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The analysis of the future development prospects of hydrogen energy from the perspective of the hydrogen energy industry chain

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Abstract. Hydrogen, with its characteristics of easy access, green, and safety has gradually become a new focus of global energy research. It is noteworthy that the current technology has also achieved the integration of traditional fuels such as hydrogen and natural gas, significantly improving energy utilization efficiency. This article will delve into the development prospects and directions of the hydrogen energy industry from multiple dimensions, including the preparation, storage, and transportation of natural gas. With the continuous progress of technology, the hydrogen energy industry will inevitably usher in a broader world, injecting new vitality into the sustainable development of human society.

Keywords: Energy transformation, hydrogen, geological storage, gas transportation.

1. Introduction

In the pursuit of sustainable development, finding a new type of energy with abundant reserves, and clean and safe energy has always been a common challenge for humanity. Hydrogen, with its characteristics of complete decarbonization and achieving zero emissions, has become the most promising sustainable energy source in the 21st century. Therefore, many countries have turned their attention to the field of hydrogen energy and vigorously supported the development of related industries, in order to provide reliable energy security for the future of human society. There are various types of hydrogen production technologies, which can be subdivided into three categories based on the source of raw materials: gray hydrogen, blue hydrogen, and green hydrogen. These technologies have their own characteristics in terms of economic cost, energy efficiency, and environmental impact, and are deeply influenced by the overall sustainability of the industrial chain and public recognition. Therefore, when selecting hydrogen production methods, it is necessary to comprehensively consider various factors in order to effectively ensure a win-win situation between economic and environmental benefits [1,2]. Hydrogen, as a clean energy source, has enormous development potential and unique advantages in transportation and storage. Salt cavern hydrogen storage is considered one of the most eye-catching methods currently, by utilizing mined salt caverns to store hydrogen underground. Compared with ground storage, salt cavern hydrogen storage has many advantages such as larger storage capacity, lower cost, and better sealing, making it an ideal choice for large-scale hydrogen storage. This method not only helps to solve the difficulties in hydrogen transportation but also provides sustainable support for the development of clean energy in the future. On a global scale, salt cavern hydrogen storage technology has broad application prospects and is expected to promote the hydrogen energy industry to new heights.

With the support of advanced technology, hydrogen is mainly used in combination with traditional fuel natural gas to achieve large-scale transportation and more efficient utilization of heat value, while reducing environmental pollution. This combined application not only achieves efficient utilization of hydrogen, but also improves energy utilization efficiency, injecting new impetus into environmental protection and sustainable energy development.

By analyzing the current situation, production and storage methods, as well as the mixed pipeline transportation of hydrogen and natural gas, this article summarizes and looks forward to the future development direction of the hydrogen energy industry [3].

2. Current Situation of the Hydrogen Energy Industry

At present, the hydrogen energy industry chain mainly revolves around the following industries: Hydrogen production, Hydrogen storage, Transportation, Refueling and Fuel cells [4].

Currently, the hydrogen energy industry is facing four major challenges: firstly, the acceptance of hydrogen energy in the market is not high, and consumer is widespread; Secondly, the technical implementation is difficult, and various aspects of the technology are not yet mature enough; Thirdly, the high cost of hydrogen production, storage, transportation, and use makes it difficult to meet the expectations of investors and consumers; The fourth is safety issues.

Although hydrogen energy will experience a market downturn in the future, countries are actively investing in research and development, promoting hydrogen energy to become one of the most promising and promising industries in the 21st century. With continuous technological breakthroughs, hydrogen energy is expected to gradually move towards widespread application [5, 6].

Although hydrogen energy faces many challenges that have not yet been resolved, significant breakthroughs in market, technology, cost, and security will become the key to promoting leapfrog development in the hydrogen energy field. Hydrogen energy plays an important role as a means for humans to have closer contact with clean energy. However, corresponding issues also need to be addressed. As these issues are gradually resolved, hydrogen energy will usher in broader development prospects, bringing new hope to the fields of environmental protection and sustainable energy.

3. Development of Hydrogen Production Technology and Hydrogen Storage Technology

3.1. Current Research Status of Hydrogen Production Technology at Home and Abroad

According to analysis, the technology and market development of grey hydrogen and blue hydrogen are relatively mature, but due to high costs and emission issues, they are still not ideal hydrogen production methods. In contrast, electrolysis of water for hydrogen production has advantages such as easy availability of raw materials and zero emissions, making it a more desirable choice. The production of hydrogen through electrolysis of water can not only reduce costs, but also reduce the impact on the environment, which is an important direction for the future development of hydrogen energy [7].

