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Research Status of Alkaline Electrolysis Hydrogen Production Technology

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ABSTRACT

This article comprehensively analyzes and summarizes the research status of alkaline electrolysis hydrogen production technology.Discuss technical principles, development history, key issues, and solutions.Through literature review and case studies, the important role and development potential of technology in the field of energy conversion have been revealed.At the same time, combining experimental data and theoretical models, the advantages and disadvantages of alkaline electrolysis hydrogen production technology were deeply explored, and future research directions and suggestions were proposed.This technology has a development t rend and application prospects in the field of industrial technology, with advantages such as high efficiency, low cost, and environmental protection, gradually becoming one of the hotspots in the research of clean energy.It has broad application prospects in new energy vehicles, energy storage, and other fields.However, there are still some technical challenges that need to be addressed, such as electrode materials, electrolytes, and electrolytic cell design.In order to promote the further development and application of this technology, this article proposes some future research directions and suggestions, which are of great significance for further exploration in this field.

1. Introduction

The research background of alkaline water electrolysis production technology is profound and important. It not only carries the expectation of promoting the development of hydrogen energy industry, but also reflects the pursuit of clean and efficient energy conversion technology in the field of renewable energy. With the aggravation of the global energy crisis and the increasingly prominent environmental problems, hydrogen energy is regarded as an ideal choice to replace the traditional fossil energy with its high calorific value, clean and pollution-free characteristics. However, the existing hydrogen preparation technologies, such as natural gas reforming and hydrogen production from coal, have significant carbon emission problems, which are contrary to the goal of sustainable development.

Alkaline electrolysis of water for hydrogen production technology, as a green hydrogen production method, directly generates hydrogen by electrolysis of water, without the consumption of fossil energy, and does not produce greenhouse gas emissions. However, the technology also faces the challenges of low energy efficiency and high equipment costs. Therefore, the research on alkaline electrolysis water hydrogen production technology not only needs to explore the reaction mechanism in principle, but also needs to innovate technically to improve its energy efficiency and reduce its cost, so as to meet the actual demand of the energy market. With the urgent global demand for renewable energy and clean energy, hydrogen energy, as a clean, efficient and renewable energy source, has received extensive attention and research. As one of the important ways of hydrogen energy production, the technology of hydrogen production research and development is of great strategic significance.

The purpose of this study is to deeply analyze and explore the current research status of hydrogen production technology by alkaline electrolysis of water, and evaluate its technological development potential and market application prospect [1]. Through a review and logical analysis of the literature, this study aims to reveal the key scientific problems and technical challenges of alkaline electrolysis of water, and to provide theoretical support and practical guidance for future research directions and strategies.

2. Overview of the hydrogen production technology by alkaline electrolysis of water

2.1 Basic principles

Alkaline electrolysis of water for hydrogen production technology, as a widely used electrochemical method, its basic principle is based on the water electrolysis reaction [2]. In the electrolytic cell, water molecules undergo electrolysis under the action of electric current, which decompose into hydrogen and oxygen. This process relies on two key electrodes, the cathode and the anode, which undergo reduction and oxidation reactions, respectively, during the electrolysis process.

Specifically, in the alkaline electrolyte, the water reduction reaction occurs on the cathode, that is, the water molecules get electrons to form hydrogen and hydroxide ions. On the anode, the water oxidation reaction occurs, that is, the water molecules lose electrons and form oxygen and hydrogen ions. The electrolytes in this process, usually strong alkali solutions, such as potassium hydroxide or sodium hydroxide, act in conducting electricity and maintaining the acid-base balance of the solution.

The alkaline electrolysis water hydrogen production technology also needs to consider the design of the electrolytic pool, the selection of

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electrode materials and the operating conditions. For example, the efficient electrode materials can reduce the energy consumption in the electrolysis process and increase the hydrogen production, and the appropriate operating conditions can ensure the stability and safety of the electrolysis process.

2.2 Reaction mechanism

As one of the more mature methods of alkaline water electrolysis for hydrogen production technology, its reaction mechanism has been widely studied in the field of electrochemistry. This technology mainly relies on the electrolytic process in the electrolytic cell, in which the electrolytic water molecules cleave under the action of the electric current, producing hydrogen and oxygen. Specifically, the water oxidation reaction occurs in the anode region to produce oxygen, hydrogen ions and electrons, while the cathode region produces hydrogen ions reduction reaction, and the electrons combine with hydrogen ions to form hydrogen gas.

During the electrolysis process, the ion transport process plays a crucial role. Through the ion exchange membrane or separator, the hydrogen ions produced by the anode can smoothly migrate to the cathode and combine with the electrons of the cathode to form hydrogen, thus realizing the effective separation and collection of hydrogen. The electrolyte solution in the electrolytic cell also provides the necessary medium and environment for ion transport.

2.3 Key components

2.3.1 Electrolytic cell

In the alkaline water electrolysis hydrogen production technology, the electrolytic cell, as the core equipment, its structure design and function realization are directly related to the efficiency and cost of hydrogen production. The membrane material separating the anode and cathode inside the electrolytic cell is the key to realize the separation of hydrogen and oxygen. Such membrane materials need a high degree of ion selectivity and stable chemical properties to ensure high purity and safety in the hydrogen production process. At the same time, the liquid circulation system plays a vital role in maintaining the concentration and temperature stability of the electrolyte in the electrolytic cell.

In the design of the electrolytic cell, in addition to the membrane material and the liquid circulation system, the control of the electrolyte concentration is also a link that cannot be ignored. Too high or too low electrolyte concentration will affect the electrolytic efficiency and energy consumption. Therefore, by precise control of electrolyte concentration, the optimal operation of hydrogen production by water can be realized.

The electrolytic cell in alkaline electrolysis of water for hydrogen production technology is a complex and critical system. Its structural design and functional realization need to consider multiple factors comprehensively in order to achieve efficient and safe hydrogen production process.

