Propellants helium saturated efforts and its effects for HTV (H-II transfer vehicle) propulsion system ground firing tests

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Abstract

It is well known that helium saturated propellants significantly effects the dynamics of propulsion system, thruster cross coupling, water hammer and thruster performance. Especially for the propulsion systems, which have multiple high thrust engines, such as HTV (H-II transfer vehicle), the effect is more important. Therefore full-saturated propellants should be used at ground tests of HTV propulsion system and evaluate its effects.

HTV is an advanced space vehicle being developed by Japan Aerospace Exploration Agency (JAXA) to enhance cargo delivery capabilities of the fleet of vehicles visiting the International Space Station (ISS).

This paper presents an overview of the successful effort of the testing with saturated propellants (MMH/MON3) for HTV propulsion system during the ground firing tests.

1. Outline of HTV

The size of HTV is 9.2 meters in length and 4.4 meters in maximum diameter. The vehicle weighs 16.5 tons and carries 6-ton payload to ISS. HTV has 2 types of logistics carrier, pressurized carrier and unpressurized carrier. Avionics module is placed beneath these carriers in launch configuration. Propulsion module for orbit and reaction control is installed at the rear of HTV. HTV propulsion system is a bi-propellant, regulated / blowdown type, Mono-Methyl Hydrazine (MMH) as fuel, Nitrogen-tetra-Oxide with 3% NO (MON3) as oxidizer, and gaseous helium(GHe) as pressurant. The overview of the propulsion module is shown in figure 1-2. It has 4 Main thrusters (500N) used for orbit control, and 28 RCS thrusters (110N) used for reaction control. They configurate a redundant system (ME-A/B, RCS-A/B). Total 12 latching valves are installed for isolation of thrusters from propellant tanks.

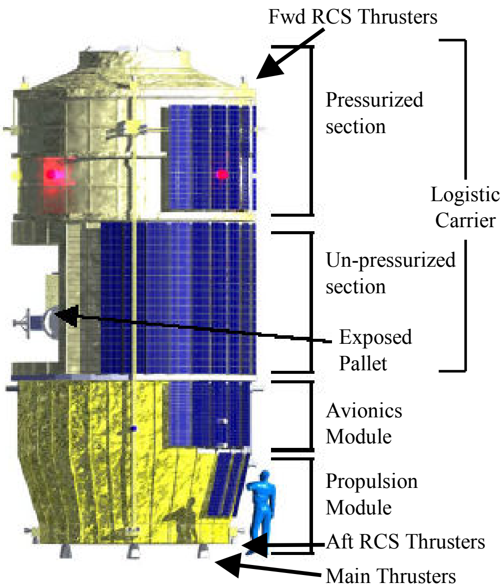


Figure 1-1. H-II Transfer Vehicle Overview.

9.2m in length, 4.2m in diameter, 16.5t in weight, 6t in ability to carry payloads.

2. Effect of Saturated propellants

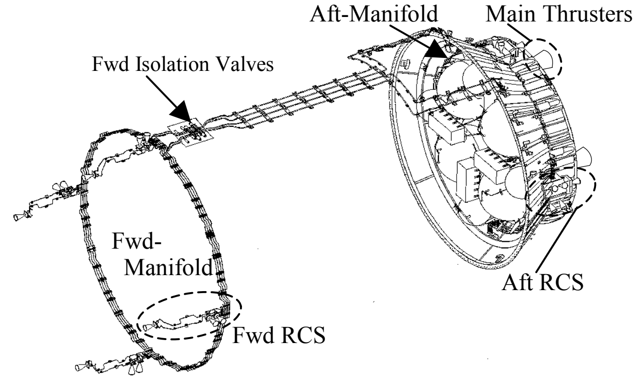
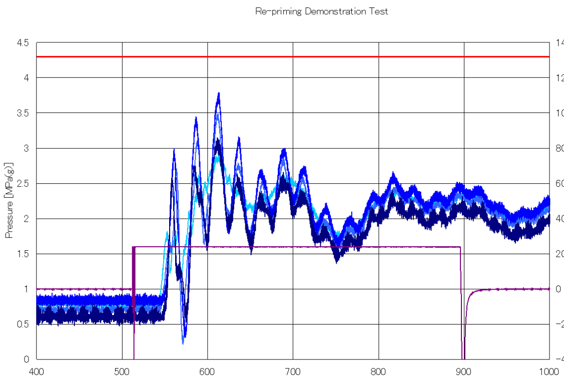
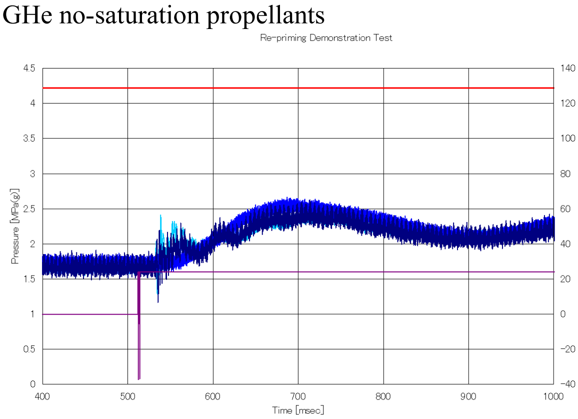


Figure 1-2. HTV Propulsion Module Overview.

