IN-28
88803
P-10

NASA Technical Memorandum 105597
AIAA-92-3385

Slush Hydrogen Pressurized Expulsion Studies at the NASA K-Site Facility

Margaret V. Whalen and Terry L. Hardy
Lewis Research Center
Cleveland, Ohio

Prepared for the
28th Joint Propulsion Conference and Exhibit
cosponsored by AIAA, SAE, ASME, and ASEE
Nashville, Tennessee, July 6–8, 1992

NASA

(NASA-TM-105597) SLUSH HYDROGEN PRESSURIZED EXPULSION STUDIES AT THE NASA K-SITE FACILITY (NASA) 10 p

N92-26131

Unclas

G3/28 0088803

SLUSH HYDROGEN PRESSURIZED EXPULSION STUDIES

AT THE NASA K-SITE FACILITY

Margaret V. Whalen and Terry L. Hardy
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

An experimental test series of the slush hydrogen (SLH_2) project at the NASA Lewis Research Center (LeRC) Plum Brook K-Site Facility has been completed. This testing was done as part of the characterization and technology database development on slush hydrogen required for the National Aero-Space Plane (NASP) Program. The primary objective of these experiments was to investigate tank thermodynamic parameters during the pressurized expulsion of slush hydrogen. To accomplish this, maintenance of tank pressure control was investigated during pressurized expulsion of slush hydrogen using gaseous hydrogen and gaseous helium pressurant. In addition, expulsion tests were performed using gaseous helium for initial pressurization, then gaseous hydrogen during expulsion. These tests were conducted with and without mixing of the slush hydrogen. Results from the testing included an evaluation of tank pressure control, pressurant requirements, SLH_2 density change, and system mass and energy balances.

Introduction

Slush hydrogen (SLH_2), a mixture of solid and liquid hydrogen, has been selected to fuel the National Aero-Space Plane (NASP).[1] The NASP will be a horizontal takeoff and landing vehicle which is expected to be built in the late 1990's. The technologies developed for NASP will be useful for many future commercial and aerospace applications. Therefore, NASP will serve as a proving ground for demonstrating various advanced technologies, including slush hydrogen fuel handling.

Slush hydrogen offers the advantages of increased fuel density and increased heat capacity relative to normal boiling point liquid hydrogen, thus potentially reducing the vehicle size and weight. Previous testing[2] at the K-Site Facility provided the first large scale production and handling experience with SLH_2. The current test series was developed to address NASP vehicle specific issues, such as tank pressure control.

Slush hydrogen is produced and exists as a mixture of solid and liquid hydrogen at 24.8 °R and 1.02 psia. This condition creates the potential for sudden sharp decreases in tank ullage pressure with fluid motion, such as fluid expulsion, mixing, and sloshing. These decreases in tank pressure could result in failure of a propellant tank. The NASP SLH_2 technology program is therefore investigating tank related operations.

Previous testing conducted at the NASA Lewis K-Site Facility investigated large scale production and transfer of SLH_2 and provided initial data on the pressurized expulsion of $7SLH_2$ using gaseous hydrogen.[2] The tests were conducted in a 5-ft-diam. spherical test tank. These tests provided information on tank pressure control, as well as pressurant gas requirements, system mass and energy balances, and SLH_2 density changes, during the expulsion of unmixed SLH_2. The results of these initial tests indicated that tank pressure could be maintained during pressurized expulsion of unmixed SLH_2. However, because of the expected tank operating scenarios for the NASP vehicle fuel tanks, additional technology data are required to address tank pressure control issues during pressurized expulsions with different pressurant gases and with in-tank mixing of the slush hydrogen.

The test results presented here are a further investigation of tank pressure control during the expulsion of SLH_2. The SLH_2 testing was conducted at the K-Site Facility from July to September 1991. The K-Site Facility is located at the NASA Lewis Research Center's Plum Brook Station. This testing was part of a complete test matrix to evaluate tank pressure control and also to obtain data on SLH_2 production and transfer and the effect of submerged injection of gaseous hydrogen on SLH_2 expulsion. The SLH_2 expulsion tests were done in a 5-ft-diam. spherical test tank mounted in the facility's 25-ft-diam. vacuum chamber. Pressurized expulsion tests were conducted by ullage injection of gaseous helium (GHe) pressurant and gaseous hydrogen (GH_2) pressurant, or with GHe pressurant during pressurization followed by use of GH_2 during the expulsion (GHe/GH_2). The tests were conducted at tank pressures of 35 and 50 psia with the pressurant gas at 540 and 250 °R. Most of the tests included in-tank mixing of the propellant using a mechanical mixer. A summary of the slush hydrogen pressurized expulsion results is provided herein.