The basic principle of hydrogen production by electrolysis of water is to achieve the oxidation-reduction reaction of reducing hydrogen ions to hydrogen gas in a system composed of electrodes, membranes, and electrolyte aqueous solutions. The alkaline electrolysis technology for hydrogen production has become relatively mature, but due to issues such as the large volume of the electrolysis tank, it cannot be produced on a large scale [8]. Therefore, finding economic and sustainable production methods is the top priority for the hydrogen energy industry. Developing more innovative and efficient hydrogen production technologies is crucial for promoting the development of the hydrogen energy industry.

It can be found that alkaline water electrolysis(AEMWE) combines the advantages of low-cost of alkaline water electrolysis (AWE), high efficiency of proton exchange membrane electrolysis of water (PEM) [9,10], and ease of operation. The principle of AEMWE is to use anion exchange membranes,

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use non-precious metals as electrode catalysts under alkaline conditions, and use pure water or weakly alkaline solutions as electrolytes, thereby reducing the cost of precious metal consumption and equipment corrosion maintenance. However, despite the enormous potential of AEMWE technology, it is still in the laboratory stage and there are still some issues that need to be addressed. Among them, the strength of the anion exchange membrane is difficult to ensure, and during the process of hydrogen and oxygen ion transfer, it may lead to a local strong alkaline environment, affecting ion exchange efficiency and possibly causing membrane damage, which can lead to battery short circuits and result in the system being unable to operate stably for a long time. To achieve the reliability and stability of AEMWE technology in practical applications, these challenges still need to be addressed.

3.2. Comprehensive Impact Assessment of Hydrogen Production Industry

Although hydrogen energy production technology is gradually maturing, the comprehensive impact assessment of the hydrogen production industry makes it difficult to achieve a perfect balance between efficiency, cost, and environmental protection. Cation exchange membrane electrolysis of water (AEMWE) is considered the most promising hydrogen production technology due to its unique characteristics, but it faces challenges such as electrode selection and membrane strength [11]. Although current technology can achieve high-performance catalytic electrodes and high-strength ion exchange membranes, it has not yet been applied to industrial-scale production. To achieve the reliability and stability of AEMWE technology, it is necessary to overcome issues such as electrode and membrane strength in order to further promote development [12]. Continuing research and innovation are key to addressing these issues and promoting the industrial production of AEMWE technology.

Therefore, the primary challenge for the future hydrogen energy industry is how to showcase existing technologies in a more economical and environmentally friendly manner. To address the challenges faced by the hydrogen energy industry, it is necessary to address issues such as low economic benefits and insufficient supply from the user end at the source and promote the sustainable development of the industry.

3.3. Hydrogen Storage Technology

Solid hydrogen storage is achieved through the adsorption of hydrogen gas on the surface of physical materials, a reaction to generate hydrides, and other methods of storage [13]. Low-temperature liquid hydrogen storage is the process of cooling hydrogen gas to -252.8 ℃ and converting it into liquid for storage [14]. Organic liquid hydrogen storage utilizes unsaturated organic compounds to react and store hydrogen gas [15]. Although various hydrogen storage technologies have advantages, there are also some limitations, such as high cost and limited size of solid hydrogen storage, high energy consumption for low-temperature hydrogen storage, purity issues with organic liquid hydrogen storage, and limited volume and scale of high-pressure gaseous hydrogen storage. In the future, it is necessary to continuously improve technology, overcome these obstacles, and promote the further development of hydrogen energy storage technology.

In summary, various hydrogen storage methods have their own characteristics, but generally have the disadvantages of high cost and low hydrogen storage capacity. In contrast, geological hydrogen storage has unique advantages and is considered the most promising development direction in the field of hydrogen storage, which is different from the other four methods.

Salt caverns are underground cavities formed after mining salt rock, which have the characteristics of low permeability, good creep performance, and self-healing, creating a long-term stable environment [15]. The advantage of salt cavern hydrogen storage lies in providing large storage capacity while saving ground area, while the characteristics of salt rock ensure the sealing and stability of storage [16]. The construction of a salt cavern-type underground hydrogen storage facility is simple, requiring only surface drilling and pipeline laying. The operation process can be completed through a single well without the need for other equipment, thereby reducing construction and maintenance costs and bringing economic benefits.

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Although salt cavern hydrogen storage provides convenience, there are also certain risks, such as corrosion of pipes by hydrogen, geological safety risks, and the impact of microorganisms on hydrogen [17]. Although underground hydrogen storage has many advantages, the uncertainty of the underground environment poses challenges to technical installation and requires high-level technical support.