Generally for satellite propulsion system propellant, which uses gaseous GHe as a pressurant, is saturated by dissolved GHe at launch phase, because of the time interval between propellant loading, pressurizing and launch is usually much enough to GHe saturation.
The GHe saturated propellants has significantly effects for space vehicle propulsion system. For example, it has the influence for pressurant gas pressure stabilization for blowdown propulsion system. And it also has the effect of propulsion system dynamics, water hammer surge pressure, cross coupling of thruster, resonance frequency of fluid system, etc,
Especially for HTV, which has multiple engine and long propellant supply lines, the saturated propellant effect is important.
Figure 2-1 shows the comparison for propulsion system surge pressure and resonance frequency with saturated and non-saturated propellants for example. Blue line shows the transient surge pressure by water hammer in HTV propellant tube near forward RCS thruster. This surge pressure will be observed at priming timing of HTV when it will departs from International space station (ISS).



(a) Example of line surge pressure test results with GHe no-saturation propellants



(b)Example of line surge pressure test results with GHe saturated propellants

<u>Figure 2-1 Surge pressure of HTV with saturated and no-saturated propellants.</u>

The surge pressure of GHe saturated propellant is usually lower than non-saturated one. But on the other hand, saturated propellant may promote thruster cross coupling effect and thrust roughness in some cases, because of its propellant line resonance frequency changing due to saturated propellants may interfere vehicle avionics control periods.
The existence of saturated GHe in propellants has such important effects of the propulsion system dynamics, so it is necessary to confirm its effect by ground test and establish the testing methods.

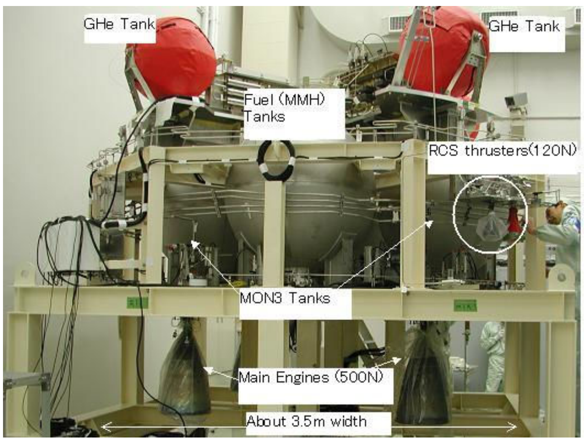
3. Propellant Saturated effort of HTV ground firing tests

To confirm saturated propellant effects during ground tests, two issues should be resolved;

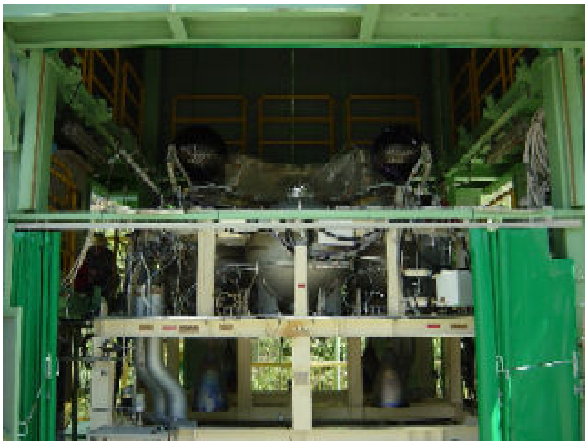
(1) To saturate propellant in limited ground test interval
(2) To evaluate saturated level just before the firing test start

IA had made efforts to resolve these issues during HTV propulsion system ground firing tests (SFT).
Figure 3-1 shows the ground firing test model of HTV propulsion system.
The propulsion system SFT)had held in summer of 2004 at IHI Aioi test facility.

During system firing test periods, the methods of blowing GHe bubble into propellant tanks had been tried to stirrer speed up. Figure 3-2 shows the schematic of GHe bubbling methods. It contributed to promote GHe full-saturation in limited test interval. The methods shortened the time to full-saturation about half or less.