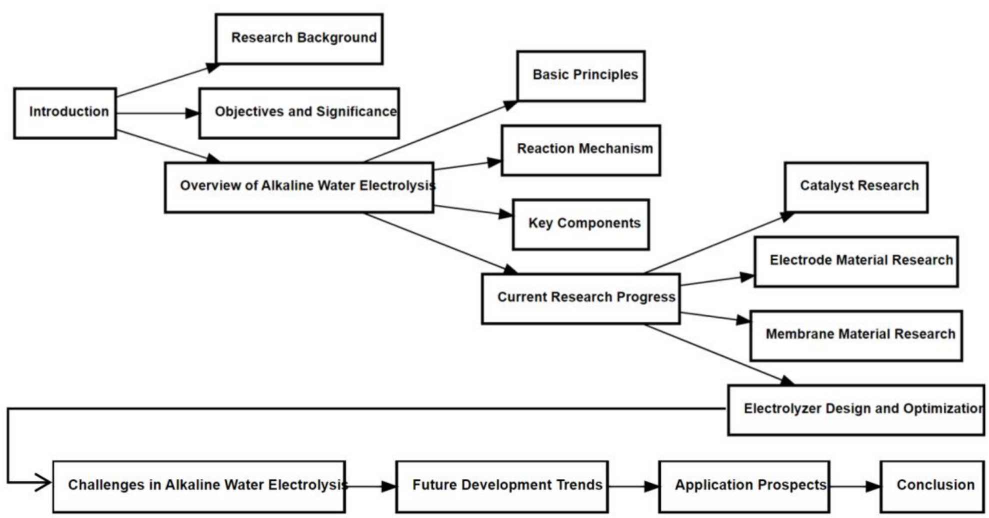

Fig 1 The research roadmap of this paper

2.3.2 Electrode

Hydrogen production by alkaline electrolysis of water is a technique for hydrogen production by electrolysis of an aqueous solution containing an alkaline electrolyte. One of the key components of this technology is the electrode, whose performance directly affects the efficiency of the whole electrolytic process and the yield of hydrogen. In the electrode materials and design of cathode and anode, researchers are constantly exploring the optimization path to improve the efficiency of electrolysis and reduce energy consumption.

The conductivity of cathode and anode is an important factor in electrode design. The high conductivity electrode material can effectively reduce the resistance loss, improve the current density, and then improve the electrolytic efficiency. Common electrode materials with excellent electrical conductivity include metals and their alloys, carbon-based materials, etc.

The choice of the catalyst has a crucial influence on the electrode performance. The catalyst can reduce the activation energy of the electrolytic reaction and speed up the reaction rate. In alkaline electrolysis of water for hydrogen production, commonly used catalysts include precious metals (such as platinum, iridium, etc.), transition metal oxides, etc. The catalytic activity of the electrode can be further enhanced by optimizing the composition and loading of the catalyst.

2.3.3 Film material

As the key link of the current hydrogen energy industry, the technology of alkaline electrolytic water hydrogen production, its corepart-membrane material selection and performance requirements are particularly important. In the process of hydrogen production by electrolysis of alkaline water, the membrane material mainly plays the role of isolating the anode and cathode, preventing gas mixing, and ensuring that hydrogen ions and oxygen ions can effectively pass through. Therefore, the ideal membrane material needs to have excellent ion permeability, and can effectively transport ions in the electrolyte.

In addition to ion permeability, membrane materials need to be highly anticorrosive and stable. There are a large number of hydroxide ions in the alkaline electrolyte environment, which may cause corrosion to the membrane material and reduce its service life. Therefore, the membrane material must be able to resist this corrosion and maintain long-term stability.

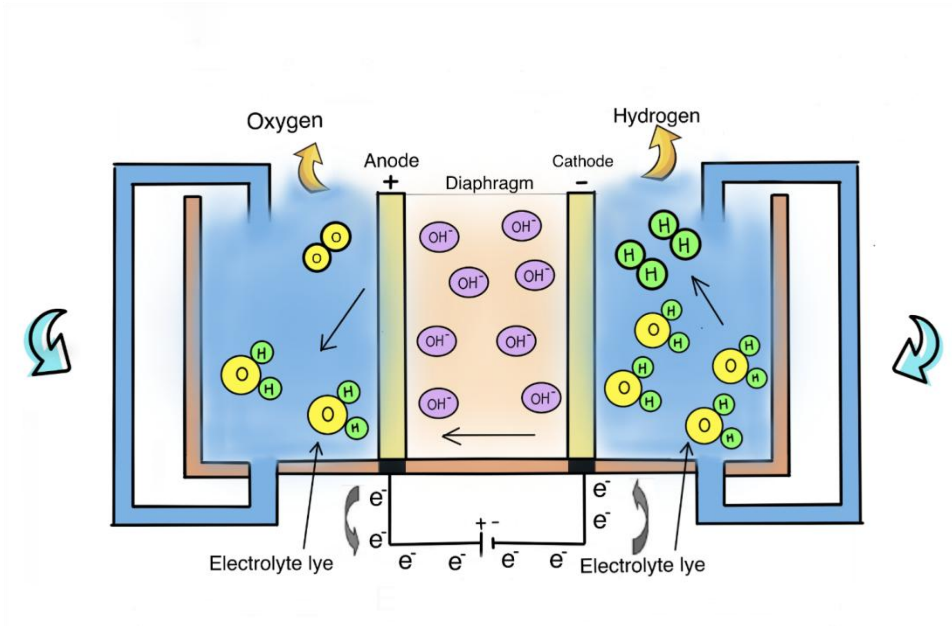

Fig 2 Schematic diagram of electrolytic water

3. Existing research progress

3.1 Catalyst study

3.1.1 Precious metal catalyst

Precious metal catalysts play a crucial role in the study of alkaline electrolysis of water for hydrogen production [3]. Precious metal catalyst has good electrocatalytic performance and stability, which can effectively promote the decomposition of water in the electrolysis process and increase the yield of hydrogen. At present, platinum, rhodium gold, palladium and other precious metal catalysts are widely used in alkaline electrolysis of water for hydrogen production technology, and many important research results have been obtained. By regulating the surface morphology, crystal surface structure and grain size of the precious metal catalysts, the catalytic performance can be optimized, and the hydrogen yield and stability can be improved. Exploring new precious metal alloy catalyst, precious metal substrate composite catalyst has also become a research hotspot, aiming to improve the activity and life of catalyst. In general, the precious metal catalyst has important application prospect and research significance in the technology of alkaline electrolysis of water, which provides an important reference for the future research direction.

