International Core Journal of Engineering Volume 8 Issue 1, 2022
ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0016

Analysis of Future Development Trend of Hydrogen Energy Production with Water Electrolysis Technology

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Abstract

Hydrogen energy is a kind of efficient and clean energy, and is one of the most promising secondary energy in the future. It will play an important role in solving the energy crisis, global warming and environmental pollution. This paper analyzes the status quo and advantages of various hydrogen production technologies, the problems and advantages of electrolysis water hydrogen production and future development direction.

Keywords

Carbon Emission, Hydrogen Energy, Water Electrolysis, Photovoltaic Electricity, Catalyst.

1. Introduction

In recent 50 years, due to the great development of global industry increased demand for energy, conventional oil, natural gas, coal and other fossil energy reserves are drying up, at the same time, a lot of carbon dioxide emissions from the burning of fossil fuels are also increasing damage to the atmosphere result that a fast global warming is happening and the natural environmental balance is being broken. Resulting from that all kinds of natural disasters are taking place more frequently and human survival environment is facing a huge challenge. Hydrogen energy is not only an efficient and clean secondary energy, but also an important medium for the conversion of various energy sources such as electricity, heat and liquid fuel. Hydrogen is a kind of good energy carrier and chemical raw materials, has rich source, zero pollution, high calorific value, the characteristics of high energy density, can effectively meet the new energy vehicles, new energy storage transformation, aerospace and other development needs, can reduce the proportion of fossil energy in the whole energy structure, further reducing carbon dioxide emissions.

In addition to being widely distributed in nature, hydrogen can also be produced on a large scale from industrial raw materials by industrial means. At present, the main sources of hydrogen include fossil fuels, hydrogen-rich gas, methanol, water hydrolysis , biotechnology and so on. Hydrogen production from fossil fuels mainly refers to hydrogen production from natural gas and coal. Hydrogen-rich gas mainly refers to tail gas of ammonia synthesis, recovery gas from refinery, recovery gas from chlor-alkali plant, recovery gas from coke oven gas, etc. Methanol hydrogen production mainly refers to methanol decomposition, methanol steam reforming, methanol partial oxidation, methanol conversion. Hydrolytic hydrogen production mainly refers to water electrolysis, alkaline electrolysis, polyelectrolyte film electrolysis, high-temperature electrolysis, photoelectrolysis, bio-photolysis and thermochemical hydrolysis. The electrolysis of water hydrogen making use of renewable energy power and the metal catalyst decomposition water exhalation hydrogen is a really no carbon dioxide efficient clean energy, if making into the fuel cell used in automobile, when using catalyst converts hydrogen to electricity, instead of gasoline and diesel engine, not only can greatly improve the efficiency of energy conversion, You can actually achieve significant reductions in carbon dioxide.

However, due to high consumption of electricity and platinum as catalysts for hydrogen production by electrolysis of water, the cost is too high compared with other methods of hydrogen production, so it is still not being widely applied. In this paper, the author analyzes the principle and cost of

ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0016

hydrogen production from water electrolysis, the cost and utilization of photovoltaic power generation, and the development of cheap catalyst, and summarizes a future development direction of hydrogen production from water electrolysis.

2. Basic Principle of Hydrogen Production by Electrolysis of Water

Electrolytic water was first discovered in 1789, Yang - Rudolf - De Man and Adrian - Pais - van Truswick through an electrostatic device to generate electricity using a gold electrode in the Leyden bottle water solution into gas.

Its basic principle is, connecting direct current into the electrolytic cell filled with electrolytic liquid, a electrochemical reaction will take place, and water molecules on the electrode will be respectively decompose into hydrogen and oxygen in the cathode and anode. The chemical equation is as follows:

(1) Alkaline conditions:

Cathode : $4H_2O + 4e^- \longrightarrow 2H_2\uparrow + 4OH^-$.

Anode : $4OH^- \longrightarrow 2H_2O + O_2\uparrow + 4e^-$.

The total equation is: $2H_2O \longrightarrow 2H_2\uparrow + O_2\uparrow$.

(2) acidic conditions:

Anode: $2\ H_2O \longrightarrow 4H^+ + O_2 + 4e^-$.

Cathode: $4H^+ + 4e^- \longrightarrow H_2$.

The reaction follows Faraday's law, the gas production is proportional to the current and the energized time. When sufficient voltage is applied, the water molecules will have a electrochemical reaction to produce hydrogen at the cathode and oxygen at the anode. Hydrogen from the cathode can be stored as fuel, while oxygen from the anode is released directly into the atmosphere. Therefore, the process of water electrolysis can be summarized as two half-reactions, that is cathode hydrogen evolution and anode oxygen evolution. During the electrolysis of water, pure water is a weak electrolyte, the degree of ionization is very low, the conductivity is poor, adding some easy to ionize in pure water, making the pH value of the electrolyte changes, the chemical reaction process of water decomposition will be affected[1].

