant prospects in aerospace.

4. Discussion and Analysis of Hydrogen-Oxygen Fuel Cells

4.1. Preponderance of Hydrogen-Oxygen Fuel Cells

Firstly, hydrogen-oxygen fuel cells only produce water and release no other waste during operation, making this new energy source cleaner compared to traditional fossil fuels, contributing to a zero-emission objective [7]. Secondly, in the process of providing energy, hydrogen-oxygen fuel cells skip the process of burning, which indicates that the process of converting energy is not restricted by the Carnot cycle [1]. When producing electrical energy, the efficiency of energy conversion can reach a minimized value of approximately 80% [1]. Compared with the efficiency of energy conversion of hydrogen-oxygen fossil fuels, conventional fossil fuels can merely reach approximately 30% [1].

4.2. Current Adversity of Hydrogen-Oxygen Fuel Cells

Firstly, the major challenge faced by hydrogen-oxygen fuel cells in the current situation is their high cost. The power generation systems of hydrogen-oxygen fuel cells often include various types of components such as the cell stack, proton exchange membrane, and catalysts [8]. China still faces certain bottlenecks in the production of these components, which results in high costs for hydrogen-oxygen fuel cells [9]. Therefore, when attempting to apply hydrogen-oxygen fuel cells on a large scale, this challenge might significantly limit their competitiveness [9]. Secondly, due to the flammable and explosive nature of hydrogen gas, using hydrogen-oxygen fuel cells often accompanies significant safety risks [10]. Moreover, since hydrogen gas belongs to the type of gases with high pressure and low density, special equipment and technologies are required for their storage and transportation, increasing the complexity of hydrogen fuel cells [11]. Finally, but still a point that needs rapid improvement, unlike oxygen and nitrogen, hydrogen gas does not exist in large quantities directly in the atmosphere. Hence, as a raw material for hydrogen-oxygen fuel cells, hydrogen gas needs to be extracted from other compounds [12]. This prerequisite requires certain technological and cost investments, which might limit the large-scale application of hydrogen-oxygen fuel cells in the market.

4.3. Potential Applications of Hydrogen-Oxygen Fuel Cells

Due to its cleanness and the capability of converting energy with higher efficiency, hydrogen-oxygen fuel cells align well with the current needs of industrial development.

Currently, hydrogen fuel cells have been partially applied in the aerospace field, but actually it can be more extensively utilized, such as in the power systems of passenger aircraft and spacecraft [5]. Looking at the adaptability of manned space missions in the future, as hydrogen-oxygen fuel cells consume hydrogen and oxygen to produce water, this application can be integrated with propulsion, thermal control, and environmental control subsystems, improving resource utilization efficiency [5]. Therefore, hydrogen-oxygen fuel cells hold significant development prospects in aerospace.

In addition to the sector of aerospace, in fields where hydrogen-oxygen fuel cells have not yet been extensively explored, firstly, in construction, buildings require environmentally friendly and efficient completion of facilities. Hydrogen-oxygen fuel cells can serve as backup power sources in the construction industry, which are capable of providing clean and efficient energy [13]. Secondly, in maritime transportation, the advantage and requirement lie in completing long routes while causing minimal environmental pollution. Given its strong sustainability and characteristics of emitting zero toxic substances, hydrogen-oxygen fuel cells also hold significant potential for applications in the maritime industry [13]. Therefore, with continuous technological advancements and the corresponding reduction in costs, hydrogen-oxygen fuel cells have the potential to be applied in sectors like maritime transportation and construction.

5. Conclusion

This study, based on the comprehension of the working principle and existing applications of hydrogen-oxygen fuel cells, discussed and analyzed the advantages, drawbacks, and potential applications of hydrogen-oxygen fuel cells. Through this discussion and analysis, it is evident that hydrogen-oxygen fuel cells are highly regarded for their high efficiency and cleanliness. However, when it comes to their applications on a large scale, hydrogen-oxygen fuel cells still face challenges such as high costs, technical difficulties in storage and transportation, and safety risks. With ongoing technological advancements and the subsequent reductions of costs, this new energy source holds promise for broader applications in sectors like maritime transportation, aerospace, and construction.

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