In summary, underground salt cavern hydrogen storage needs to be improved in four aspects: pipeline materials, above ground and underground equipment, hydrogen purity testing, etc [18].

4. Transportation of Hydrogenated Natural Gas

Currently, as shown in figure 1., hydrogen production in China is mainly concentrated in the central and western regions, while high utilization areas of hydrogen are distributed in the southeastern coastal areas, making hydrogen transportation a challenge. Hydrogen trailer transportation is limited by factors such as scale and cost, and cannot be transported on a large scale [19]. The existing natural gas pipeline for hydrogen transportation is a feasible option, but single hydrogen transportation may face cost and technical challenges [20]. Therefore, blending hydrogen into natural gas pipelines while transporting hydrogen has become a solution, but safety and technical issues still need to be addressed. To achieve effective hydrogen transportation, it is necessary to comprehensively consider the challenges of cost, technology, and safety, and promote the development and application of hydrogen transportation technology.

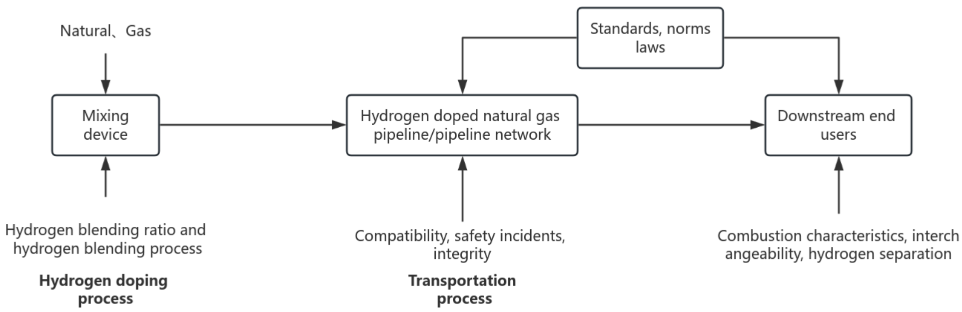

Figure 1. Main links of hydrogen-doped natural gas pipeline transportation

4.1. Current Status of Hydrogen-Doped Natural Gas Pipeline Technology

By comparing the physical properties of methane and hydrogen, it can be found that in the stationary state of the mixed gas, gas stratification occurs due to different densities. In addition, under the same pressure conditions, the volume change of hydrogen gas is about eight times that of methane, which makes it difficult to control the pressure during transportation [21], posing a challenge to the stable operating range of the compressor. In addition, adding hydrogen to natural gas can cause a series of problems, such as differences in pipeline material and gas density, which can easily lead to hydrogen embrittlement in pipelines and increase the risk of leakage [22]. In summary, mixed gases face multiple challenges during transportation and need to be overcome in order to effectively promote the development of hydrogen and natural gas mixed transportation technology.

After adding hydrogen, natural gas pipelines may experience problems such as hydrogen bubbling, hydrogen embrittlement, decarburization, and hydrogen corrosion, among which hydrogen embrittlement is the most harmful to pipeline materials [23]. Hydrogen embrittlement refers to the process in which hydrogen forms solid solutions, hydrides, and other products with metal pipelines, weakening the bonding strength of metal materials and easily leading to pipeline damage [24]. At the same time, the density difference between hydrogen and natural gas causes gas stratification inside the pipeline, especially at high convexities where hydrogen accumulates, increasing the concentration of hydrogen and affecting the service life of the pipeline. To ensure the safe operation of pipelines, it is necessary to solve the related problems caused by hydrogen, improve the hydrogen resistance and safety of pipelines, and ensure the stability and reliability of the transportation process.

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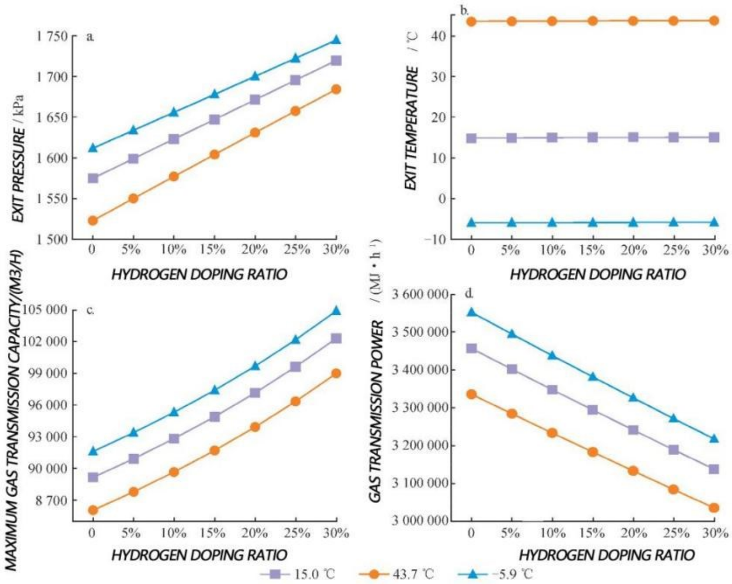

