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The Development Status and Shortcomings of Hydrogen Fuel Vehicles

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Abstract: As one of the power sources in the new era, new energy fuel cells play an important role in realizing the decarbonization transformation process of transportation. Hydrogen fuel cells have attracted the attention of many countries as a technology with high efficiency, clean, and zero pollution emissions. This paper uses the method of literature review to review the development status of this technology in China, the technical problems, and corresponding measures, including on-board hydrogen storage, long-distance hydrogen transportation, hydrogen refueling stations, and related safety issues. The results show that China has become a global leader in alkaline electrolysis hydrogen production, and hydrogen production technologies such as PEM, SOEC, AEM, and so on are also in the R&D and verification stage. However, at the same time, it is also facing the problems of high transportation costs, imperfect hydrogen storage technology, and an insufficient number of hydrogen refueling stations. Therefore, in the future, more attention should be paid to the development of midstream hydrogen storage and downstream hydrogenation technology.

Keywords: hydrogen fuel cells cars, carbon fiber technology, hydrogen storage, hydrogen infrastructure.

1. Introduction

New energy is the foundation and driving force of human civilization and progress, it is related to people's livelihoods, economic and social development, and secondly, it will promote the sustainable development of the economy and environment. Most of today's new energy vehicle batteries are lithium-ion batteries, but in the final analysis, lithium ore is a non-renewable material. In addition, the convenient life of human beings is also one of the issues to be considered. Compared with hydrogen fuel cells, lithium-ion batteries have lower endurance capacity and longer charging time, resulting in inconvenience for long-distance driving. Thus, to promote the realization of carbon neutrality, the research of hydrogen fuel cells has become a scientific and technological development goal. With the release of national policies to promote the development of hydrogen fuel vehicles, PEMFC technology of hydrogen fuel cell vehicles has developed from the embryonic stage to the mature stage, related patents have been increasing, and national policies and regulations have been continuously improved [1]. However, hydrogen energy vehicles as a whole still have problems in the on-board hydrogen storage bottle and hydrogenation process. For example, steel, aluminum and other metal materials in the hydrogen storage tank will react with hydrogen embrittleness, leading to hydrogen leakage, and causing serious safety problems. In addition, a small number of hydrogenation facilities also hinder the popularity of hydrogen fuel vehicles. In order to prevent impurities from entering the fuel cell during transportation, CO poisoning will cause its performance to decline, and purification methods should also be considered [2]. This paper explores the problems affecting the popularity of hydrogen fuel vehicles and the corresponding solutions through some literature review, so as to better study and solve the problems in the future to accelerate the development of hydrogen fuel vehicles and achieve the ultimate goal of decarbonization transformation.

2. Vehicle hydrogen storage problem

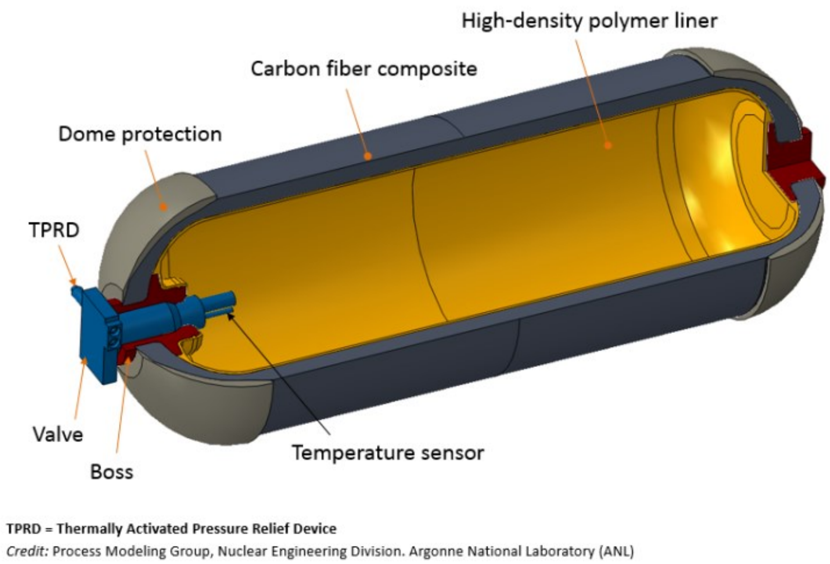

Figure 1: High pressure gaseous hydrogen storage tank [3]

