

Research Progress in Hydrogen Energy Utilization and Technology Development

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Abstract

The latest developments of hydrogen energy production and storage technology are reviewed in this paper. Biomass hydrogen production, solar thermochemical cycle hydrogen production, nuclear energy hydrogen production and other technologies have the advantages of abundant resources and using renewable energy. They can also overcome the shortcomings of high energy consumption and limited mineral raw materials in traditional electrolytic water hydrogen production. What's more, they become the research focus of improving hydrogen production efficiency and achieving large-scale production. The research progress of pressurized compression hydrogen storage technology is mainly embodied in improving container materials and developing hydrogen-absorbing materials. The liquefied hydrogen storage technology focuses on reducing energy consumption and cost. Hydrogen energy production and storage technology is moving towards practical stage. The main technical direction is to use water as raw material to achieve large-scale, economic, efficient and safe hydrogen production and storage, promoting the sustainable and clean utilization of hydrogen energy and energy security.

Keywords

hydrogen energy; hydrogen production; hydrogen storage; hydrogen energy utilization; new energy sources.

1. Introduction

Hydrogen can be used to store energy and is an important secondary energy source. Hydrogen energy is the energy contained in hydrogen. It has the characteristics of friendly environment, abundant resources, high calorific value, good combustion performance and high potential economic benefits. Although hydrogen is easy to explode when it reaches the lower explosion limit, it is safe to use hydrogen as fuel in general because of its light weight, strong leakage, large diffusion, wide combustion range and low ignition energy. The research on hydrogen energy production, storage and utilization technology is developing towards systematization, scientificization and low cost. Hydrogen production and storage technology is one of the key technologies for large-scale utilization of hydrogen energy [1].

2. Sustainable Development and New Energy Development

If we continue to use fossil fuels as energy without restraint, we can foresee that the living environment of mankind will become worse and worse. The concept of sustainable development began in the 1980s. It refers to the development that not only meets the needs of contemporary people, but also does not damage the ability of future generations to meet their needs. Sustainable development is a comprehensive concept involving economy, society, culture, science, natural environment and so on. It is based on the sustainable use of natural resources and good ecological environment, taking sustainable economic development as the

premise, and aiming at the overall progress of society. However, at present, our fossil fuel-based energy system is far from that goal. With the development of economy and the substantial increase of energy consumption, the contradiction between energy reserves, production and use has become increasingly prominent, which has become one of the major problems facing all countries in the world. On the other hand, the large-scale exploitation and application of fossil energy also leads to the deterioration of human living environment. Over the past decades, countries have invested tremendous funds in the development and application of new energy, and started a new period of development and utilization of new energy, which has achieved fruitful results. The development and application of clean new energy, such as atomic energy, solar energy, hydrogen energy, geothermal energy and tidal energy, has led to the diversification of human energy use [2].

3. Prospects for Hydrogen Energy

Hydrogen can be regarded as the energy of the 21st century, and it will dominate the world in the future. The atomic number of hydrogen is 1. It is gaseous at room temperature and pressure, and liquid at ultra-low temperature and high pressure. As an energy source, hydrogen energy has some characteristics that other energy sources do not have. Firstly, it is a renewable clean energy source. The combustion products of hydrogen are water, no carbon dioxide and nitrogen oxides, basically achieving zero emissions of greenhouse gases and pollutants. At the same time, water can be re-converted into hydrogen in various ways to realize the recycling of energy, which will never end. Secondly, high chemical activity, good combustion and high calorific value. It is flammable in the range of 3%-97%, and its calorific value is three times that of gasoline. Thirdly, rich in resources and diverse sources. Hydrogen makes up 75% of the mass of the universe, has a large storage capacity and can be converted through a variety of energy sources. It can be seen that hydrogen energy can meet the requirements of resources, environment and sustainable development at the same time, which is incomparable with other energy sources, and its application prospects are promising.

Developed countries such as the United States, Europe and Japan have formulated long-term hydrogen energy development strategies from the perspective of national sustainable development and security strategies. The road map of hydrogen energy development in the United States can be divided into four stages in terms of time: technology, policy and market development; transition to market; market and infrastructure expansion; and entering the era of hydrogen economy. From 2000 to 2040, a phase is achieved every 10 years.

The research and development of hydrogen energy in China can be traced back to the early 1960s. In order to develop the space industry, Chinese scientists have done a lot of effective work on the production of liquid hydrogen as rocket fuel and the development of H₂/O₂ fuel cell. In the 1970s, hydrogen was developed as an energy carrier and a new energy system. In November 2003, China joined the International Partnership for Hydrogen Economy and became one of its first member states. At present, China has made many progress in the research and development of hydrogen energy related technologies. With the support of the Ministry of Science and Technology and the projects funded by various ministries and commissions, China has initially formed a team of professionals engaged in the research, development and utilization of hydrogen and fuel cells, mainly in universities, Chinese Academy of Sciences, energy companies, fuel cell companies and automobile manufacturing enterprises. The research and development field involves the basis of hydrogen economy and related technologies, technology development and demonstration test. Especially, the national "973" project "Basic Research on Hydrogen Energy Scale Preparation, Storage and Transportation and Related Fuel Cells" and "Basic Research on Hydrogen Production by Solar Energy Scale" have a large number of participants and have a great impact [3].