Figure 2. The influence of hydrogen blending ratio on pipeline operating parameters under different pressures and temperatures [25]

As shown in Figure 2, hydrogen addition can have an impact on the transportation efficiency of pipelines. For example, if the hydrogen flow rate is too low, it may exacerbate the phenomenon of stratification inside the pipeline, and it is also more likely to occur under low temperature and high pressure conditions. Therefore, when operating hydrogen doped natural gas pipelines, they should be operated at low pressure and high speed to improve transportation efficiency and reduce the stratification phenomenon between hydrogen and natural gas.

Therefore, it is crucial to conduct a comprehensive analysis and evaluation of the mechanical properties and chemical composition of pipelines. At present, there is a lack of relevant regulations in China, while foreign countries have specified some regulations such as ASME B31.12-2014 Hydrogen Pipeline and Pipelines, which help ensure the safety and efficiency of pipelines when transporting hydrogen doped gas.

4.2. Influence of Hydrogen Blending Ratio on Compressor

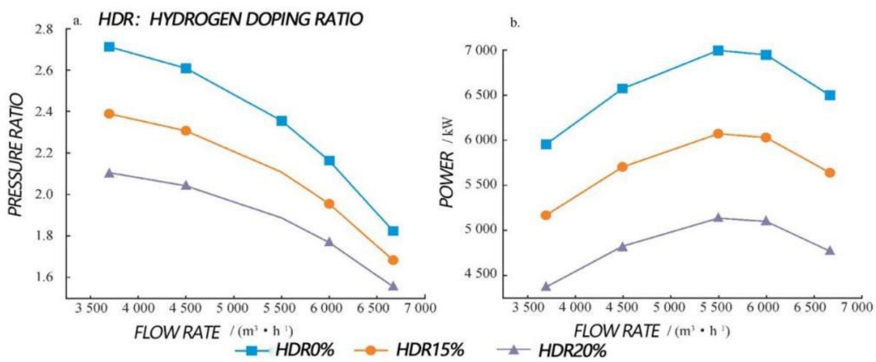

Figure 3. The effect of different hydrogen blending ratios on compressor performance [25]

As shown in figure 3, in hydrogen blending transportation, as shown in the table above, when the efficiency of the compressor decreases, the corresponding compressor speed remains unchanged, and the hydrogen blending ratio increases [25]. Therefore, in hydrogen blending transportation, it is necessary to optimize compressor design and operation to improve energy efficiency and meet the compression needs of hydrogen and natural gas.

4.3. Summary and Prospect of Hydrogen Blending Pipeline Network Transportation

According to the above information, hydrogen blending pipeline network transportation is still in an immature stage of development, mainly reflected in incomplete pipeline standards and specifications, low compressor accuracy, and mismatched user gas appliance models. To address these issues, the hydrogen energy industry should establish a comprehensive regulatory system that is applicable globally as soon as possible [26]. At the same time, it is necessary to continuously improve the strength, accuracy, and process performance of hydrogen doped workpieces, in order to provide more user-friendly hydrogen doped natural gas and provide users with more convenient solutions. Through continuous improvement and innovation, this paper aim to promote the development of hydrogen blending pipeline transportation technology and assist the hydrogen energy industry in achieving wider application and development.

5. Conclusion

It is expected that by 2050, approximately 25% of global hydrogen energy will be able to achieve cross-border transactions [27]. Hydrogen energy has been identified as the development trend of future mainstream energy. In the upstream, midstream, and downstream of the hydrogen energy industry, although there are some immature aspects, there are also various opportunities.

Building a new pattern is an urgent task. The good relationship between energy and nature is an important issue for the future. Energy transformation requires comprehensive technological innovation, including hydrogen production, storage, and transportation. By improving the accuracy and strength of existing equipment, promoting new technologies, and achieving full industry chain upgrading. International cooperation is also crucial in promoting cooperation and development in the field of energy business, and advancing together. It is necessary to improve the regulations and norms of the hydrogen energy industry to ensure that hydrogen is delivered to users more economically and conveniently. Through unremitting efforts, promote innovation and cooperation in hydrogen energy technology, achieve sustainable development of hydrogen energy, and help promote the transformation of clean energy.

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