International Core Journal of Engineering Volume 6 Issue 9, 2020
ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0038

Research Progress of the Technology for Nuclear Production of Hydrogen

Jiahui Wang, Lu Han, Liang Ma and Chunhai Lu

Sichuan Key Laboratory of Applied Nuclear Techniques in Geosciences, Chengdu University of Technology, Chengdu 610059, China.

Abstract

As a clean energy source, hydrogen has a good application prospect. However, it's production needs to use primary energy. In order to achieve the widespread use of hydrogen, it is necessary to achieve a large-scale production of hydrogen in a sustainable manner, which is required abundant raw materials and no greenhouse gas emissions. As a clean primary energy source, using nuclear energy to produce hydrogen will be a promising industry. This paper will introduce several traditional methods of hydrogen production, as well as several main methods of the technology for nuclear production of hydrogen. At the same time, the main problems in the technology for nuclear production of hydrogen are expounded, and the development prospects of the technology are summarized.

Keywords

Hydrogen energy, Nuclear production of hydrogen, Thermochemical cycle.

1. Introduction

Energy is the foundation of the national economy. The development of society and economy and the improvement of people's living quality cannot be separated from energy. Since the 21st century, the global energy field is facing great challenges. The contradiction between the increasing energy demand and the increasingly serious environmental pollution is full of hard to solve, and there are many regional conflicts over the limited resources. China's energy is mainly based on fossil fuels. Due to its limited reserves, a large number of greenhouse gases are produced in the process of use, which cause serious environmental pollution problems. Therefore, to change the current energy pattern and find new clean energy to gradually replace the existing fossil fuels has become an important issue to be solved urgently.

Hydrogen energy is a kind of clean and green energy, with high calorific value, no pollution, renewable, no greenhouse gas generation and other unique advantages, and has the characteristics of storage and transport, so people have attracted more and more attention. At present, hydrogen production mainly consists of fossil fuel production and water decomposition production.In the process of hydrogen production from fossil fuels, a large amount of carbon dioxide will be produced, which will cause serious environmental pollution problems when discharged into the air. The method of hydrogen production by water decomposition has low energy conversion efficiency and high cost, and usually needs to consume a large amount of electric energy. Therefore, it cannot meet the development requirements of hydrogen energy efficiency and economy. Therefore, it is urgent to research and develop a new method of hydrogen production.

As a clean primary energy, nuclear energy has been gradually mature after more than half a century of development. Nuclear production of hydrogen is the large-scale production of hydrogen by coupling a nuclear reactor with an advanced hydrogen production process. Nuclear energy provides

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0038

both electricity for large-scale electrolysis of water and a hot source for thermalization of hydrogen. The combination of the two will make the process of energy production and utilization basically clean.

2. Introduction to traditional hydrogen production methods

2.1 Hydrogen production from fossil fuels

The basis of developing hydrogen economy is to produce hydrogen on a large scale and at low cost. At present, hydrogen production methods mainly include fossil fuel hydrogen production, water hydrogen production and biological hydrogen production [1].

Hydrogen production from fossil fuels is the main industrial hydrogen production method at present, including hydrogen production from gas fossil fuels, coal and liquid fossil fuels. It is a relatively mature hydrogen production technology.

But because irrefragable and limited reserves of fossil fuels, and the hydrogen production process may cause serious pollution to the environment, the use of fossil fuels, hydrogen production can't get rid of the dependence on conventional energy and the destruction of natural environment, therefore the technology in the long run only as a renewable energy hydrogen production technology mature before a transitional measure.

2.1.1 Hydrogen production from natural gas

Hydrogen production from natural gas refers to a series of chemical reactions between alkane and water vapor in natural gas under the action of a certain pressure and a certain high temperature as well as a catalyst, thus producing hydrogen.Hydrogen from natural gas is often used in large-scale hydrogen supplies, and in gas-rich areas, hydrogen from natural gas is the best option [2].

Hydrogen production from natural gas desulfurization technology is to turn the gas pressure after desulfurization with steam is equipped with special conversion furnace cracking catalyst reforming, generation of H_2 and CO and CO_2 gas, after some of this heat recovery, lower levels of carbon monoxide in the conversion of gas after transformation, then shift gas by pressure swing adsorption (PSA) purification, can get 99% ~ 99.999% volume fraction of hydrogen [3].

2.1.2 Hydrogen is produced from coke oven gas

In the process of coal coking, a kind of combustible gas, namely coke oven gas, can be obtained. The original hydrogen-containing volume fraction of coke oven gas is up to 55%, so it can be separated efficiently by psa method alone, and its cost is relatively low, which is a relatively economical method for hydrogen production [4].

Xu-liang li [5] will be leveling coking company of coke oven gas to remove most of the tar, use the process, such as pressure, cooling and preprocessing to remove impurities, such as water, tar, benzene, then make use of the degreaser, equipment such as the preprocessor to further removal of water and trace a restructuring, finally the decarburization process to remove the gas by pressure swing adsorption desulfurization in the HGN, C^{2+}, CO_2 and organic sulfur, and most of the CH_4, CO, etc., can get the volume fraction of 95% ~ 98% of the semi-finished products. After the process of hydrogen extraction by psa, the product hydrogen with volume fraction above 99.9% was finally obtained.