3. Comparison of the Advantages and Disadvantages of the Electrolytic Water Hydrogen Production Technology

According to different electrolytes, water electrolysis hydrogen production technology currently mainly includes alkaline electrolysis (ALK), proton exchange membrane (PEM) electrolysis and solid oxide (SOEC) electrolysis.

Alkaline water electrolysis technology (ALK) uses 20%-30% KOH electrolyte, which needs a large area and has a high operation and maintenance costs. The operating temperature is 70-90 degrees, and the operating life of the electrolytic cell is about 12,000 hours. The energy efficiency is usually about 60%, and the safety is poor, requiring stable power supply.

PEM electrolytic device adopts PEM, which occupies a small area, has higher flexibility and reactivity in operation, does not use corrosive liquid, low operation and maintenance cost, the operating temperature is 70-80 degrees, the operating life of the electrolytic cell is about 10000 hours, can use fluctuant power supply, energy efficiency is about 80%.

Compared with ALK and PEM, SOEC technology has the highest efficiency of hydrogen production by electrolysis of water, but requires ceramics and some rare materials as the catalyst layer and high temperature heat source, so the investment cost is relatively much higher[2].

The key characteristics of three electrolytic water hydrogen production technologies are described in the following table 1:

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Table 1. Key Characteristics of Three Water electrolysis Hydrogen Technologies

Characteristics	ALK	PEM	SOEC
Efficiency	60%-75%	70%-90%	85%-100%
Operating temp.	70-90	70-80	700-1000
Curr. A/cm2	0.2-0.4	1-2	1-10
Energy consumption Kwh/Nm3	4.5-5.5	3.8-5.0	2.6-3.6
Power quality	stable	stable or varied	stable
Electrolyte	20-30%KOH	PEM(Nafion)	Y2O3/ZrO2
Maintenance	hard ,cost high	easy,cost low	Non
Life time of electrolyzer	12000h	10000h	Non
Cost of electrolyzer $/kw	400-600	aprx. 2000	1000-1500
Safty	low	good	low
Area occupy	big area	small	Non

From the key characteristics described in the above table, we can find that, PEM hydrogen production equipment cover an area of smaller comparison to the other 2, it will significantly improve the flexibility of operations, and make the building easier and cost lower. In addition, PEM is able to use a variable power supply, this will make possible to use various renewable energy with variable power output. PEM electrolytic units can also produce hydrogen at a higher pressure (30bar) than ALK electrolytic units (15bar), which is better suited for downstream applications with high pressure requirements. Because PEM has obvious advantages in hydrogen production, it is attracting more interesting in the hydrogen energy industry.

4. The Main Bottleneck Restricting the Development of Electrolytic Water Hydrogen Production Technology

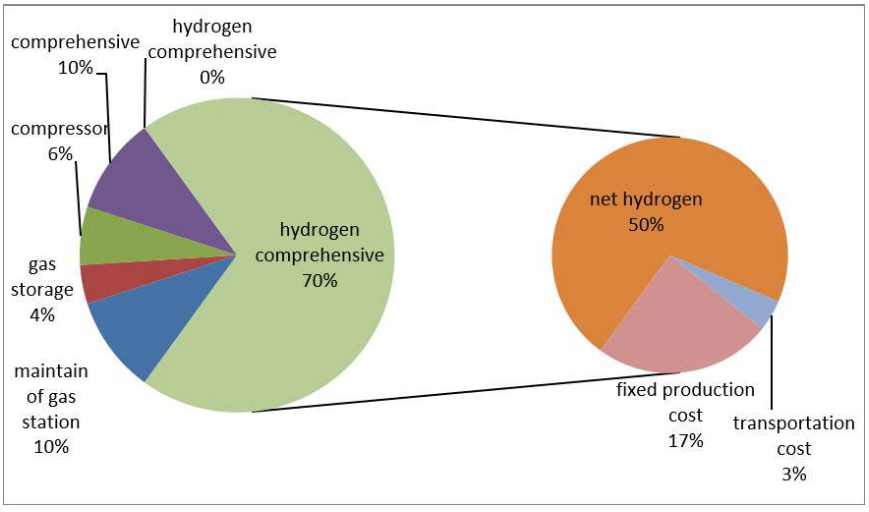

Figure 1. Hydrogen cost accounts for 70% of the selling price of hydrogen

A major constraint on the marketing of hydrogen energy is its higher price compared to conventional energy sources such as gasoline. In the price of hydrogen energy sold by hydrogenation stations, the cost of hydrogen energy including hydrogen production, storage and transportation accounts for 70%, of which the price of net hydrogen is 50%, which is the most important part. The followed figure 1 shows the cost structure of hydrogen supply station. Therefore, whether the cost of hydrogen production can be reduced is the key factor to reduce the price of hydrogen[3].