3.1.2 Non-noble metal catalyst

In the research status of alkaline water electrolysis of hydrogen production technology, non-precious metal catalyst, as the key factor to improve efficiency and reduce cost, has been widely concerned and deeply studied. Such catalysts, especially those based on transition metals (such as nickel, cobalt, iron, etc.) and carbon-based materials, show significant advantages in terms of catalytic activity and stability.

Transition metal catalyst is a research hotspot in the field of alkaline water electrolysis for hydrogen production because of its abundant earth reserves, low cost and good catalytic performance. By means of alloying and surface modification of nanostructure, the catalytic activity and stability of transition metal catalyst can be significantly improved, so as to improve the efficiency and economy of water electrolysis hydrogen production.

Carbon-based materials, such as graphene and carbon nanotubes, also show great potential in alkaline water electrolysis to produce hydrogen due to their excellent electron transmission capacity and stability. Through recombination and modification with other materials, the catalytic performance of carbon-based catalysts can be further enhanced, making them a wider application prospect in industrial production.

3.1.3 Preparation method and properties of the catalyst

In the research status of alkaline electrolysis of water for hydrogen production technology, the catalyst, as the key element, its preparation method and performance evaluation have attracted wide attention. At present, the preparation methods of catalysts mainly include physical methods, chemical methods and biological methods. Physical methods, such as grinding and ball milling, improve the structure and properties of the catalyst through mechanical forces. Chemical methods involve precipitation, impregnation, sol-gel and other technologies, which aim to accurately control the composition and morphology of the catalyst [4] through chemical reactions. Biological laws are an emerging approach for using specific enzymes or microorganisms within living organisms to synthesize catalysts to achieve environmentally friendly and sustainable development.

3.2 Study on electrode materials

3.2.1 Conventional electrode material

In the research of traditional electrode materials, platinum (Pt) has always been regarded as the benchmark material for alkaline water electrolysis to produce hydrogen, and it has attracted much attention for its excellent catalytic activity and electrical conductivity [5]. However, the high cost and scarcity of Pt has limited its use in large-scale applications. Therefore, the researchers turned to explore other low-cost, high-performance electrode materials.

As an analogue of Pt, Palladium (Pd), although with slightly less catalytic activity than Pt, performs well in corrosion resistance and stability, and is regarded as a potential alternative to Pt [6]. However, Pd also faces costly problems.

In contrast, transition metals such as copper (Cu) have attracted much attention in [7] because of their low cost and rich resources. Although the catalytic activity of Cu is inferior than Pt and Pd, its catalytic performance can be significantly improved by suitable surface modification and nanostructure design [8]. Cu base alloys and composites also show excellent catalytic properties and stability, and have become a research hotspot in the field of alkaline water hydrogen production [9].

3.2.2 New electrode material

In the research of hydrogen production technology by alkaline electrolysis of water, the innovation and development of electrode materials are crucial to the improvement of the overall performance [10]. Recently, new electrode materials such as metal oxides and transition metal compounds have been widely used in this field, significantly improving the efficiency and stability of water electrolysis.

Metal oxides have attracted much attention for their excellent electrocatalytic activity and stability. Among them, precious metal oxides such as IrO2 and RuO2 show extremely high oxygen evolution reaction (OER) activity, but their high cost and scarcity limit their widespread application of [11]. Therefore, the development of low cost, precious metal oxides with stable performance and high activity has become the current research [12].

Transition metal compounds, especially those containing non-metal elements such as nitrogen, sulfur and phosphorus, show great potential in water electrolysis for hydrogen production [13] due to their unique electronic structure and chemical properties. These compounds are not only of low cost, but also have good catalytic activity and stability, thus making them ideal [14] for alternative precious metal electrode materials.

