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Hydrogen Energy Application of an Intelligent Active Dry-hydrogen Light-mixing System under a Carbon Neutralization Background

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Abstract: With the worsening of global climate change, carbon neutrality has become the common goal of all countries. Hydrogen energy, as a clean and efficient energy source, plays an important role in the carbon neutralization process. In this paper, the application of an intelligent active dry-hydrogen light-mixing system in the field of transportation was studied by comparing and analyzing the technical routes of the hydrogen energy industry and combining them with the key technologies in the field of hydrogen energy application. The technical principle and working process of the intelligent active dry-hydrogen light-mixing system were established, and the economic and social benefits of the intelligent active dry-hydrogen light-mixing system were analyzed by taking Aneng Company (China) as an example. The application of an intelligent active dry-hydrogen light-mixing system in the field of transportation was examined.

1. Introduction

With the growing global demand for energy and the increasing scarcity of fossil fuel resources and environmental damage[1], the development and use of clean energy has become a global goal. Carbon neutrality, an important means to achieving the goal of reducing and eliminating greenhouse gas emissions on a global scale and protecting the earth's environment, has been highly valued by governments and institutions[2]. In the process of achieving carbon neutrality, transportation has become a key area of fossil energy consumption and greenhouse gas emissions[3], so the new clean energy substitution of transportation equipment is an important means of carbon emissions reduction in transportation. Hydrogen energy will play an important role as an efficient, clean, and renewable energy source.

Currently, the main application field of hydrogen energy research is the development of hydrogen batteries and hydrogen vehicles. The intelligent active dry-hydrogen light-mixing system adopts the hydrogen energy application mode of "oil-gas mixing" of hydrogen and diesel, which can effectively reduce costs and improve energy efficiency. The special technology of this system combines big data, cloud computing, and other technologies to build a hydrogen cloud platform, which can achieve full-cycle carbon-emissions management and is a supplement and improvement to the hydrogen industry chain. Based on the comparison and analysis of the technical routes of the hydrogen energy industry, the technical principle, working process, and application benefits of an intelligent active dry-hydrogen system are proposed in this paper. The application of an intelligent active dry-hydrogen light-mixing system in the transportation energy industry is prospected and suggested.

2. Analysis of the Hydrogen Energy Application Technology Route

Hydrogen is the most abundant substance in the world, accounting for approximately 75% of its total mass. Hydrogen energy is the energy released by hydrogen in the process of physical and chemical changes. It is called the most potential sustainable clean energy in the 21st century, and its demand and application fields are expanding. The four main directions in the research of the hydrogen energy technology route are hydrogen production, hydrogen storage, hydrogen transportation, and hydrogen utilization.

2.1. Technical route of hydrogen production

Hydrogen production is in upstream of the hydrogen energy industry chain, and the Global Hydrogen Review 2022, released by the International Energy Agency (IEA) in 2022, shows that hydrogen production from fossil fuels is still the main method of hydrogen production. Fossil fuel hydrogen production technology is relatively mature, mainly being achieved through natural gas hydrogen production and coal hydrogen production, of which natural gas reforming hydrogen production without CCUS equipment accounts for approximately 62% of the total hydrogen production. Steam reforming technology is the endothermic conversion of methane and steam into hydrogen and carbon monoxide. The current popular method of producing hot steam is to use methane combustion in furnaces or electricity. This process produces more by-products, but significant improvements can be achieved by combining natural gas reforming with concentrated solar energy[4]. The membrane reactor using molten salt as the heat transfer fluid can simultaneously carry out methane steam reforming, the water vapor shift reaction, and hydrogen separation. The reactor can be integrated with a next-generation concentrating solar thermal system to provide process heat[5]. In 2021, the world's hydrogen production from coal accounted for 19% of the total hydrogen production. The technology of hydrogen production from coal includes coking and gasification of coal. Coal coking to produce hydrogen is to isolate coal from air and then heat it to 900–1000 ℃ to produce coke, produce coke oven gas, and finally purify the hydrogen in coke oven gas[6]. Hydrogen production by coal gasification is the reaction of coal with a gasifying agent at a high temperature to produce carbon monoxide, hydrogen, and other gases. These gases can be further processed to extract high-purity hydrogen, and the new three-step gasification thermally coupled chemical looping combustion process technology can reduce the consumption and destruction of the coal gasification process and improve cold gas efficiency[7]. Hydrogen production from water electrolysis, powered by renewable energy, is an emission-free technology that uses redox reactions to split water into hydrogen and oxygen. Currently, typical water electrolysis technologies mainly include alkaline water electrolysis, AEM water electrolysis, PEM water electrolysis, and solid oxide water electrolysis[8]. Hydrogen production from industrial by-products can utilize waste resources in industrial production; for example, the reductive sulfur-containing by-products (S-BPs) discharged from industry can be used to produce hydrogen by exploiting reductive S-BPs to some extent[9]. In addition, prospective hydrogen production technologies include photocatalytic and biological hydrogen production, which are not mature.

