OCEAN TRANSPORTATION OF HYDROGEN

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Contents

1. Introduction
2. Liquid Hydrogen Property for Cargo
3. Problems of Liquid Hydrogen Tankers
4. Performance of Energy Transportation
5. Conclusion
Glossary
Bibliography
Biographical Sketch

Summary

Global liquid hydrogen energy systems have benefits as follows. First, there is no limitation of material source, so the system can be established everywhere if the primary energy can be obtained. Second, liquefaction of hydrogen is an established technology. Third, it is free from the CO_2 problem because carbon is not used.

On the other hand, the disadvantages are as follows. First, liquid hydrogen has ultra low temperature and it makes the storage cost very high. Second, as liquid hydrogen has thin energy density per capacity, there are many unsolved problems with tanker transportation. Third, energy loss of liquefaction is large.

1. Introduction

Transportation of large quantities of liquid hydrogen is one of the most important key technologies to establish a global hydrogen energy system. Energy per capacity of gas hydrogen is 12.4 MJ Nm^{-3}. It is merely 1/3000 of oil.

For the reason of the thin energy density, storage and transportation of hydrogen are quite inferior to fossil fuels. On the other hand, the main areas of energy supply are generally located far from the energy consumption areas, about 10 000 km across the ocean. This fact becomes a serious problem for hydrogen energy systems.

One of the plans for remote transportation of hydrogen is conversion of gas hydrogen to liquid hydrogen. By the liquefaction, capacity of hydrogen is reduced to 1/800 (density kg/m^3: 0.089/gas $\rightarrow$ 71/liquid). Thus, the proposed configuration of a global energy system through liquid hydrogen looks relatively simple, as shown in Figure 1.

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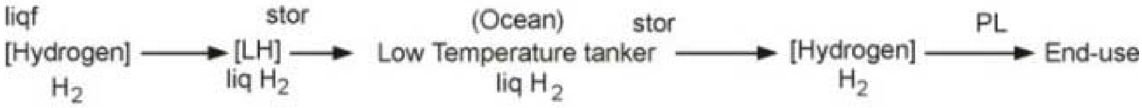

Figure 1. Global energy system configuration of liquid hydrogen; LH: liquid hydrogen, liqf: liquefaction plant, liq: liquid, stor: storage, PL: gas pipeline

Designing of huge energy transportation by liquid hydrogen was proposed by EQHHPP (Euro-Quebec Hydro-Hydrogen Pilot Project) in 1986 at the beginning. They chose the liquid hydrogen among the various energy media such as methanol, ammonia, metal hydride, and methyl cyclohexane. However, liquid hydrogen is too light to transport, and it has a very thin energy density. Moreover, it is ultra low temperature that makes global transportation very difficult. Therefore, various kinds of tankers were proposed such as container ship, tank barge ship, twin hull ship, etc.

EQHHPP had the pilot plan of 15 000 m^3 grade that was far beyond the reach of conventional LNG ships of 125 000 m^3. Thereafter, HDW of Germany proposed liquid hydrogen ship of 120 000 m^3. In Japan, from 1993, a national research project called "WE-NET" in the New Sunshine Project was started for the utilization of hydrogen energy in 2020. They are working on the fundamental research for a liquid hydrogen tanker based on the basic technology established through the LNG tanker.

Figure 2 shows the position of the global liquid hydrogen system in energy transportation. As for the continental transportation between neighboring areas, gas pipelines have advantages. Remote transportation, especially trans-ocean, and liquid hydrogen transportation have appeared on the scene. However in this case, the liquid hydrogen systems always face competition to alternative selection, that is easy tanker transportation systems for synthetic fuels.

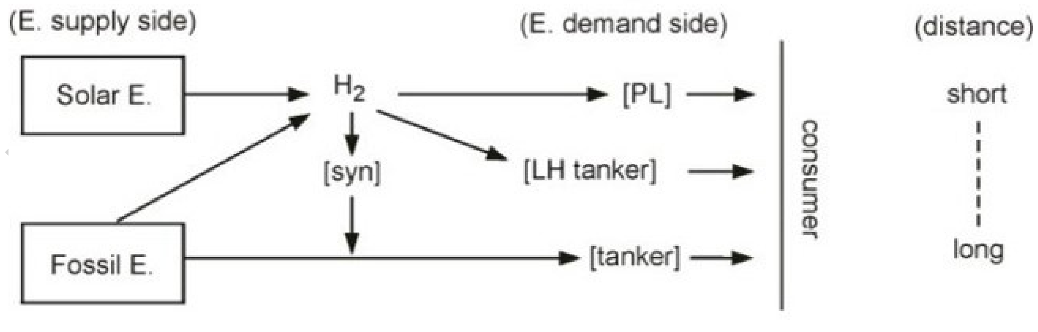

Figure 2. Position of liquid hydrogen tanker system; E: energy, syn: synthesis, PL: gas pipe line, LH: liquid hydrogen