2.1. The constitutive structure of hydrogen storage tank

The hydrogen storage tank is divided into three parts, the inner liner, the middle layer, and the outer layer. Figure1 shows the basic composition of hydrogen storage cylinders. Nowadays, our country is mainly divided into type I all-metal seamless cylinder structure, type II metal inner liner fiber circumferential winding cylinder, type III resin-based composite material wrapped outer surface structure of the inner liner and type IV plastic inner liner fiber structure [4]. For onboard hydrogen storage cylinders, the working pressure is generally 35MPa and 70MPa, and type III and type IV can meet the pressure demand [4]. In addition, the weight of the cylinder is also an issue that needs to be considered. Therefore, Type III structure and Type IV structure are the usual choices for hydrogen fuel vehicles in China. However, the lining of the current type III bottle is still made of steel or aluminum, and we should know that the role of the lining is to isolate hydrogen and prevent hydrogen leakage from causing safety accidents. This undoubtedly leads to another problem - hydrogen embrittlement. Hydrogen embrittlement reaction is the phenomenon in which hydrogen atoms in the hydrogen transport pipeline interact with the metal layer to cause metal failure. This phenomenon can cause cracks in the metal lining, potentially leading to hydrogen leakage. Its mechanism consists of six parts: hydrogen generation - metal adsorption - absorption - diffusion - aggregation - hydrogen induced crack initiation the process is as follows: 1-7, hydrogen is adsorbed on the surface of the aluminum to become externally adsorbed hydrogen, then dissolved into internally adsorbed hydrogen, and finally into hydrogen in the aluminum matrix [5-7].

$$Al \rightarrow Al^{3+} + 3e^{-} \quad (1)$$

$$H_2O \rightarrow OH^- + H^+ \tag{2}$$

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \tag{3}$$

$$H^+ + e^- \rightarrow H \tag{4}$$

$$H + Al \rightarrow H_{ad}Al \tag{5}$$

$$H_{ad}Al \rightarrow AlH_{ab} \tag{6}$$

$$AlH_{ab} \rightarrow Al + H \tag{7}$$

The plastic liner also has the characteristics of low cost, long service life under high pressure, and corrosion resistance. Therefore, the future development goal is to replace the metal liner with a plastic composite liner.

Compared with polyethylene fiber and glass fiber, carbon fiber has the characteristics of less tensile deformation under the same tensile stress, so its high tensile strength and lightweight ability make it possible to make the hydrogen storage cylinder bear greater pressure [8].

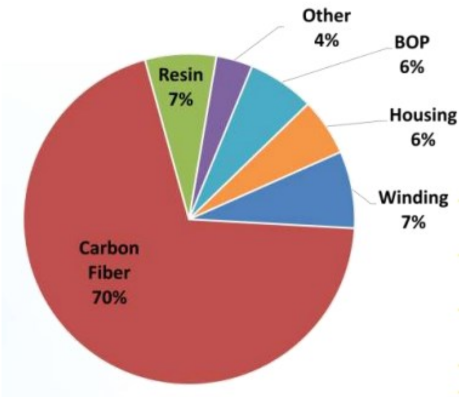

Figure 2: 700bar type 4 storage cost breakdown [10]

However, its disadvantage is that it is expensive. According to relevant research statistics, the cost of a hydrogen storage cylinder made of carbon fiber composite material is about 40kg, and the cost of a hydrogen storage bottle accounts for about 70% of the cost of the hydrogen storage bottle. A hydrogen fuel vehicle needs to be equipped with an average of 6 hydrogen storage cylinders, which undoubtedly leads to the high cost of hydrogen fuel vehicles [9-10]. It can be concluded that in the future, China needs to develop new materials to replace carbon fiber, and also needs to develop new production technology and processing technology. In addition, China also needs to pay attention to the development of carbon fiber large tow, which refers to the number of carbon fibers, generally more than 48,000, including 50k, 60k. Under the same production conditions, large tow can increase the production capacity of carbon fiber single wire and reduce the production cost. Finally, the surface of the hydrogen storage cylinder is wrapped in glass fiber, which does not need to be improved too much.