Hydrogen production technology based on photodestruction relies on photocatalysts to achieve water decomposition, which can directly convert solar energy into valuable products[10]. Biological hydrogen production can produce hydrogen from biological waste by photobiology and dark fermentation techniques[11,12]. However, biological hydrogen production technology also has disadvantages such as yield and cost[13].

2.2. Hydrogen Storage Technology Route

High-pressure gaseous hydrogen storage has the advantages of low cost and rapid charging and discharging at room temperature, but it has low hydrogen storage capacity and high technical requirements for high-pressure hydrogen storage bottles, which may have potential safety hazards. In terms of technology maturity, safety, and economy, high-pressure gaseous hydrogen storage is still the best choice at present and will remain mainstream in the short and medium term[14]. The storage vessel of cryogenic liquid hydrogen storage is small in volume and has the largest hydrogen storage capacity, but the liquefaction energy consumption is high, and the storage conditions are harsh, resulting in high costs. Moreover, maintaining hydrogen at the very low temperatures required for liquefaction is probably the most difficult aspect of cryogenic hydrogen storage. The liquefaction process can take a long time and consume a large amount of energy[15]compared with compressed hydrogen storage, where only approximately 10% of the energy is lost. The third is organic liquid hydrogen storage technology, whose hydrogen storage capacity is between high-pressure gaseous hydrogen storage and low-temperature liquid hydrogen storage, with moderate technical difficulty, cost, and transportation convenience. Owing to the lag of the 70-MPA high-pressure hydrogen storage and transportation standard in China and the high cost of low-temperature liquid hydrogen storage, organic liquid hydrogen storage technology may become the mainstream choice for hydrogen storage and transportation. However, organic liquid hydrogen storage technology needs the process of catalytic hydrogenation and dehydrogenation, which is more complex. Still, one of its greatest advantages is that it can be used as a fuel, and for short-term storage processes, liquid storage methods are preferred. The last option is solid-state hydrogen storage technology (e.g., metal hydride). Metal hydride is a compound containing metal and hydrogen, which has a high storage capacity, but the metal is expensive and its use is limited. Different catalysts are often used to improve their performance[16]. However, the efficiency of metal hydrides is not optimal because the high temperatures during refueling and operation result in energy losses and bulky insulation. Although some positive results have been achieved with metal hydrides, further research is needed to develop optimal materials[17].

2.3. Technical route of hydrogen transportation

Hydrogen transportation is mainly divided into gas hydrogen transportation, liquid hydrogen transportation, and solid hydrogen transportation. Gas and hydrogen can be transported mainly by pipeline, but this is more stringent for infrastructure construction. Hydrogen can be transported and mixed into the natural gas transmission pipeline network, or existing pipelines, especially parallel or unused pipelines, can be reused for hydrogen [18]. Liquid hydrogen (i.e., hydrogen stored in an organic liquid hydrogen carrier) is suitable for long-distance transportation from the point of view of cost-effectiveness[19,20], and it can support vehicle transport, ship transport, and rail transport. Metal hydrides have the characteristics of a high volumetric hydrogen storage density, safety, as well as high-purity hydrogen, simple operation, convenient transportation, and low costs [21].