(a) SFT test model



(b) Test stand setup

(c) Thruster firing
(left: Main engine, right: RCS thruster)

Figure 3-1 HTV propulsion system ground firing test model (SFT)

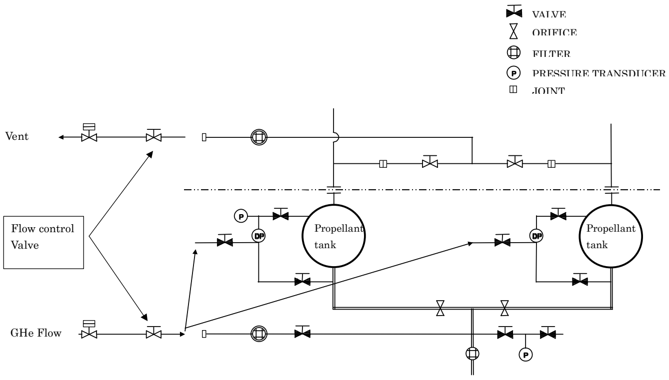


Figure3-2 Schematic of Blowing GHe bubble methods

4. Propellant Saturated level measurement methods of HTV ground firing tests

Two methods had tired to confirm gas saturated level during SFT.
One is bubble point technique and another is gas chromatography analyze.

Bubble point technique
Bubble point technique was originally developed at the White Sands Test Facility (WSTF) NASA to provide a method to determining gas saturation pressure of propellant. The bubble point was defined as the pressure at which gas coming out of the solution can be visually detected.
Figure 4-1 shows the bubble point detected device used for SFT.
The pressurized propellant drained to this device and depressurized. The bubble point pressure is observed visually in sight glass and able to defined GHe saturated level as the pressure.

Figure 4-1 The bubble point detected device

This method is very simple and convenient. But the defects of this methods is always detectable pressure is lower than actual by visualization constraints of sight glass, especially MON3 is hard to detect the exact bubble point pressure.
As for the defects this methods need to correlate other methods.

Gas chromatography analyze technique
Gas chromatography analyze technique was also applied for HTV SFT.
Gas chromatography can measure gas solubility directly.
Figure 4-2 shows the setup of gas chromatography analyzer and Figure 4-3 shows the schematic of gas sampling system.

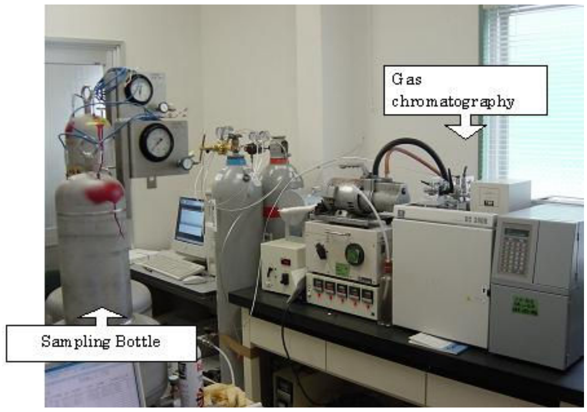


Figure 4-2 Setup of gas chromatography analyzer

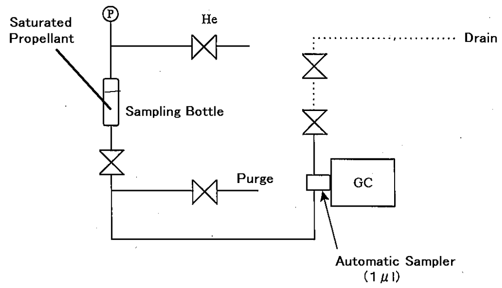


Figure4-3 Gas sampling schematics for gas chromatography analyzer

Gas chromatography analyze technique is more accurate and quantitative methods. But it is not easily applied for real time estimation just before the test started because it has enough time to get analyzes results.
So it had better to correlate bubble point technique by gas chromatography results.

Test results
The measurement gas solubility results of bubble points technique is lower than gas chromatography analyze method.
The deviation of both methods is mainly come from the visibility of bubble in sight glass.
For MMH propellant, it is relative easy to detect the bubble, the difference was under 5% but for MON3 propellant the difference was approximately 15%.
Table4-1 shows the solubility measurement results of both methods with 2.0[Mpa] pressurized propellant tanks.

Table 4-1 GHe solubility measurement results

	MMH	MON3
Bubble point technique	40	80
Gas chromatography analyze	46.0	96.1

[ppm]

Nevertheless of its difference the bubble point technique is still useful to save cost and test interval, so it had better to use combination of both methods.

5. Conclusion

Helium saturation technique is important to evaluate Propulsion system characteristics. The effective way to saturate and confirm propellant saturated level was established and successfully applied to HTV propulsion system development.

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