2.2. Workmanship

In addition to developing new dry, wet, and semi-dry methods, China also needs to address the issues with carbon fiber winding stability, high yarn rate, and poor winding process. The need to address material fatigue resistance and temperature adaptability will come next [8]. Carbon fiber acts as a force, so it has a key role in composite materials, for example, the fatigue strength of carbon/epoxy is better than that of glass/epoxy. Therefore, to improve the fatigue resistance of composite materials, most of them are to improve the toughness of the matrix, thereby slowing down the formation and

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expansion of matrix cracks and improving the life [8]. At present, the main processing technologies of carbon fiber composite materials are water jet processing, laser processing, electric discharge machining, and traditional machining, but each method has shortcomings, water jet processing, with high-energy flow will penetrate carbon fiber and weaken the energy, resulting in the problem of incision slope; The high temperature during laser processing will lead to excessive cutting of materials, and the attenuation of energy will also cause low cutting efficiency. The controllability of EDM is poor. Traditional machining tools and processing technology have low adaptability [11]. Therefore, the future development of adaptive tools and processes should also improve the other three processes, efficient multi-channel development.

2.3. Solid state hydrogen storage technology

In addition to on-board hydrogen storage tank technology, solid-state hydrogen storage has also become a major way to store hydrogen. The principle is to store hydrogen in a solid state through physical or chemical methods. The technology can achieve hydrogen storage at low pressure, which is more convenient and efficient; hydrogen in the solid to form a solid solution or hydride has better stability and safety, which can reduce explosion accidents. In addition, the solid hydrogen storage theory has a higher hydrogen storage density. Now magnesium-based solid hydrogen storage devices have become possible.

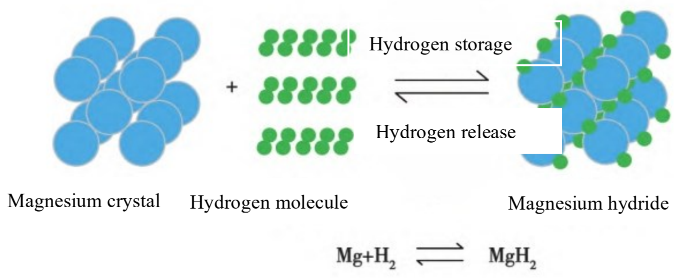

Figure 3: Principle of magnesium-based solid hydrogen storage [12]

Hydrogen is adsorbed on solid magnesium to achieve storage, and under certain conditions, hydrogen enters the magnesium crystal structure to form magnesium hydride to achieve hydrogen storage [12]. However, the adsorption material used for solid hydrogen storage has a high production cost, and hydrogen absorption and desorption also need to be at a specific temperature and pressure. Because of the low degree of commercialization, it has not yet been applied in automobiles, so the future development goal should improve the adsorption material to reduce the cost, improve the manufacturing process, and make it widely used in society.

3. Hydrogenation process

3.1. First step

At the very beginning, hydrogen fuel vehicles have just entered the public field of vision, and the development technology is not very mature, people do not fully trust hydrogen fuel vehicles, resulting in relatively low enthusiasm in the social market, so there is relatively little investment in hydrogen fuel vehicles, resulting in hydrogenation supporting facilities in society, which cannot meet the needs of the public. Fortunately, the number of hydrogen refueling stations has increased rapidly in recent years, indicating that hydrogen fuel vehicles have gradually adapted to society under the promotion of national policies. Table 1 shows the operation scale and growth rate of hydrogen refueling stations in China from 2018 to 2022 [13].

Table 1: Scale and growth rate of hydrogen refueling stations in China from 2018 to 2022

Years	Operating hydrogenation station	Year-on-year growth rate
2018	19	111.1
2019	50	163.2
2020	102	104.0
2021	190	86.3
2022	245	28.9

3.2. Hydrogen transport

At present, there are three main ways to transport hydrogen, high-pressure gas transport, low-temperature liquid transport, and pipeline transport, of which high-pressure gas transport is the current mainstream transport mode. It usually compresses hydrogen to 20Mpa and transports it with a long tube trailer. As the name suggests, it is gaseous, indicating that hydrogen is still a gas, so its transportation mass rarely accounts for 1%-2% of the final transportation mass, with low efficiency and low-cost performance [14]. The cost is mainly used in manpower and material resources.

Figure 4: Long tube trailer(left) and tube bundle container(right)

Liquid hydrogen transportation needs to be frozen to 21K under low-temperature conditions, but fortunately, the mass of liquid hydrogen in the tank truck can reach 4000kg, which is more than 10 times that of gaseous hydrogen, so the transportation efficiency is improved. However, this method consumes more energy in the production of liquid hydrogen before transportation, which increases the cost. In addition, the key equipment for producing liquid hydrogen still relies on imports, so this method has not become a mainstream means of transportation [14].