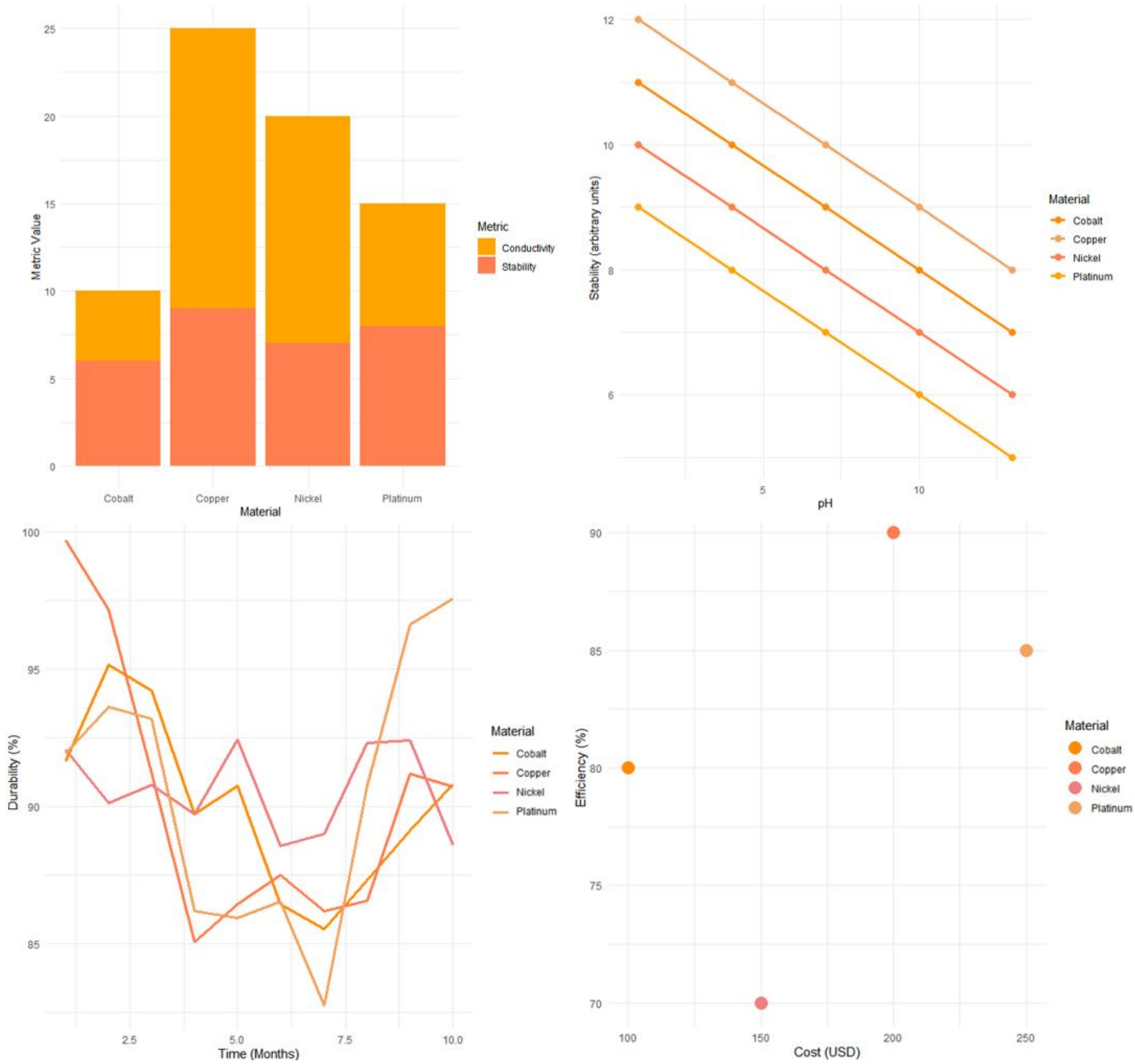

Fig 3 Comparative Analysis of Electrode Materials for Energy Storage Systems

Figure 3 shows the multifaceted performance of four conventional electrode materials (cobalt, copper, nickel and platinum). The image above on the left shows how these materials perform in terms of electrical conductivity and stability; The upper right shows the stability trend of the material at different pH values. The lower left chart depicts the durability changes of the materials over different time periods, while the lower right chart compares the relationship between the cost and efficiency of these materials. Through these data, we can comprehensively understand the advantages and disadvantages of each material in the energy storage system, and provide a scientific basis for selecting the best material.

3.2.3 Performance optimization of electrode materials

In the alkaline water electrolysis technology, the performance of the electrode material plays a decisive role in the overall hydrogen production efficiency and cost [15]. At present, the performance optimization of electrode materials has become a research hotspot. In terms of surface modification, researchers have significantly improved the catalytic activity and stability of electrodes by the design of nanostructures and coating treatment. For example, the deposition of noble metal nanoparticles on the electrode surface by the chemical vapor deposition method not only improves the electrochemical properties of the electrode, but also effectively reduces the overpotential.

In terms of synthesis methods, new preparation technologies such as sol-gel method and electrodeposition method are widely used in the preparation of electrode materials. These methods can accurately control the microstructure and composition of the material, so as to improve the catalytic performance of the electrode [16]. The use of additives is also one of the important means of performance optimization. The catalytic activity and stability of the electrode can be effectively improved by adding appropriate cocatalyst and conductive agent to the electrode material.

3.3 Study of membrane materials

3.3.1 Common membrane materials

In the study of alkaline water electrolysis technology, the selection and performance of film materials play a crucial role in the overall hydrogen production efficiency. Currently, the cation exchange membrane (CEM) and the anion exchange membrane (AEM) are the two main membrane materials, [17]. CEM is popular for its high ionic conductivity and good chemical stability, but it is prone to degradation in high alkaline environments, limiting its long-term used stability [18]. AEM is favored by researchers because it can remain stable under strong alkali conditions, but its lower ionic conductivity and poor chemical stability still need further improvement of [19].

3.3.2 New type of membrane material

The existing research progress in alkaline electrolysis of water hydrogen production technology mainly focus on membrane preparation technology and membrane performance evaluation [20]. As the core component of the electrolysis process, the performance of the membrane directly affects the efficiency of the electrolysis and the hydrogen purity. With the progress of science and technology, more and more new membrane materials have been introduced into this field.

In terms of membrane material research, polymer membranes have attracted much attention due to their good film amenability and chemical stability. However, its low proton conductivity and high permeability to hydroxide ions are still urgent to be solved. In contrast, the inorganic composite film shows higher proton conductivity and corrosion resistance, but its preparation cost and film formation are still the focus of research.

3.3.3 Performance improvement of membrane materials

The performance improvement of membrane material is one of the key points of hydrogen production by alkaline electrolysis of water. With the development of materials science, several modification methods have been applied to improve the properties of membrane materials. Surface modification techniques improve the wettability and ion exchange capacity of the membrane surface by introducing functional groups, thus optimizing the transport efficiency of water molecules and hydroxide ions. The introduction of cross-linking technology can enhance the chemical stability and mechanical strength of membrane materials, and maintain their stable performance in long time operation and high pressure environment.

The use of additives is also a common method to improve the membrane properties. By adding additives such as nanoparticles and organic polymers, the key properties of membrane materials such as electrical conductivity, ion selectivity and gas permeability can be effectively improved. The addition of these additives can not only improve the overall performance of the membrane material, but also realize the customized design of specific functions to meet the needs of different application scenarios.

With the deepening of membrane material performance improvement research, the future alkaline electrolysis of water hydrogen production technology is expected to achieve more efficient, more stable, more environmentally friendly hydrogen production.

4. Electrolycell design and optimization

4.1 Structure design of the electrolytic cell

As the core component of the alkaline water electrolysis hydrogen production technology, the design of the electrolytic cell is directly related to the hydrogen yield, purity and the energy efficiency of the system. The liquid circulation system requires that the electrolyte is evenly distributed in the electrolytic tank to maintain constant electrolytic conditions, which requires the design of reasonable fluid channels and pumping equipment. The electrode layout should consider the uniformity of current distribution and the rationality of electrode spacing to reduce the polarization loss and the bubble wall effect. The selection of membrane materials should have excellent ion conductivity, chemical stability and mechanical strength to ensure the effective separation of hydrogen and oxygen and the long-term stable operation of the system.

Based on the design of the electrolytic cell, the structure is further optimized by flow field analysis and heat transfer model. Flow field analysis can reveal the flow state of fluid in the electrolytic cell and guide the design and optimization of fluid channel. The heat transfer model can evaluate the temperature distribution in the electrolytic cell and provide theoretical support for the design and maintenance of the heat dissipation system. Through these advanced analytical tools and frameworks, we can more accurately grasp the operation rules of the electrolytic cell, and provide strong support for the further optimization of hydrogen production by alkaline water electrolysis technology.