2.4. Hydrogen Technology Route

There are four main technical routes for hydrogen use: industrial hydrogen, hydrogen fuel cells, hydrogen internal combustion engines, and hydrogen refueling stations. In industry, hydrogen is mainly used in traditional fields such as oil refining, ammonia synthesis, and methanol synthesis. In the transportation industry, there are two main ways to use hydrogen energy: fuel cells and internal combustion engines, which are promising trends in the future transportation industry[22]. A fuel cell is a cell that can be continuously refueled and maintain electrical output indefinitely, converting hydrogen or hydrogen-based fuels into electricity and heat through the electrochemical reaction of hydrogen and oxygen. The beginning of the 19th century was the starting point for research in the field of fuel cells. In 1801, Humphry Davy proved the basic principle of fuel cell function, and in 1839, William Grove accidentally discovered the principle of fuel cells in an electrolysis experiment, calling it a "gas cell." However, Grove's battery has no practical application owing to electrode corrosion and material instability. The term "fuel cell" was first used in 1889 by Langer and Mond, who observed that platinum black was less reactive in contact with the electrolyte and that it extended the life of the fuel cell by retaining the electrolyte in nonconductive porous materials[23]. In the past two decades, the use of fuel cells, especially covering portable, mobile, and stationary fields, has increased rapidly owing to technological advances and concerns about reducing dependence on fossil fuels. Hydrogen fuel cell vehicles use high purity (>99.99%) hydrogen at high pressure (350 or 700 bar). Stored in cylinders composed of composite materials, compressed hydrogen provides fuel cell vehicles with uniquely high energy and is, therefore, suitable not only for cars but also for heavier trains and ships[24]. Furthermore, the hydrogen internal combustion engine is an important technology to accelerate decarbonization, and hydrogen has been used as internal combustion engine fuel for more than 200 years[25]. In 1807, Fran FrançoisIsaac de Rivaz from Switzerland invented and designed the first hydrogen-oxygen internal combustion engine. Because hydrogen internal combustion engines were not as efficient as hydrocarbon engines, were difficult to store, and were relatively expensive, hydrogen-based engines were not widely implemented in later years, despite initial success in their development at the time. This did not stop the pace of human exploration, and the First World War and the Second World War made great progress in the technology of hydrogen fuel vehicles. In 1979, Bayerische Motoren Werke (BMW, Germany) launched the first hydrogen car in partnership with DFVLR[26]. The 20th century saw the further development of hydrogen engine technology and demonstrated the possibility of using hydrogen in existing engine designs without major modifications to the original components[27,28]. The use of hydrogen as a fuel to power internal combustion engines has significant advantages because internal combustion engine technology is more mature than fuel cell technology, more tolerant to pollution, and easier to adapt to hydrogen operation[22]. Finally, with the development of hydrogen fuel cell vehicles, the infrastructure construction and technical requirements of hydrogen refueling stations are becoming higher[29]. By the end of 2020, more than 90% of the 127 hydrogen stations (including internal experimental stations) built and operated in China were 35 MPa, a few 70 MPa hydrogen stations had been built, and there was no liquid hydrogen station. Currently, China is focusing on 70-MPa hydrogen station technology[30]. as shown in Figure 1