Figure 5: Japan Iwatani liquid hydrogen tank truck(left),Zhongke Fuhai liquid hydrogen tank truck(middle), Beijing Special Research Institute 45 cubic meters liquid hydrogen tank truck(right)

The last method is pipeline transportation, which has the advantages of large scale, long distance, and low cost. However, China's transportation pipeline is only less than 100 km, and hydrogen will also have a hydrogen embrittlement reaction with the metal of the pipeline, resulting in the pipeline costing of more than twice that of natural gas. Therefore, China is studying the compatibility of hydrogen and natural gas, so it does not have the conditions of mainstream transportation [14].

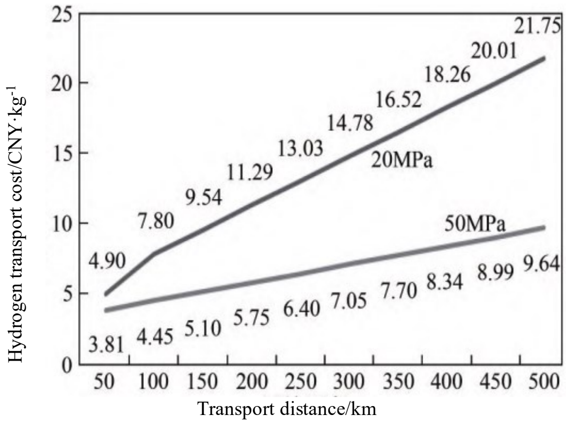

Figure 6: The unit hydrogen transport cost of 20MPa and 50MPa at different transport distances

As can be seen from Figure 6, the farther the distance, the higher the cost, so hydrogen transportation can only be within a certain distance. Therefore, from an economic point of view, the future development direction is to increase the hydrogen storage pressure of steel cylinders to transport more hydrogen, while reducing the price of renewable energy and focusing on the development of electrolytic water hydrogen production [14]. The country needs to solve technical problems as soon as possible to achieve self-sufficiency in key equipment. The state has actively promulgated relevant policies to transform the current off-site hydrogen supply into in-station hydrogen supply, and finally improve the utilization rate of hydrogen storage facilities to reduce losses and costs [14].

4. Security

Although hydrogen energy is a volatile, flammable, and explosive energy, these hazards occur under certain conditions, so they can be avoided as long as the conditions are well controlled. China also attaches great importance to the safety of fuel vehicles. More than 65% of the national standards and specifications are aimed at safety. Meanwhile, various enterprises control the system safety from many aspects during the research and development of fuel vehicles, such as material selection, hydrogen leak detection, electrostatic protection, explosion and flame retardant, etc.[15] For fuel vehicles, the safety protection of the hydrogen system is the most important. This includes the design of hydrogen storage bottles, hydrogenation ports, bottle valves, check valves, safety valves, pressure-reducing valves, pressure sensors, hydrogen sensors, etc. in accordance with T/ZSA 103-2021 Technical Specifications for On-board Hydrogen Systems in Fuel Cell Commercial Vehicles [16-19]. Therefore, in the future, improving the relevant detection technology and accessories is the development goal.

5. Conclusion

This article introduces the current situation of hydrogen fuel vehicles in the composition of hydrogen storage bottles, which leads to the current development of carbon fiber in China and some shortcomings in production capacity and technology. Using type III hydrogen storage bottles and the hydrogen embrittles reaction as an example, it is clear that the next step in the development of hydrogen storage bottles will be to make type IV hydrogen storage bottles, which are made of plastic composite materials instead of aluminum metal products. Next, the issues that come up because of the fact that China does not have enough hydrogenation stations and their pressures are too high for modern on-board hydrogen storage tanks are talked about. Finally, the safety problems related to the detection technology and equipment accessories of fuel vehicles are explained, which shows that China attaches great importance to the safety of fuel vehicles. However, this article is only a review of hydrogen storage, hydrogenation, and safety issues of hydrogen fuel vehicles, and the data are not recent values, for reference only. It is hoped that China can pay more attention to the development of hydrogen fuel vehicles in the future and make up for some of the current policy and technical deficiencies.

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