4.2 Material selection of the electrolytic cell

In the technology of alkaline electrolysis by water, electrolytic cell is a crucial component, and the material selection of electrolytic cell directly affects the efficiency and stability of the electrolysis process. Generally speaking, the material of the electrolytic cell needs to have good electrical conductivity, chemical stability and corrosion resistance.

In practical applications, some commonly used electrolytic cell materials include nickel, iron, molybdenum and other metal materials, and zirconia, alumina and other ceramic materials. These materials have different properties and can be selected according to the specific electrolysis conditions and requirements.

In the experiment of hydrogen production by electrolysis of water, the performance of the electrolytic cell material can be evaluated by measuring the production rate of hydrogen gas in the electrolyte. Among them, the rate of hydrogen production can be calculated by Faraday's law, namely:

$$\frac{d[V(H_2)]}{dt} = k \cdot [H^+] \cdot [OH^-]$$

Where, the volume of hydrogen, the time, is the reaction rate constant, and the concentration of hydrogen and hydroxide ions, respectively. By determining the production rate of hydrogen under different materials, a suitable electrolytic cell material can be selected.

4.3 Optimization of electrolytic cell performance

The design and optimization of electrolytic cell is the key link to realize the high efficiency of alkaline water hydrogen production technology. In terms of performance optimization, we first need to focus on temperature control. Because the electrolysis reaction is sensitive to the temperature, the precise control of the temperature distribution in the electrolytic cell can significantly improve the reaction efficiency. By introducing advanced thermal management systems, such as circulating cooling systems and intelligent temperature monitoring technology, the stability of the temperature in the electrolytic tank can be effectively maintained.

The rationality of the gas distribution is of great significance for reducing the bubble aggregation and improving the gas diffusion efficiency. By improving the structure and layout of the gas diffusion electrode and optimizing the design of the electrolyte flow field, the uniform distribution of the gas in the electrolytic cell can be realized, and then the uniformity and efficiency of the electrochemical reaction can be enhanced.

5. Challenges of alkaline water electrolysis technology for hydrogen production

5.1 Catalyst cost and durability problem

Alkaline water electrolysis for hydrogen production technology, although widely regarded as a clean and sustainable energy production technology, still faces significant challenges. Among them, the cost and durability of the catalyst are particularly prominent.

The cost of the catalyst cannot be underestimated. In the process of alkaline electrolysis, efficient catalyst is crucial to improve the reaction efficiency and hydrogen production. However, these catalysts are made from rare metals or expensive materials, greatly increasing the production costs. Economic analysis shows that the cost of catalyst accounts for a large part of the cost of the whole electrolytic water system, and becomes one of the key factors limiting the large-scale application of the technology.

The durability problem of the catalyst can not be ignored. In actual operation, the catalyst may be gradually inactivated due to chemical reactions, electrolyte erosion or operating conditions. The catalyst life test results show that the durability of the current catalyst is generally insufficient, and it is difficult to meet the needs of long-term stable operation. This not only affects the economic benefits of water electrolysis to produce hydrogen, but also restricts its wide application as a renewable energy technology.

5.2 Stability and efficiency of the electrode materials

Although alkaline water hydrogen production electrolysis technology shows broad application prospects, the stability and efficiency of electrode material are still the core challenge restricting its further development.

From the point of view of durability test, the performance decline and structural destruction of electrode materials will inevitably occur in the process of long time and high strength electrolysis. This will not only affect the continuation of the electrolysis reaction, but also lead to the reduction of hydrogen production efficiency. Therefore, how to improve the stability and durability of electrode materials is the focus of the current research.

From the perspective of efficiency assessment, the catalytic activity of the electrode material directly determines the rate and efficiency of the electrolytic reaction. However, existing electrode materials remain to be improved in catalytic activity and selectivity. On the one hand, more efficient catalysts need to be designed to reduce the energy consumption in the electrolysis process, and on the other hand, the electrode structure needs to be optimized to improve the transport efficiency of the reactants and products.

5.3 Performance and life problems of membrane materials

Alkaline electrolysis of water for hydrogen production technology plays an important role in promoting the development of clean energy, but its development also faces many challenges. Among them, the performance and life problems of membrane materials are particularly prominent.

As the core component of the electrolytic cell, the performance of the membrane directly affects the electrolytic efficiency and the purity of hydrogen. However, the existing alkaline water electrolysis hydrogen film materials generally have problems such as low ion conductivity and poor stability, which not only leads to low electrolysis efficiency, but also increases the operation cost and maintenance difficulty.

The life problem of membrane material is also an important factor restricting the development of this technology. Due to the strong alkaline and high temperature environment produced in the electrolysis process, the membrane materials are prone to degradation and aging, thus shortening the service life of the electrolytic tank.

5.4 Complcomplexity and cost of electrolytic cell design

In the technology of hydrogen production, the design of electrolytic cell is a crucial link. Electrocell is the key equipment for electrolytic reaction, which affects the efficiency and cost of hydrogen production. However, the complexity and cost of electrolytic cell design is one of the main challenges facing this technology.

Electrolysis cell design needs to consider many factors, such as electrolyte selection, electrode material, electrolytic reaction conditions, etc. These factors interact with each other and need to design an efficient electrolytic cell structure. The size, shape and layout of the electrolytic cell also have a direct impact on its performance, increasing the complexity of the design.

The design of the electrolytic cell also needs to consider the cost factor. The materials, adding process and maintenance cost required for the preparation of electrolytic cell will directly affect the economy of hydrogen production technology. Therefore, how to reduce the cost while ensuring the electrolytic performance is a problem that needs to be solved. The complexity and cost of electrolytic cell design are the key problems to be solved in the research of hydrogen production by alkaline electrolysis water. Only by overcoming these challenges can we promote the development of alkaline water electrolysis technology and realize the wider application of hydrogen energy.

6 Future Development trend

6.1 Development of new catalysts

Future trends show that alkaline electrolysis of water for hydrogen production technology will play a crucial role in the field of energy transition and environmental protection. With the deepening of research, the development of new catalysts has become one of the important directions in this field.

In the development of novel catalysts, transition metal oxides have received much attention for their unique electronic structure and catalytic properties. Such catalysts show excellent stability and activity in alkaline environment, and are expected to play an important role in reducing the cost and efficiency of water electrolytic hydrogen production. Non-precious metal compounds also show great potential, and their low cost and renewability give them significant advantages in industrial applications.