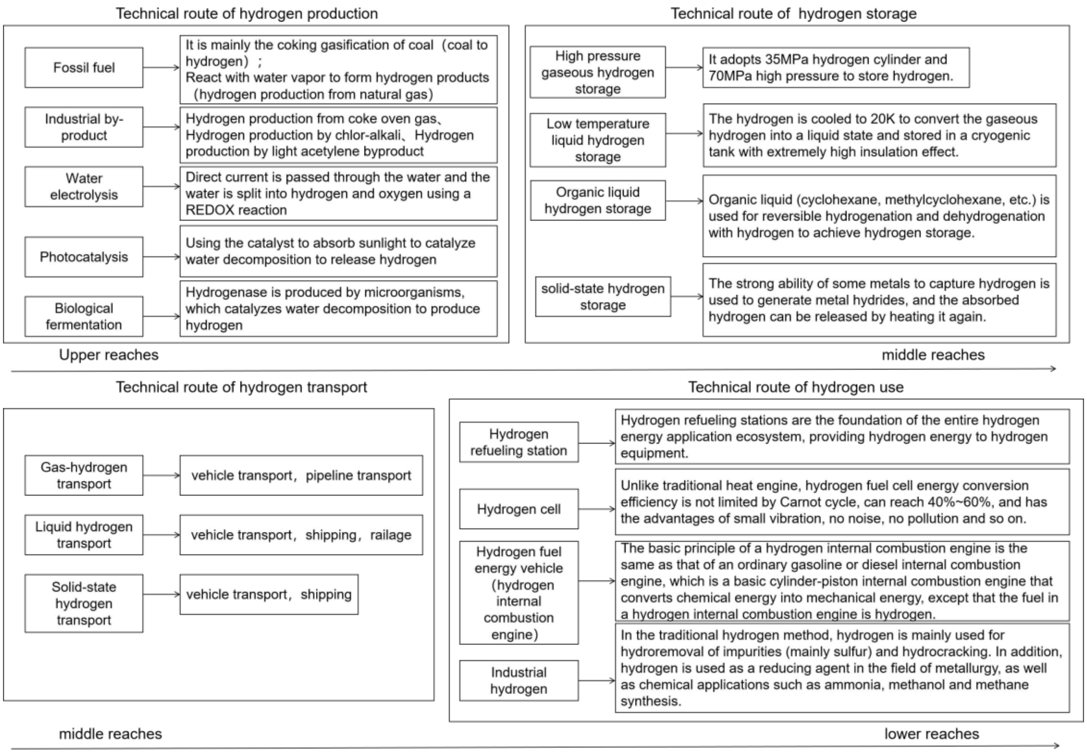


Figure 1: Hydrogen Energy Technology Roadmap.

3. Technical Principle of an Intelligent Active Dry-Hydrogen Light-Mixing System

The intelligent active dry-hydrogen light-mixing system uses pure dry hydrogen stored in solid metal hydride tanks to release pure dry hydrogen through effective computer diagnosis and proportioning. Furthermore, it uses a reverse carbonization process to convert carbon into hydrocarbons in air manifolds, piston rings, valves, and spark plugs. It achieves sufficient combustion support and improves the performance of the internal combustion engine vehicle. The system also uses iEGA technology to customize the hydrogen-mixing combustion of internal combustion engine vehicles to fully support combustion and improve the performance of internal combustion engine vehicles.

The system technology is based on cloud computing technology, using the global positioning system (or BeiDou system) to monitor vehicles in real time, collecting large amount of data in a cloud database, and then using artificial intelligence analysis. Thus, we can complete the full cycle of carbon emission management and achieve the carbon reduction target of green travel, thereby promoting the smooth transition from fossil fuel vehicles to clean energy vehicles.

4. Benefit Analysis of the Application of an "Intelligent Active Dry-Hydrogen Light-Mixing System" in Heavy Trucks

With technological transformation, the intelligent active dry-hydrogen light-mixing system has shown obvious economic benefits in different brands of medium and heavy trucks. China's medium and heavy truck market sold approximately 1.4 million vehicles in 2021, and the total demand for medium and heavy trucks in 2022 was estimated at 1.2 million. By 2030, China is projected to achieve the goal of 2 million hydrogen fuel vehicles. Taking the cost reduction scheme of 4,000 vehicles of Aneng Company as an example, we set the application scope of this system to heavy trucks. After the application had been completed, the required total cost of LCC was composed of the equipment’s initial investment cost, operation cost, and later maintenance cost. The minimum service life of the application equipment was 10 years, so this study took 10 years as the full life cycle of the equipment.

4.1. Analysis of Fuel-Saving Rate and Total Cost Saving

After the application had been completed, we mainly analyzed the hydrogen-powered heavy truck and fuel heavy truck, as shown in Table 1.

Table 1: Comparison of Specific Cost Reduction Schemes for Hydrogen-Mixed Vehicles and Fuel Vehicles.

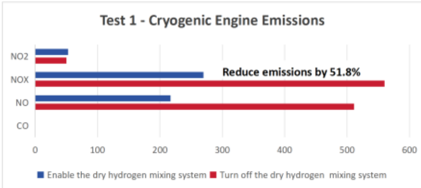
17.5M Diesel heavy truck evaluation calculation table(Fuel consumption per 100 km is 33 liters)					8.38 yuan/liter
	100 km (liter/unit)	1500 km (liter/day/unit)	Rate of fuel saving (%)	Total fuel cost (yuan/day/unit)	Cost saving (yuan/year /unit) Based on 300 days
Original fuel consumption	33	495	0	4148.1	1244430
Mixture hydrogen	28.5	427.5	14	3570	1071000
Facility cost(yuan)	100000				
Profit(yuan)	73430				
Gross profit (yuan)	293720000				