4. Hydrogen Energy Technology

Hydrogen energy refers to the energy released by the reaction between hydrogen and oxygen. As an energy source, hydrogen energy has the following main characteristics. The heat release efficiency of hydrogen is high, combustion of 1g of hydrogen can release 14×10^4 J heat, which is about three times the heat release of combustion of 1g of gasoline. In the combustion process of hydrogen, in addition to releasing enormous energy, the waste generated is only water, which will not cause environmental pollution. So hydrogen energy is also known as clean fuel.

There are three main ways of utilizing hydrogen energy. They are direct combustion, conversion of hydrogen energy into electricity through fuel cells and nuclear fusion. One of the safest and most efficient ways to use it is to convert hydrogen energy into electricity through fuel cells, such as hydrogen fuel cells. The main difference between hydrogen fuel cells and ordinary batteries is that dry batteries and storage batteries are energy storage devices, which can store electric energy and release it when needed, while hydrogen fuel cells are strictly a power generation device, just like power plants, which directly convert chemical energy into electrical energy.

The development and utilization of hydrogen energy should solve the key problems of hydrogen production and storage.

4.1. Hydrogen Production Technology

4.1.1. Hydrogen Production from Electrolytic Water

Hydrogen production from electrolytic water is the most widely used technology to convert renewable resources into hydrogen. Hydrogen production process is the reverse process of hydrogen and oxygen combustion to produce water. The process is relatively simple and does not cause pollution. However, the energy of water decomposition needs to be provided by the outside world, and the consumption is large.

4.1.2. Hydrogen Production Technology from Fossil Fuels

Using coal, oil and natural gas as raw materials is the main method to produce hydrogen at present, but its reserves are limited, and the process of hydrogen production will pollute the environment. Hydrogen produced is mainly used as chemical raw materials, and some products containing hydrogen are also used as gas fuel to supply urban gas.

There are two main methods to produce hydrogen-containing gas from coal: coal coking (also known as high temperature dry distillation) and coal gasification. Coking is the production of coke from coal at $900-1000^\circ\text{C}$ under the condition of air isolation. The byproduct is coke oven gas. Coke oven gas can be used as city gas as well as raw material for hydrogen production. Gasification refers to the conversion of coal into gaseous products by reaction with gasifier under high temperature, normal pressure or pressure. The purpose of gasification is to produce chemical raw materials or city gas.

Production of hydrogen from natural gas or light oil method is to produce hydrogen by reacting with steam in the presence of catalyst.

Hydrogen production from heavy oil by partial oxidation is also familiar. Heavy oil feedstock include fuel oils from atmospheric, vacuum residues or deep processed. Heavy oil reacts with water vapor and oxygen to produce hydrogen-containing gas products have attracted much attention because of its low cost of raw materials.

4.1.3. Biomass Hydrogen Production Technology

Biomass resources are abundant and important renewable energy. Biomass hydrogen production technology has good environmental and safety, which contains biomass gasification for hydrogen production and microbial hydrogen production.

Hydrogen-containing fuel gas can be produced by gasification or pyrolysis of biomass raw materials such as firewood, sawdust, wheat straw and rice straw in a gasifier (or cracker). On the other hand, some algae in rivers, lakes and seas, such as chlorella and nitrogen-fixing cyanobacteria, can emit hydrogen continuously by using sunlight and water as raw materials. Similarly, microbial hydrogen production from industrial and domestic organic wastewater and agricultural by-products wastes has attracted much attention.

4.1.4. Solar Thermochemical Cycle Hydrogen Production Technology

Solar thermochemical cycle hydrogen production technology uses solar concentrator to collect solar energy to generate high temperature and promote thermochemical reaction. From the point of view of the whole life cycle process, the processing of thermochemical reactor and the final waste abandonment, as well as the use of metal and metal oxides, will bring certain environmental pollution. In addition, since the reactions are carried out at high temperatures, the recombination of hydrogen and oxygen in the reactor may cause explosion.

4.1.5. Other Hydrogen Production Technologies

In addition to thermochemical methods, photocatalytic hydrogen production by solar semiconductor photocatalysis is also a widely studied hydrogen production technology. Titanium dioxide (TiO₂) and transition metal oxides, layered metal compounds such as K₄Nb₆O₁₇ and Sr₂Ta₂O₇, as well as catalytic materials such as CdS and Cu-ZnS which can utilize visible light, have been found to be able to catalyze the decomposition of water under certain illumination conditions to produce hydrogen. However, due to the photolysis of many semiconductors in the process of photocatalytic hydrogen production, and the current photocatalytic hydrogen production efficiency is too low, the large-scale hydrogen production needs further study.

Nuclear hydrogen production technology is also a process of decomposition of water by thermochemical cycle, i.e. decomposition of water to produce hydrogen by thermal energy of high temperature reactor or nuclear reactor [4].

5. Conclusion

The development and use of fossil fuels have made great progress in the industrial civilization of human society, but human beings have paid a heavy price for it. The living environment of human beings has been seriously damaged and natural disasters occur frequently. Therefore, in order to achieve sustainable development of human society, it is necessary to correctly understand the interaction between human beings and the nature. In front of the natural interface, human beings should be more in harmony with it, rather than blindly asking for it.

In the development of new energy, we must speed up the pace of new energy development and develop green new energy sources with sufficient sources as soon as possible to replace the current fossil fuels. Then we should make full and rational use of renewable resources as the main energy sources, and strictly control the use of energy sources that have a huge negative impact on human living environment in order to ensure the sustainable development of human society.

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