2.2 Hydrogen production from water

2.2.1 Electrolysis of water to produce hydrogen

As a mature and traditional hydrogen production method, electrolysis water has the advantages of simple process and no pollution, but it needs to consume a lot of electric energy, low energy utilization rate and high production cost, so the process is limited by certain application.

At present, common electrolytic water hydrogen production systems are divided into basic, solid polymer electrolytic cell (SPE) and solid oxide electrolytic cell (SOEC) hydrogen production systems. The research shows that the electrolytic efficiency and total hydrogen production efficiency of SOEC

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0038

hydrogen production system are the best, followed by SPE hydrogen production system and basic hydrogen production system.

2.2.2 Light decomposes water to make hydrogen

The principle of photodecomposition water to produce hydrogen is that the optical quantum can break the hydrogen bonds in water and other hydrogen-containing molecules, and the energy required is solar energy. Sun et al. [6] synthesized a new nanoscale photocatalyst SR-NATAO3 by using a simple molten salt method, and its catalytic water photodissociation hydrogen production rate could reach 4.89 mmol/h.

2.3 Hydrogen production from biomass

Hydrogen production from biomass is a kind of "clean energy", which makes use of the reproducibility and reproduction of biomass.It has the advantages of no pollution, low cost and renewable [7]. However, biomass energy is not suitable for use as energy in modern industrial equipment and often needs to be converted into gas or liquid fuel for operation.

Yang et al. [8] found that the yield of biological hydrogen production could be improved by combining dark fermentation and light fermentation. In the first stage, hydrogen was produced by anaerobic fermentation and corn cob was used as substrate. The maximum hydrogen production and hydrogen production rate reached（0.1203±0.0052）m^3/kg and 3.6m^3/（m^3·d）, respectively; In the second stage, the photosynthetic bacteria were used to obtain hydrogen through the photofermentation process using the digestive sewage generated in the dark fermentation process as the substrate, and the yield of hydrogen could reach （0.7136±0.0441）m^3/kg. Meanwhile, the removal efficiency of COD is as high as 90%.

3. Brief introduction of hydrogen production technology by nuclear energy

The principle of hydrogen production by nuclear energy is to make use of the heat generated by nuclear reactors as the energy for hydrogen production. Through the selection of appropriate technologies, the purpose of efficient and large-scale hydrogen production can be achieved, while the emission of greenhouse gases can be reduced or completely eliminated.Advanced hydrogen production process also needs to have the characteristics of abundant raw materials. At present, the process of hydrogen production by nuclear energy mainly includes the following three kinds.

3.1 Methane steam reforming

Methane steam reforming (steam methane reforming, SMR) is the main hydrogen production technology [9]. Taking natural gas as raw material has the advantage of low cost.When a nuclear reactor is used as a heat source for steam reforming, the amount of methane required for the process can be significantly reduced. However, it adopts the traditional hydrogen production technology, which can only reduce the emission of carbon dioxide, but cannot completely eliminate it. Therefore, it can only represent the recent nuclear thermal hydrogen production technology.

The research shows that the temperature of methane steam reforming process should be as high as possible, but when the temperature exceeds 1000℃, the further increase of temperature will not have obvious change to the system performance. At the same time, in order to improve the working efficiency of the system, the latent heat and by-product CO of excess water vapor should be recovered as much as possible, and the heat loss of the system to the environment should be reduced. In addition, the reforming reaction can be promoted if a certain amount of water vapor is added to the reaction gas.

3.2 High temperature electrolysis

Electrolysis requires a lot of electricity and is suitable for industrial applications where cheap electricity can be produced or where hydrogen is needed in high purity. The process of steam high temperature electrolysis is the reverse reaction process of solid oxide fuel cell. High temperature

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0038

electrolysis of water vapor hydrogen production process does not involve high corrosive environment, improve the service life of equipment materials and other advantages [10].

The current research shows that the ceramic connection system as high temperature electrolysis hydrogen production cell has the advantages of high temperature resistance, corrosion resistance, long life, can replace stainless steel materials, and its average hydrogen production density is 25% more than stainless steel materials. It's sealing effect is better, not easy to deform and crack, reduce the use of replacement times, and reduce the cost of maintenance.

The research shows that the high temperature solid oxide electrolytic cell (SOEC) combined with advanced nuclear energy can achieve 50% thermal hydrogen conversion efficiency. The Institute of Nuclear Energy and New Energy Technology of Tsinghua University developed high temperature gas-cooled test reactor (HTR-10), which coupled high temperature solid oxide electrolysis hydrogen production technology with advanced nuclear reactors, opened up new application fields of nuclear energy, and realized the harmonious development of nuclear hydrogen energy system.

3.3 Thermochemical cycles break down water

The process of breaking down water into several steps using a number of chemical reactions is known as thermochemical cycling. It can reduce the reaction temperature and avoid the problem of hydrogen-oxygen separation. At the same time, other reagents used in the circulation can be recycled. Thermochemical cycles have high hydrogen production efficiency, with theoretical efficiencies up to 50% or even higher for some cycles. The thermochemical cycle proposed at present mainly includes sulfur cycle, oxide cycle and low temperature cycle. At present the most promising applications are sulfur-iodine cycle and mixed sulfur cycle [11].