With high-throughput screening techniques, researchers can quickly evaluate the performance of a large number of catalysts to screen candidates with potential. At the same time, the activity mechanism will reveal the mechanism of the catalyst in the reaction process, and provide theoretical support for the design and optimization of the new catalyst. These research results will inject new impetus into the development of alkaline water hydrogen production by electrolysis technology and promote its wide application in the field of energy.

6.2 Research and development of high-efficiency electrode materials

In the future development trend, the application prospect of high efficiency electrode materials in alkaline water hydrogen production technology is particularly noteworthy. With the progress of new materials synthesis technology, a variety of electrode materials with excellent catalytic properties and stability have been developed. In particular, metal alloy materials, such as Ni-Mo, Fe-Co, etc., can significantly improve the catalytic activity of electrolytic water through reasonable element ratio and structural design, and then reduce the cost of hydrogen production by [22].

As another important direction of electrode materials, nanomaterials show extremely high catalytic activity and good electrochemical stability due to their unique nano-effect and large specific surface area. The preparation and characterization techniques of nanoscale catalysts, such as physical vapor deposition, chemical vapor deposition, and sol gel method, provide strong support for the realization of efficient water electrolysis.

6.3 Application of new membrane materials

The future development trend indicates that the alkaline electrolysis of water for hydrogen production technology will continue to receive attention and research investment. Among them, the application of new membrane materials will become a key research focus.

With the rapid development of materials science, the ion exchange membrane shows great potential in the alkaline electrolysis of water for hydrogen production with its excellent ion selectivity penetration performance. For example, some new ion exchange membranes significantly improve the ion conduction efficiency and durability by optimizing the structural design and improving the material composition, thus improving the overall hydrogen production efficiency.

As a new material integrating the characteristics of various materials, composite materials also show unique advantages in the field of alkaline water electrolysis to produce hydrogen. With careful design and preparation, the composite materials can combine the advantages of different materials to achieve better electrolysis efficiency and stability. Therefore, the research and development of high performance composite materials will become an important development direction of alkaline electrolysis hydrogen production technology in the future.

The application prospect of the new film material in the alkaline water electrolysis hydrogen production technology is broad, and its research and development will bring revolutionary changes to this field.

6.4 Innovation in electrolytic cell design

In the future development trend, the innovation of electrolytic cell design will become the key to further breakthrough of alkaline water electrolysis technology. At the micro level, the study of micro-nanostructures is gradually attracting public attention. By finely controlling the micro and nano structure of the electrode material, the activity and efficiency of the electrolytic reaction can be significantly improved, and the energy consumption can be reduced. The introduction of 3D printing technology has revolutionized the electrolytic cell design. Using 3D printing technology, electrolytic cells with complex internal structure and efficient mass transfer performance can be made, thus further improving the efficiency and stability of [23].

In terms of system optimization, flow field simulation becomes an indispensable tool. Through the simulation analysis of the fluid flow and material transmission inside the electrolytic cell, the dynamic changes in the electrolytic process can be deeply understood and provide a scientific basis for the optimal design of the electrolytic cell. Multi-scale modeling and simulation also provide strong support for system optimization, which can be considered at the macro and micro levels to achieve global optimization of the system.

Looking into the future, with the continuous progress of science and technology and the deepening of research, alkaline electrolysis of water hydrogen production technology will usher in a broader development prospect.

7 Application prospects

7.1 Industrial hydrogen production

In the industrial field, the technology of alkaline electrolysis has shown a broad application prospect. With the global pursuit of clean energy and sustainable development, reducing production costs and reducing carbon emissions have become an inevitable trend of industrial development. As a green and efficient hydrogen production method, alkaline electrolysis of water hydrogen production technology can not only provide pure hydrogen resources, but also reduce the emissions of greenhouse gases such as carbon dioxide in the process of hydrogen production, which is of great significance for the realization of low-carbon transformation in the industrial field.

Specifically, alkaline water electrolysis of hydrogen production technology produces hydrogen through water electrolysis. Its raw material is only water and electricity, without the need to rely on fossil fuels, so it has significant environmental advantages. At the same time, the technology has high efficiency of hydrogen production and low cost of hydrogen production, which makes its large-scale application in the industrial field possible. By integrating the alkaline electrolysis of water hydrogen production technology and the industrial production process, the production cost can be effectively reduce, the product quality can be improved, and the green and sustainable development of industrial production can be realized.

7.2 Transportation field

In the application prospect, alkaline electrolysis of water for hydrogen production technology plays an important role in the field of transportation. With the growing global pursuit of green travel and sustainable energy use, the promotion and popularization of hydrogen fuel cell vehicles, as a clean and efficient energy solution, is particularly important. Alkaline electrolysis of water for hydrogen production technology, as a core component of hydrogen fuel cell vehicles, can provide a stable and reliable supply of hydrogen, thus ensuring the normal operation of hydrogen fuel cell vehicles.

Specifically, alkaline water electrolysis of hydrogen production technology has the advantages of fast reaction speed, high efficiency and relatively low cost, which make it have a broad application prospect in the field of transportation. For example, in long-distance transportation, public transportation and other fields, hydrogen fuel cell vehicles have gradually become the preferred energy solution because of their zero-emission and long-endurance characteristics. Therefore, in-depth research and exploration of alkaline water electrolysis of hydrogen production technology is not only of great significance for promoting the development of hydrogen fuel cell vehicles, but also has a profound impact on the transformation and upgrading of the global energy structure.

7.3 Energy storage field

Alkaline electrolysis of water for hydrogen production technology has shown broad application prospects in the field of energy storage. With the large-scale grid connection and intermittent problems of renewable energy, energy storage system has become the key to balance the supply and demand of the grid and improve energy efficiency. Alkaline electrolysis water hydrogen production technology plays an increasingly important role in energy storage system in its high efficiency, stability and environment protection.

Alkaline electrolysis of water breaks down water into hydrogen and oxygen, which stores the electricity in the form of hydrogen energy. This energy storage method can not only effectively solve the intermittent problem of renewable energy, but also convert hydrogen energy into electric energy through fuel cells during peak power demand, improving the flexibility and stability of the grid.

