Model establishment and process analysis of liquid hydrogen energy storage

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Under the general trend of energy reform and utilization of renewable energy, the key role of hydrogen energy has been becoming increasingly prominent. The IEA report highlights hydrogen as an integral part of net zero emissions, and many countries are developing strategies to incorporate hydrogen into the major energy plans. Hydrogen is an ideal efficient clean energy, which can be used in fuel cell vehicles and other new energy power. In addition, in the field of cryogenics and refrigeration, such as aerospace, superconductivity technology, high-energy physics and other big scientific devices, hydrogen is commonly used as a cryogenic working medium, but also as rocket propellant, and liquid phase can be used as coolant.

In the hydrogen energy industry chain of production-storage-transportation- utilization, compared with gas phase at high pressure, liquid hydrogen has advantages such as high density, low transportation cost, high purity of vaporization and short filling time, which make it more suitable for the large-scale development of hydrogen energy. Liquid hydrogen can also be used as an energy storage medium, providing cold energy and electricity to smooth out fluctuations in renewable energy generation and reduce abandonment of wind and light.

In this article, a model and analysis of energy storage process using liquid hydrogen at low temperature was established, including purification and liquefaction, liquid hydrogen storage, pressurized vaporization, cold energy utilization, power generation output and other processes, selecting appropriate methods and equipment, systematically contacting all aspects of liquid hydrogen energy storage and application, evaluating its efficiency, economy, environmental protection and expansibility, and comparing it with other energy storage methods, such as thermal energy storage and electric energy storage. Their application scenarios and development prospects were analyzed, seeking solutions on how to rationally and efficiently utilize liquid hydrogen energy storage and reduce costs, so as to provide new ideas for the actual storage and application of hydrogen energy.

LH_2 MODEL CRYOGENIC HYDROGEN LIQUEFACTION ENERGY STORAGE

SYSTEM

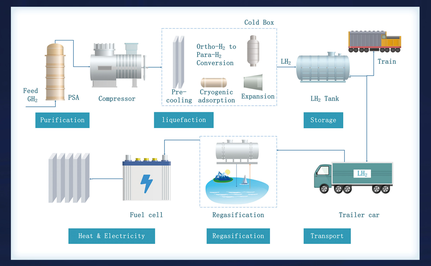

Fig. 1 schematic diagram of liquid hydrogen energy storage process

As shown in figure 1, in the process of liquid hydrogen energy storage, the input gaseous hydrogen goes through the preliminary purification process of pressure swing adsorption to obtain higher purity hydrogen, and after liquefaction, high purity liquid hydrogen is obtained. And this part includes compression, pre-cooling, Orthohydrogen-Parahydrogen conversion, low-temperature adsorption for further purification and expansion. Liquid hydrogen is stored in cryogenic storage tanks and can be transported to the user side by train or trailer, re-gasified by heat exchange with sea water, or collecting the cold energy for other purposes, and then fuel cells can be used to generate electricity while providing some heat. This process completes the state change of hydrogen from gaseous state to liquid state and then to gaseous state, and consumes part of the electric energy to convert hydrogen energy into electric energy and thermal energy, which improves the energy density and storage and transportation efficiency of hydrogen energy.

LIQUEFACTION

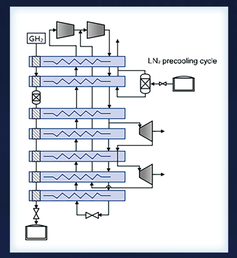

Figure 2 Revised Claude Liquefaction Cycle

Evaluation of subsystem efficiency based on specific energy consumption (SEC) :

$$SEC=\frac{W_{net}}{m_{LH_2}\times 3600}$$

$$W_{net}=W_c-W_t$$

$$W_c=m_{H_2}C_p T_H\left(\gamma^{\frac{R}{C_p}}-1\right)\frac{1}{\eta_c}$$

$$W_t=m_{H_2}C_p\frac{SEC=\frac{W_{net}}{m_{LH_2}\times 3600}}{W_{net}=W_c-W_t}$$

$$\eta_{round}=\frac{P_{H_2}+Q_{cool}/3600}{SEC\cdot\rho V}$$

Where *W*net represents net work, *W*c represents compressor power consumption, and *W*t represents the work done by the expander. In order to evaluate the performance of the entire process, the round-trip efficiency is represented by the ratio of power harvesting and cold energy recovery to power consumption, where P_{H_2} includes the power generation and heat generation of hydrogen, and Qcool is the lost cold energy.