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A 2L gasoline car consumes 6-8 liters of fuel per 100 kilometers. According to the gasoline price of 7.3 RMB /L, the fuel cost for 100 kilometers is up to 58.4 RMB. Toyota Mirai hydrogen fuel cell vehicle, for example, has an average hydrogen consumption of 1kg per 100km, which means that the price of hydrogen needs to fall below 58.4 RMB /kg to be equivalent to gasoline, indicating that the cost of hydrogen needs to fall to 29.2 RMB/kg. Since hydrogen is almost a kind of ideal gas, it can be estimated that 1Kg hydrogen is about 11.19Nm3 according to the ideal gas equation. So the ideal cost of hydrogen is about 2.6 RMB/Nm3.

Compared with other hydrogen production methods, refer to the table 2 as below, water hydrolysis and photocatalytic are the only two methods without carbon emission and environment pollution to produce hydrogen and with no limits of source. The bottleneck restricting its industrial development is the production cost, which is as high as 3-5 RMB per cubic meter[3].

Table 2. Different methods of hydrogen energy production

Methods	source	carbon emission & environment pollution	source limits	electricity consumption	efficiency	production cost(RMB/Nm3)
fossil fule	natural gas	yes	yes	low	83	0.6-1.2
	coal	yes	yes	low	63	1-1.2
industry by-product	coke-oven gas	yes	yes	low	/	1.2
	chlor-alkali	yes	yes	low	/	1.3-1.5
water hydrolysis	water	no	no	high	70-100	3-5
photocatalytic water	water	no	no	low	low	>5
biotechnology	organics	low	yes	low	low	>5

5. The Possibile Approach to Reduce Production Cost of Hydrogen from Electrolytic Water

Table 3. The breakdown of hydrogen Production cost

Item		thousands of RMB	Basis
investment	equipments	12000	
	installation	480	4% of equipments
	building	1620	
	sum	14100	
cost estimate	electricity	27000	4.5Kwh/Nm3,0.6RMB/Kwh
	water	32	0.8T/Nm3,4RMB/T
	depreciation	1329	10 years of Dep.
	maintenance	249	2% of equipments
	management	600	5 staffs
	interests	330	6% loan interests
	sum	29540	
cost RMB/Nm3		2.95	
sales RMB/Nm3		3.69	20% of gross profit

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According to the calculation data of GUANGZHOU GUANGDONG Securities Hang Seng Securities Investment Consulting Co., LTD. (HEREINAFTER referred to as "HANG Seng Consulting "), with a production capacity of 1000 cubic meters of hydrogen per hour and an annual output of 1 million cubic meters of hydrogen, the cost of hydrogen production by electrolytic water is calculated as the following table 3[3]:

It can be seen that the biggest cost of electrolysis water hydrogen production technology mainly comes from two aspects: equipment investment cost and electricity cost.Where the key cost is determined by :(1) energy consumption per cubic meter of hydrogen(2) Electricity price (3) electrolytic cell cost. That is, if possible to find cheap and enough electricity and lower the cost of equipments investment, electrolysis water will become the optimal way to produce hydrogen.

6. To Combine Photovoltaic Power Generation Could be One of the Best Selection to Produce Cheaper Hydrogen in the Near Future

In recent years, photovoltaic power generation technology has advanced by leaps and bounds, and the cost of power has dropped significantly, reaching 0.2 RMB per KWH in 2020 in China. Since the construction of photovoltaic power stations requires a large amount of lands, large-scale photovoltaic power stations are suitable to be built in inaccessible areas such as adjacent to deserts, which cause a large amount of electricity waste. Establishing hydrogen production stations near photovoltaic power stations can significantly reduce the cost of hydrogen production from 2.95 RMB per cubic meter to 1.15 RMB per cubic meter through using cheap PV electricity. At the same time, it is also the use of one kind of clean energy to create another kind of clean energy, which really reduces the emission of carbon dioxide, and obtains the dual benefits of reducing costs and carbon emissions.

7. Alkaline Solid Anion Exchange Membrane(Aem) Water Electrolysis is Possible and Anticipated Technology for Future Hydrogen Production

AEM water electrolysis combines the advantages of ALK and PEM, on the one hand, AEM electrolysis adopts alkaline solid polymer anion exchange membrane that can conduct OH-, on the other hand, it can use cheaper catalyst like Ni, Co, Fe and other non-noble metal catalysts. Compared with PEM electrolysis using precious metal Ir, Pt, catalyst cost will be greatly reduced, and the corrosion requirements of electrolytic cell bipolar material are far lower than the requirements of PEM electrolysis[4]. That will greatly reduce equipment investment and operating costs.

8. Conclusion

In 2021, most of the countries around the world have set up the specific goals and timetables for reducing carbon dioxide emissions, where the use of hydrogen energy will play a important role, from various hydrogen production methods, the electrolysis of water technology is the best choice to produce hydrogen combined with cheap and variable photovoltaic electricity.In particular, alkaline solid anion exchange membrane (AEM) water electrolysis technology, combining the advantages of ALK and PEM technology, can further reduce investment and operating costs, improve energy conversion efficiency, will be one of the main directions of future hydrogen production technology development.

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