Alkaline electrolysis of water for hydrogen production technology also has the characteristics of a friendly environment. In the process of hydrogen production, only hydrogen and oxygen are produced, with no pollutant emission, which is in line with the trend of green and low-carbon energy development.

Alkaline water electrolysis of hydrogen production technology has great application potential in the field of energy storage, and is one of the important technologies to promote the transformation of energy structure and realize the sustainable development of energy [24].

7.4 Other potential applications

In terms of application prospect, alkaline water and hydrogen production electrolysis technology has shown great potential. In the aerospace field, hydrogen is regarded as the ideal energy source for future aircraft due to its high energy density and clean combustion characteristics. Using alkaline electrolysis water to produce hydrogen technology, the independent production and supply of hydrogen in the space station or spacecraft, greatly improving the self-sufficiency of energy.

The military sector also needs efficient, clean energy support. Alkaline electrolysis of water for hydrogen production technology can provide stable hydrogen energy for military facilities, especially in remote or complex environments, and its independence and reliability are particularly important.

In the field of home energy, alkaline electrolysis of water for hydrogen production technology also has a broad application prospect. With people's pursuit of clean energy and environmentally friendly life, the home energy system is gradually changing to renewable energy. By combining alkaline electrolysis water hydrogen production technology and other clean energy technologies, household energy can achieve self-sufficiency and green emissions, providing residents with a more comfortable and environmentally friendly living environment.

8 Conclusion

8.1 Summary of the main research results

In recent studies, significant advancements have been made in catalyst development for alkaline electrolysis hydrogen production. For instance, MXene-mediated reconfiguration has demonstrated enhanced robustness in nickel–iron catalysts tailored for industrial-grade water oxidation [25]. Furthermore, the synthesis of ternary-metal hydroxysulfide catalysts through cathodic reconstruction, regulated by ion dynamics, has shown promising results for achieving industrial-level hydrogen generation [26]. Iron-locked hydr(oxy)oxide catalysts, engineered via ion-compensatory reconstruction, have been proven effective in boosting large-current-density water oxidation [27]. Additionally, the development of self-stabilized electrodes by etching nickel foams into catalyst-substrate fusion configurations has shown potential for advancing industrial-scale water electrolysis [28]. These studies collectively contribute to the ongoing research landscape of alkaline electrolysis technology."After a thorough analysis of the current situation of hydrogen production by alkaline electrolysis, we can conclude that although the technology has made significant progress in industrial application, it still needs to be further explored and optimized in efficiency improvement, cost reduction and sustainable development.

The main research results are summarized as follows: in catalyst research, various efficient and stable catalysts were successfully developed, which significantly improved the energy efficiency of the electrolysis process; electrode materials, the introduction of new materials not only enhanced the conductivity and stability of the electrode, but also optimized the gas precipitation and separation in the electrolysis process; membrane materials, the development of new ion exchange membrane effectively reduces the energy consumption and pollution in the electrolysis process; electrolytic cell design improves the electrolytic efficiency and system stability by optimizing the structure and operation parameters.

However, the realization of these achievements is accompanied by complex processes and high costs, which to some extent limits the wide application of alkaline electrolysis of water for hydrogen production technology. Therefore, future research should pay more attention to the economy and environmental friendliness of the technology in order to realize the sustainable development of the technology.

8.2 Recommendations for future studies

Through the in-depth research of alkaline electrolysis of water for hydrogen production technology, it is not difficult to find its great potential and application value in the field of clean energy. However, current technologies still face challenges such as high energy consumption and short catalyst life. In order to promote the further development of alkaline electrolysis, we need to explore the mechanism and optimize it from multiple dimensions.

In view of the challenges facing the current technology, we propose further research from the following aspects: strengthen the development of new efficient catalyst and explore to improve hydrogen production efficiency; optimize the design and preparation process of electrode materials, reduce the resistance of electrode and improve the electrode performance; as a key component of hydrogen production technology of alkaline water electrolysis, the efficiency and energy consumption, so the research and development of new membrane materials should be strengthened; the overall design and optimization of electrolytic cell should be considered to realize a more efficient and economical hydrogen production process of alkaline water electrolysis. Through these measures, we believe that alkaline electrolysis of water for hydrogen production technology will play a more important role in the clean energy field in the future.

As one of the key technologies in the field of sustainable energy, the research of alkaline electrolysis hydrogen production technology has attracted wide attention. The technology produces hydrogen and oxygen in alkaline electrolyte by electrolysis water molecules, which has the advantages of a wide range of raw materials and simple operation. However, the electrolysis efficiency, the energy conversion rate and the stability of the electrode materials are still the bottleneck of restricting their commercial application.

In response to these challenges, researchers have carried out a lot of experimental and theoretical research in recent years. On the one hand, the electrolytic efficiency is improved by optimizing the structure and electrolyte composition of the electrolytic cell; on the other hand, the author improves the electrode stability and energy conversion efficiency. Advanced data analysis tools and computational methods are introduced to investigate the reaction mechanism during electrolysis to guide experimental design and optimization of [29].

References

[1] Ding Guijun. Economic analysis of hydrogen production by alkaline electrolysis using nuclear power [J]. Contemporary Chemical Industry Research, 2023, (06): 191-193.

[2] Huang Congqi, Wu Yimei, Chen Jianye, Shao Shuangquan. Simulation study of thermal management system for hydrogen production device of alkaline electrolysis water [J]. Journal of Chemical Industry, 2023,74 (S1): 320-328.

[3] Ma Jingwen, Wang Jun, Li Xiang. Research progress of hydrogen production catalyst by ruthenium-based alkaline water [J]. Inorganic Salt Industry, 2022,54 (04): 69-73.