ENERGY ANALYSIS

The calculation results show that the liquefaction SEC is 13.48kWh/kgLH_2, and the round-trip efficiency is 19.04%. Among them, the liquefaction rate of liquid hydrogen has the greatest impact on energy consumption and round-trip efficiency, which requires the use of more efficient liquefaction cycle or better performance compressor and expander equipment. The use of Brayton cycle and recovery of LNG cold energy precooling can reduce energy consumption, but will correspondingly increase the complexity and space constraints of the system.

CONCLUSION

Improving the liquefaction cycle and fuel cell efficiency and formulating a more reasonable and efficient operation strategy are the key points to reduce the cost and improve the practicability in liquid hydrogen energy storage. However, hydrogen energy storage also has the advantages of the highest energy density, the fastest reaction time, high compatibility and little impact on the environment, so it has a wide research and application prospect in the energy storage requirements of large-scale, fast response and coupling with the power grid. On the basis of this paper, it is the new and efficient liquefaction cycle, more detailed storage and transportation and fuel cell layout, energy utilization of different grades of hydrogen, a more comprehensive and practical evaluation method, and more practical and specific cold energy recovery and utilization methods that can also be studied.

ECONOMIC CALCULATION

$$Total\ \ cost=CAPEX+\sum_{i=1}^{n}\frac{OPEX_{yr}}{(1+i)^r}$$

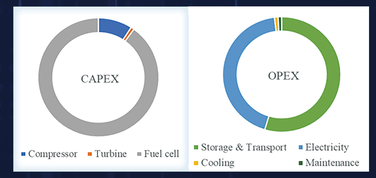

Fig. 3 Composition of initial equipment investment and later operation and maintenance costs

Where *CAPEX* is the initial equipment investment, and *OPEX* is the post operation and maintenance cost, *i* is the interest rate, and n is the lifespan.

The total investment is USD 409.93million, and the energy cost is $1.20/kWh. Obviously, this is a more conservative evaluation result. Fuel cell costs account for a higher proportion due to factors such as technology maturity, number of discharge cycles, high consumption, large number of units, etc.

So how to improve fuel cell efficiency and reduce large-scale use costs in hydrogen energy storage process, to better match hydrogen power generation, hydrogen fuel vehicles and other high-power use scenarios, is one of the directions of vigorous research. Among the operating costs, the proportion of electric power consumption and hydrogen storage and transportation are the largest, which corresponds to the specific energy consumption of liquefaction equipment and liquid hydrogen tank trailer, respectively, so improving the liquefaction cycle with lower energy consumption and higher liquefaction rate, the design of storage tanks with less heat leakage and stable reserves and efficient and economical transportation strategy is also an important research direction in the hydrogen industry.

COMPARISON & ANALYSIS

Table Comparison of common new energy storage technologies

energy storage	energy density (Wh/kg)	power density (W/kg)	efficie -ncy (%)	maximum depth of discharge (%)	reaction time	discharge time	energy cost ($/kWh)	electricity cost ($/kW)
compressed air	30-60	-	70-80	70	sec-min	hours-days	50-150	400-800
High-temperature heat	80-200	10-30	30-60	-	Not for rapid	hours	3-130 3500-7000 (CSP)	100-400
Superconducting magnetic energy	0.5-5	500-2000	90-95	100	5ms	Seconds-30min	1000-10000	200-300
Lead-acid battery	25-45	180-200	65-80	60-70	<5ms	Seconds-hours	0.1-0.3	150-500
hydrogen	300-1200	500+	20-50	90	<5ms	minutes-hours	2-15	500-10000
(LH2)	2343Wh/L						0.9/kgH_2	
(CGH2)	792Wh/L						0.3/kgH_2 (storage)	
[23]								

For large-scale energy storage, some applicable systems, including compressed air energy storage, high-temperature heat storage and hydrogen energy storage, generally have the problems of high cost and unsatisfactory efficiency. High power consumption, low efficiency of indirect power supply methods such as fuel cells, etc., but hydrogen energy storage has its own advantages such as the highest energy density, the fastest reaction time, and small impact on the environment. It is liquid hydrogen storage and high-pressure gaseous hydrogen storage that also were compared in Table 5. Although CGH_2 is relatively low in cost because of its easy operation, it has low energy density and is more suitable for short-distance and small-scale transportation and energy storage. In addition, compared with high-temperature heat storage, hydrogen energy storage tanks are mobile and have a wider range of use; compared with compressed air energy storage, hydrogen energy storage fuel cells can be highly integrated and more flexible. Unlike other energy storage, hydrogen energy storage can have dual functions of resource and energy. Apart from power generation, liquid hydrogen itself can also be used as a product in other fields such as hydrogen fuel vehicles and aerospace.

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