Development Potentials for LH2 Storage System with Advanced Boil-off Management

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ABSTRACT:
This paper describes our R&D until 2004 for liquid hydrogen components and system, and current development status summary from 2005 for the LH2 storing, transporting, and refuelling system with the advanced boil-off management using “slush hydrogen”, sponsored by NEDO (domestic projects). The objectives of our study from 2005 are to prove the reduction of the evaporation loss (BOG loss) by utilizing the slush hydrogen, which is the mixture of solids and triple point liquid hydrogen. Use of slush hydrogen rather than atmospheric pressure liquid hydrogen provides the advantage in density and cooling capacity. Assuming a vehicle storage tank size such as 100 to 200 litter ones, the BOG rate can be reduced to 30 percent less than the atmospheric pressure liquid hydrogen is. Present execution plan is to develop, built, and test experimental equipments composed of a slush hydrogen generator, a transfer line, and a storage tank during three years from 2005 to 2007.

KEYWORDS: Liquid hydrogen, Slush hydrogen production, Boil-off gas management

1. Introduction
Hydrogen is supposed to be the useful energy media for future hydrogen vehicles, both by fuel cell and by internal combustion engines. Liquid hydrogen(LH2), in particular, has the capability to store more amount of energy because of its high density, therefore some parts of overall system including hydrogen vehicles and LH2 refueling system should be constructed by utilizing LH2. LH2, however, has the difficulty in storing and transporting because of the cryogenic temperature, therefore technical challenges such as boil-off gas loss minimization are now under study in the world.

This paper describes our R&D until 2004, and current development status from 2005 for the LH2 storing, transporting, and refueling system with advanced boil-off management using “slush hydrogen”, by NEDO (New Energy and Industrial Technology Development Organization, Japan) project. Development risk for LH2 related system and system components could be minimized mainly by taking advantage of H-IIA rocket launch vehicle development background in MHI.

2. R&D in 2004
Multiple cryogenic components and system such as a refueling interface, a storage tank, and overall refueling system have been developed, built, and tested. Cryogenic tests (using Liquid Nitrogen (LN2)) have been conducted in 2004 by MHI to evaluate the performance of the overall system and system components. As for the remarkable performance, boil-off gas rate of the vehicle side storage tank (@100 liter) is approximately 3 to 5 percent/day, and refueling time is 1 to 2 minutes and total time necessary for a refueling sequence (including connection of the refueling interface (=coupler), cooldown of the system, refueling, pressurization, disconnection of the refueling interface, and preparation for the next refueling procedure) is within 10 minutes.

Such cryogenic test results are reflected on the present study. To establish both intelligent system and advanced system components, most effective implementation is now under study, for example, research for the remarkable method with “slush hydrogen” to reduce boil-off gas rate as far as possible and extend driving time. In this case, even one-flow typed coupler, in which the LH2 filling line and GH2 re-flow line is the same one, will provably be convenient. (see figure 2) These activities and the results are sure to be very useful in the near future for hydrogen vehicles and refueling stations. (see next section)
Figure 1: Overall Test Configuration

Figure 2: Refueling Interface and Test Equipments
3. R&D Results and considerations during 2005

3.1 Objectives of our study
The objectives of our study from 2005 are to prove the reduction of the evaporation loss (BOG loss) by utilizing the slush hydrogen, which is the mixture of solids and triple point liquid hydrogen. Use of slush hydrogen rather than atmospheric pressure liquid hydrogen provides the advantage in density and cooling capacity. Assuming a vehicle storage tank size such as 100 to 200 litter ones, the BOG rate can be reduced to 30 percent less than the atmospheric pressure liquid hydrogen is. Present execution plan is to develop, built, and test experimental equipments composed of a slush hydrogen generator, a transfer line, and a storage tank during three years from 2005 to 2007.

3.2 Design and manufacture of an integrated slush hydrogen generator
Design and manufacture of an integrated slush hydrogen generator with glass dewar have been performed during 2005. The glass dewar enables to monitor slush production and flow behavior such as settling of solids, evaporation, aging, etc. During 2005 a slush hydrogen generator with glass dewar has been developed in order to demonstrate slush production and evaluate the coolant effects of slush hydrogen. Also, auger method is applied because of several advantages:
- Large-scale production
- Production in atmospheric pressure
- Control of solid particles size, production rate, etc

Solid hydrogen is generated on the surface of heat exchanger by cryogenic helium (6 to 13K(Kelvin)) as a refrigerator, and then solid hydrogen is scraped off by the edge of the auger.

The data over the wide range of solid particle size and slush production rate have been tested by varying several parameters of a coolant unit and a slush hydrogen generator unit. (As to the coolant unit, large-scale production required for the next phase( in 2006) has been performed in 2005.)

3.3 Slush hydrogen production tests summary
Slush hydrogen production tests have been conducted by using an integrated slush hydrogen generator with glass dewar. Two significant conclusions can be drawn from production tests:

- Slush hydrogen with 50 percent mass fraction has a coolant capacity that the BOG rate for a 100 to 200 liter sized vehicle storage tank is reduced to approximately 30 percent less than the atmospheric pressure liquid hydrogen is, because of its advantage in density and cooling capacity.

- Slush hydrogen production of 50 to 60 percent in mass fraction of solids and triple point liquid hydrogen by controlling the slush hydrogen particle size to the level (from 0.001 millimeter to 1) and production rate.

3.4 Design and modeling of a slush hydrogen generator for large-scale production
Experimental equipment for large-scale production is now under study. This equipment is composed of mainly two devices such as a slush hydrogen generator unit and a coolant unit using cryogenic helium as a refrigerator. The latter has been designed, built, and tested during 2005 (See section 3.2 and 3.3).

Test results with glass dewar(See section 3.2) and considerations can be applied to the design for a slush hydrogen generator unit to be built in 2006.
Figure 3: Test Configuration

Figure 4: Test Configuration
Figure 5: Test Results

Figure 6: Slush Hydrogen Production
4. Conclusion
The objectives of our study in 2005 to 2007 by NEDO project are to prove the reduction of the evaporation loss by utilizing the slush hydrogen. Design and manufacture of an integrated slush hydrogen generator with glass dewar have been conducted during 2005. Slush hydrogen production tests have been performed by using this experimental equipment.

Two significant conclusions can be drawn from these tests. Slush hydrogen with 50 percent mass fraction has a coolant capacity that the BOG rate for a 100 to 200 liter sized vehicle storage tank is reduced to approximately 30 percent less than the atmospheric pressure liquid hydrogen is, because of its advantage in density and cooling capacity. Also, slush hydrogen production of 50 to 60 percent in mass fraction of solids and triple point liquid hydrogen has been accomplished by controlling the slush hydrogen particle size to the level from 0.001 millimeter to 1 and slush hydrogen production rate.

Experimental equipment for large-scale slush hydrogen production is now under study. Additionally, most effective implementation is now under study for developing and improving multiple cryogenic components and system such as a liquid hydrogen refueling interface, a vehicle storage tank, and so on.

References:
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