It can be seen from Table 1 that from the perspectives of 100 km (liter/vehicle) and 1500 km (liter/vehicle), the fuel-saving rate of hydrogen-mixing consumption required by hydrogen-powered heavy trucks was approximately 14% compared with the original fuel consumption of fuel vehicles, and the total fuel cost saved was 578.1 yuan/day/vehicle. The total cost of LCC saved in one year (calculated for 300 days) was 73,430 yuan, which indicates good economic benefits and energy-saving and carbon-reduction effects. The application of an intelligent active dry-hydrogen light-mixing system can increase the horsepower and torque of heavy trucks by 10–16%. One of the biggest advantages of hydrogen hybrid vehicles over fuel vehicles is that they are cleaner and have higher fuel efficiency. Hydrogen hybrid vehicles can travel longer distances than fuel vehicles with the same fuel consumption. At the same time, the application of an intelligent active dry-hydrogen light-mixing system can save fuel up to 10–30%. Hydrogen hybrid vehicles reduce the consumption of diesel fuel and save operating costs for users, helping to cope with rising fuel prices.

4.2. Analysis of the Social Benefit of Emissions of Pollutant Gases

This analysis was mainly based on the detection data of pollutant gases emitted by heavy truck engines. Different gases have different chemical reaction coefficients, so the emission volume and proportion were different. The detected gases were mainly NO2, NOx, NO, and CO, which are four pollutant gases. The social benefits of the intelligent active dry-hydrogen light-mixing system detected by the gas detector are shown in Figure 2.

	Text 1		
	Turn off the dry hydrogen mixing system	Enable the dry hydrogen mixing system	variation
NO_2	50	53	-6.00%
NO_X	560	270	51.80%
NO	511	217	57.50%
CO	0	0	0.00%



	Text 2		
	Turn off the dry hydrogen mixing system	Enable the dry hydrogen mixing system	variation
NO_2	71	19	73.20%
NO_X	477	374	21.60%
NO	466	355	23.80%
CO	12	5	58.30%

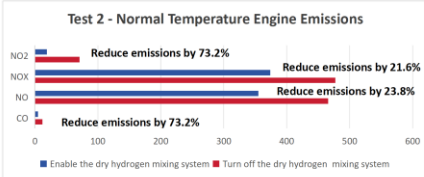


Figure 2: Social benefits of intelligent active dry hydrogen light mixing system.

It can be seen from Figure 2 that when the intelligent active dry-hydrogen light-mixing system was started at a low temperature, the emissions of NOx and NO were significantly reduced. When the intelligent active dry-hydrogen light-mixing system was started at normal temperature, the emissions of the four pollutant gases were reduced, the proportion of NOx and NO emissions reduction was reduced compared with low temperature, and the proportion of NO2 and CO emissions reduction was significantly increased compared with low temperature. It can be seen that the intelligent active dry-hydrogen light-mixing system had a different emphasis on reducing the emission of gases at different temperatures, which could effectively reduce the emission of pollutant gases.

5. Conclusion

In the context of carbon neutralization, hydrogen energy, as a clean and efficient form of energy, has a wide range of applications. In the hydrogen stage of the hydrogen energy industry chain, the key technology of a hydrogen internal combustion engine application still needs to be broken through, and it is difficult for traditional energy vehicles to transform into pure-hydrogen clean energy vehicles. Based on this, we proposed the application of intelligent active dry-hydrogen light-mixing system in the field of transportation and discussed the technical principle and working process of the intelligent active dry-hydrogen light-mixing system. Furthermore, through experiments, we confirmed that the application of the intelligent active wet-hydrogen light-blending system in the field of medium and heavy trucks had obvious economic and social benefits. These results indicate that the application of intelligent active dry-hydrogen light-mixing system can significantly reduce fuel costs, save operating costs for users, promote the development of the transportation industry, improve the relevant industrial chain, and reduce the generation of greenhouse gases such as carbon dioxide. Thus, the application of intelligent active dry-hydrogen light-mixing system significantly reduces carbon emissions, which is conducive to the transition from traditional energy to clean energy in the field of transportation energy and can accelerate the realization of carbon neutrality. The application of an intelligent active dry-hydrogen light-mixing system can serve the process of realizing the low-carbon transformation of the economy and energy structure with high quality, and it has great application potential in the future transportation energy industry.

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