4. The main problems of nuclear hydrogen production technology

One of the most critical problems to be solved in developing nuclear hydrogen production technology and realizing its large-scale and low-cost commercial hydrogen production is the material problem. Many research institutions have done a lot of research on materials in sulfur-iodine cycle and high temperature electrolysis hydrogen production process [12].

Sulfuric acid, hydroiodate, iodine, and a mixture of these materials are present in the sulfuric acid iodine circulation system, which constitutes a corrosive environment. In order to improve the service life of equipment material, it is necessary to choose a kind of material with good corrosion resistance [12]. The results show that silicon - containing ceramic material has good sulfuric acid corrosion resistance. The development of sulfur-iodine circulation technology can be guaranteed only by researching suitable anti-corrosion materials. The corrosive environment of high temperature electrolysis is much less corrosive than that of sulfur-iodine circulation system, but it is still in a relatively harsh environment. In order to achieve a larger scale of hydrogen production, multiple electrolytic cells need to be formed into a cell reactor. The main materials of the connector used are ceramic materials and superalloy materials, and the sealing materials mainly include glass materials based on silicate, borate and phosphate, ceramic composite materials and glass-ceramic composite materials.

The safety of nuclear hydrogen [12] is also a key problem in the hydrogen production technology of nuclear energy. Nuclear hydrogen production technology must ensure public health and environmental safety issues. Therefore, in order to realize the good development of hydrogen production technology by nuclear energy in the future, we must pay attention to the material problems and safety problems of hydrogen production by nuclear energy.

5. Conclusion

Hydrogen, as a kind of clean energy, is a kind of resource that will be used on a large scale in the future.As a clean primary energy source, nuclear energy has been gradually developed and matured

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0038

for more than half a century.Hydrogen production by nuclear energy has achieved a good combination of the two and opened a new way for the development of hydrogen economy in the future.

This paper introduces the characteristics and methods of hydrogen production by traditional and nuclear methods.Compared with traditional hydrogen production methods, using nuclear energy to produce hydrogen has the advantages of significantly improving efficiency, reducing environmental pollution, sustainability and expansibility.It could also be more competitive economically.Among the main processes of hydrogen production from nuclear energy, the most promising one is the hydrogen-producing method of thermochemical cycle decomposition of water, which can not only directly convert nuclear energy into hydrogen energy, but also eliminate the emission of greenhouse gases.

The future energy development direction is sustainable, hydrogen energy is the representative of the future energy direction, nuclear hydrogen production is an effective method to achieve large-scale hydrogen production.Our country must strengthen the research in this field in order to occupy a favorable position in the future energy competition.

References

[1] Y. Pei, H.J. Ni, S.S. Lv, et al. Research status and development prospect of hydrogen production technology (The modern chemical industry, China 2013), p. 31-35. (In Chinese)

[2] Y.J. Zhang, J.Y. Li. Current situation and development of hydrogen production process from natural gas (Guangzhou chemical industry, China 2012), p. 41-42. (In Chinese)

[3] Y.W. Shi, J. Liu. Research progress of hydrogen production process from natural gas (When chemical issue, China 2009), p. 59-61+68. (In Chinese)

[4] A new way of energy development: hydrogen production from coke oven gas (Sintering technology, China 2006), p. 37-37. (In Chinese)

[5] X.L. Li. Comparison of hydrogen production units (Fertilizer industry, China 2011), p. 56-59. (In Chinese)

[6] J. Sun, G. Chen, J. Pei, et al. A simple approach to strontium sodium tantalite mesocrystals with ultra-high photocatalytic properties for water splitting (Journal of Materials Chemistry, 2012) p. 5609-5614.

[7] X.F. You, X.Y. Guo. Research status and development trend of biological hydrogen production technology (Henan chemical, China 2003), p. 4-6. (In Chinese)

[8] H. Yang, L. Guo, F. Liu. Enhanced bio-hydrogen production from corncob by a two-step process: Dark- and photo-fermentation (Bioresource Technology, 2010), p. 2049-2052.

[9] S.X. Yan, X.D. Li, L. Zhong, et al. Sliding arc plasma assisted methane vapor reforming for hydrogen production (Journal of Solar Energy, China 2011), p. 766-770. (In, Chinese)

[10] S.J. Mou, J. Lin, X.T. Xin High temperature solid oxide electrolysis water to hydrogen energy storage technology and its application prospect (The grid technology, China 2017), p. 3385-3391. (In Chinese)

[11] P. Zhang, B. Yu, J.Chen, et al. Research progress in hydrogen-producing from thermochemical cyclic decomposition of water (Progress in chemical, China 2005), p. 643-650. (In Chinese)

[12] P. Zhang, B. Yu, J.M. Xu. Development of hydrogen production technology by nuclear energy (Nuclear chemistry and radiochemistry, China 2011), p. 193-203. (In Chinese)