[4] Merabet Nour Hane,Kerboua Kaouther.Membrane free alkaline sono-electrolysis for hydrogen production: An experimental approach[J].International Journal of Hydrogen Energy,2024,49(PC):

[5] Xuan Deng-Hui,Qiu Yu-Ping,Wang Ping.Rapid hydrogen generation from the reaction of aluminum/activated charcoal composite with alkaline solution[J].Journal of Alloys and Compounds,2023,947

[6] Rafael d'Amore Domenech,Isabel Carrillo,Emilio Navarro,Teresa J.Leo.Alkaline Electrolysis for Hydrogen Production at Sea: Perspectives on Economic Performance[J].Energies,2023,16(10):

[7] Lu Nan,Yan Xiaoqing,Tan Hui Ling,Kobayashi Hisayoshi,Yu Xuehan,Li Yuezhou,Zhang Jiemei,Peng Zhengxin,Sui Jing,Zhang Ziying,Liu Wen,Li Renhong,Li Benxia.Carbon-catalyzed oxygen-mediated dehydrogenation of formaldehyde in alkaline solution for efficient hydrogen production[J].International Journal of Hydrogen Energy,2022,47(65):

[8] Wang Tongzhou,Cao Xuejie,Jiao Lifang.PEM water electrolysis for hydrogen production: fundamentals, advances, and prospects[J].Carbon Neutrality,2022,1(1):

[9] Zhuk A.Z,Borzenko V.I,Buzoverov E.A,Ivanov P.P,Shkolnikov E.I.Comparative analysis of hydrogen production technologies: Hydrothermal oxidation of the carbonless aluminum and water electrolysis[J].Renewable Energy,2022,197

[10] Choi Baeck B,Jo Jae Hyeon,Lee Taehee,Jeon Sang Yun,Kim Jungsuk,Yoo Young Sung.Operational Characteristics of High-Performance kW class Alkaline Electrolyzer Stack for Green Hydrogen Production[J].JOURNAL OF ELECTROCHEMICAL SCIENCE AND TECHNOLOGY,2021,12(3):

[11] Liao Peisen,Kang Jiawei,Zhong Yicheng,Xiang Runan,Wang Shihan,Li Suisheng,Liu Xianlong,Li Guangqin.Recent advances of two-dimensional metal-organic frameworks in alkaline electrolysis water for hydrogen production[J].Science China Chemistry,2023,66(7):

[12] Chandrasekar M,Gopal P,Ramesh Kumar C,Edwin Geo V.Effect of solar photovoltaic and various photovoltaic air thermal systems on hydrogen generation by water electrolysis[J].International Journal of Hydrogen Energy,2022,47(5):

[13] Siqi Chai,Guojie Zhang,Guoqiang Li,Yongfa Zhang.Industrial hydrogen production technology and development status in China: a review[J].Clean Technologies and Environmental Policy,2021,23(7):

[14] Chen Yuning,Liu Jiajun,Feng Li.Transient analysis of a green hydrogen production and storage system using Alkaline electrolyzer[J].Fuel,2022,324(PC):

[15] Chen Yu,Chen Jiaojiao,Bai Ke,Liu Jingyun,Xiao Zeyi,Fan Senqing.Microporous structure flowing integrated with electrolytic water splitting based on stacked mesh electrode for hydrogen production[J].Fuel,2024,358(PB):

[16] Ren Zhibo,Wang Jinyi,Yu Zhiyong,Zhang Chang,Gao Shiwang,Wang Pengjie.Experimental studies and modeling of a 250-kW alkaline water electrolyzer for hydrogen production[J].Journal of Power Sources,2022,544

[17] Xiao Zehao,Yang Mei,Liu Canhui,Wang Bowen,Zhang Shilin,Liu Jingyan,Xu Zonglin,Gao Ruijie,Zou Ji-Jun,Tang Aidong,Yang

Huaming.Artificial modulated Lewis pairs for highly efficient alkaline hydrogen production[J].Nano Energy,2022,98

[18] Schropp Elke,Naumann Gabriel,Gaderer Matthias.Prospective Life Cycle Assessment: a Case Study of Hydrogen Production with Water Electrolysis[J].Procedia CIRP,2022,105

[19] Truche Laurent,Bourdelle Franck,Salvi Stefano,Lefeuvre Nicolas,Zug Apolline,Lloret Emily.Hydrogen generation during hydrothermal alteration of peralkaline granite[J].Geochimica et Cosmochimica Acta,2021,308

[20] Wang Peican, Wan Lei, Xu Zi'ang, Xu Qin, Wang Baoguo. Status and prospect of hydrogen production by alkaline membrane electrolysis [J]. Journal of Chemical Industry, 2021,72 (12): 6161-6175.

[21] Wang Shan,Lu Aolin,Zhong Chuan Jian.Hydrogen production from water electrolysis: role of catalysts[J].Nano Convergence,2021,8(1):

[22] Yin Hang,Xu Yue,Wang Jiahuan.Deep learning-based optimization of a hydrogen and oxygen production system for patients in hospital with alkaline electrolyzer[J].Fuel,2023,333(P2):

[23] Gong Junda,Sun Cong,Shi Huangang,Tan Wenyi.Response behaviour of proton exchange membrane water electrolysis to hydrogen production under dynamic conditions[J].International Journal of Hydrogen Energy,2023,48(79):

[24] Yang Chengyu, Ma Jun, Li Guangyu, Zhao Xiaoliang, Gu Yongxin. Application and practice of many-to-one application of large alkaline water electrolysis hydrogen production equipment [J]. Solar energy, 2022, (05): 103-114.

[25] Yu Q, Chen Y, Liu J, et al. MXene-mediated reconfiguration induces robust nickel–iron catalysts for industrial-grade water oxidation[J]. Proceedings of the National Academy of Sciences, 2024, 121(9): e2319894121.

[26] Fang P, Zhu M, Liu J, et al. Making Ternary-Metal Hydroxysulfide Catalyst via Cathodic Reconstruction with Ion Regulation for Industrial-Level Hydrogen Generation[J]. Advanced Energy Materials, 2023, 13(35): 2301222.

[27] Liu J, Du W, Guo S, et al. Iron-locked hydr (oxy) oxide catalysts via ion-compensatory reconstruction boost large-current-density water oxidation[J]. Advanced Science, 2023, 10(16): 2300717.

[28] Zhu Z, Yang X, Liu J, et al. Handily etching nickel foams into catalyst–substrate fusion self-stabilized electrodes toward industrial-level water electrolysis[J]. Carbon Energy, 2023, 5(10): e327.

[29] Qin Wu,Luo Laixing,Chen Shubo,Iqbal Tahir,Xiao Xianbin,Dong Changqing.Efficient strategy of utilizing alkaline liquid waste boosting biomass chemical looping gasification to produce hydrogen[J].Fuel Processing Technology,2021,217