2. Liquid Hydrogen Property for Cargo

The problem of liquid hydrogen as fuel cargo is a conflicting requirement: large cargo volume and small cargo weight. In the case of cargo that has specific gravity lighter than water, the carrying capacity of a tanker depends on cargo capacity, not on cargo weight. The heating value per capacity is as small as 10.1 GJ m^{-3}. This value is only 42% of LNG (23.7 GJ m^{-3}) and 22% of oil (45 GJ m^{-3}). This suggests that five liquid hydrogen tankers are necessary to transport the same amount of energy by one oil tanker. On the other hand, the heating value per weight is 142 kJ/g, 3.1 times higher than that of oil. Hence, it is clear that liquid hydrogen has an advantage as fuel for space ships, because the energy per weight is important. However, light liquid hydrogen has little chance to show its merit for large heating value per weight in the case of tanker transportation.

Property	**LH**	**LNG**	**Remarks**
Q, GJ/t	142	56	at bp.
Q, GJ/m^3-liq.	10.1	23.7	at bp.
Q, GJ/m^3-gas	12.8	45.9	at 273K
q, MJ/t	447	510	at bp.
q, MJ/m^3-liq.	31.6	216	at bp.
bp., K	20 (–253 °C)	110 (–163 °C)	cf. N_2: –196 °C
d, kg/m^3	71	426	at bp.

Table 1. Comparison of the properties of liquid hydrogen and LNG; Q: higher heating value, bp: boiling point, q: latent heat of vaporization, d: specific gravity.

Additionally, it is indispensable for liquid tankers to maintain ultra low temperature (–253°C) that is much lower than LNG tanker (–163°C), which is known as having the lowest temperature. The Δt (difference of temperature) between room condition and liquid hydrogen is about 1.5 times larger than that of LNG.

$$\Delta t_{LH} / \Delta t_{LNG} = (295\text{-}20) / (295\text{-}110) = 1.49$$

The ultra low temperature of liquid hydrogen brings the following problems:

(i) Large energy is lost at liquefaction (over than 20%).
(ii) Large amount of boil-off gas is lost at the loading and unloading, and during the navigation.
(iii) Re-liquefaction, which is usually operated at LPG tanker (–42°C), is disadvantageous for liquid hydrogen because the energy loss is too large.
(iv) An expensive and huge liquid hydrogen tank has to be constructed at the ports of origin and arrival.
(v) Spherical tank must be adopted for its high-performance insulation. Consequently, 1/3 of the ship body becomes dead space and it makes the tanker much bigger.

Liquid hydrogen is quite light and the specific gravity is 1/14 of water. So the liquid hydrogen ships have a peculiarity that the displacement is small in spite of the huge capacity. If it is the same ship-type as an oil tanker, the draft becomes smaller, the center of the ship becomes very tall, and ship stability is lost. At the same time, screw

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immersion cannot be kept. If ballast is loaded to keep a deeper draft, large volumes (10 times of cargo) of water is needed. This makes the displacement bigger. Therefore, as for ship-types for tankers of big and light cargos, twin hull ships are promising as a replacement for conventional mono-hull ships.

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Biographical Sketch

Hirosi Sano graduated from Chemical Division, Faculty of Science, Niigata University (March 1955); he then joined GIRIO (Government Industrial Research Institute of Osaka JAPAN) Chemistry Section (April 1955), before moving to Osaka Gas Co., Ltd. Research Center (February 1992). He then moved to Lab. Office of Global Energy System (to follow up to RITE, CO. chemical recycling project). Project and Theme; Dr. Engineering at Kyoto University (1978); Sunshine Project (Hydrogen Energy System) (1974–1990); awarded "Approach toward Compatible Solution for Energy & Global Environmental Problems" by Japan Society of Energy & Resources (1989); RITE Feasibility Study "CO_2 global recycling system Using by Natural Energy" (1990–1993); RITE Project "CO_2 chemical recycling system" (1995–).

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