K-Site Facility Description

Facility

The testing was conducted at NASA LeRC's Plum Brook K-Site Facility, which was designed to allow experimental evaluation of flow dynamics and thermal protection subsystems for cryogenic propellant tankage. The facility (shown in Fig. 1) includes the main test building which houses the vacuum chamber, the remotely located control room, cryogenic and gas storage areas, and the SLH_2 production subsystem. All the tests were conducted under vacuum inside the facility's 25-ft-diam. spherical vacuum chamber to reduce the heat transfer to the propellant test tank. The steady-state vacuum level in the chamber during this testing was approximately 1×10^{-6} torr. A general facility schematic is shown in Fig. 2.

A facility heat exchanger was used to precondition the pressurant gas by cooling it with liquid nitrogen. This test series used 540 and 250 °R pressurant gas. The flow rate of the pressurant gas was measured using an orifice meter. A closed-loop pressure control circuit was used to control the initial rate of pressurization of the test tank and to maintain constant tank pressure during the expulsion.

The SLH_2 was produced in a slush hydrogen generator, which is a 1300-gallon-capacity dewar with a liquid nitrogen shield in addition to the vacuum jacket with multilayer insulation. A 6000-ft^3/min vacuum pumping subsystem was used in the evaporative cooling (freeze-thaw) production of the SLH_2.

A pressurant supply subsystem was used for pressurized transfer of SLH_2 from the generator to the test tank. Slush hydrogen density in the generator was measured using a nuclear radiation attenuation densimeter with a 150-millicurie (mCi) cesium 137 source.

Test Package

The test tank was a 5-ft-diam. spherical vessel. The tank was constructed of 6061 aluminum with 0.31-in.-thick walls; total tank volume was 61.7 ft^3. The test tank was supported from a cradle structure which hung from the rail support system in the K-Site vacuum chamber (Fig. 3). During testing the SLH_2 was transferred into and expelled from the test tank through a 1.5-in.-diam. port in the bottom of the test tank.

The stainless steel tank lid contained a 1.5-in.-diam. port to bring pressurant gas into the tank ullage space. Inside the test tank an 8.0-in.-diam. hemispherical diffuser attached to the 1.5-in.-diam. pressurant line dispersed the pressurant uniformly in all directions into the ullage volume. The tank lid also contained a 2.0-in.-diam. port that was modified to allow sampling of the ullage gas. Five 0.125-in.-diam. tubes for sampling the ullage gas were brought through a 2.0-in.-diam. port in the lid. The lid also contained various feedthroughs for the test tank instrumentation. The test tank had a view port with a 3.25-in.-diam. window on which a camera was mounted to allow visual observation of the testing. Four quartz lamps were mounted at various levels in the tank to provide lighting. During testing only one lamp was operated at a time at ~50 to 75 W to minimize heat addition to the system. A mechanical mixer was installed in the tank to provide fluid mixing during testing. The mixer included a 1/3 HP explosion proof motor and a three-blade, 10-in.-diam. axial flow impeller. The mixer was operated at a maximum speed of 600 rpm, with speed reduced to maintain constant fluid flow as the liquid level in the tank decreased during expulsion.

The test tank instrumentation is shown schematically in Fig. 4. Silicon diode temperature sensors covering the range of 2.5 to 850 °R were used to measure the tank wall temperatures. Chromel-constantan thermocouples and PRT sensors were used to measure tank lid temperatures. Chromel-constantan thermopiles, PRT sensors, and silicon diodes provided temperature distribution measurements of ullage gas inside the test tank. A capacitance liquid level probe was used to provide continuous level measurement in the tank. Tank pressure was continuously monitored by a 0- to 100-psia strain-gage-type pressure transducer. The output of this transducer was fed back to the closed-loop controller used to increase the tank pressure during pressurization and to maintain constant tank pressure during expulsion. A bullseye capacitance densimeter located approximately 12-in. from the bottom of the test tank enabled the measurement of SLH_2 solid fraction inside the tank. An NRA densimeter with a 25-mCi cesium 137 source was mounted on the transfer line approximately 9 ft from the tank outlet to provide density measurements during tank fills and expulsions. All the data collected during testing were recorded using the ESCORT D data recording system.

Testing Procedure

The generator was typically filled with 810 to 890 gal of normal boiling point liquid hydrogen at the start of production. After the liquid had been cooled to triple point temperature, it would take 1.5 to 3 hr of freeze-thaw cycling to generate a batch of at least 50-percent-solid-fraction SLH_2. After production and prior to SLH_2 transfer, the transfer line and test tank were prechilled using normal boiling point liquid hydrogen ($NBPH_2$). Immediately after the tank was prechilled the SLH_2 transfer process began. The generator was pressurized with GHe to between 25 and 40 psia and the appropriate valves were opened to begin the transfer. The SLH_2 flowed through the line bypassing the test tank until the line densimeter indicated approximately the same density as the generator densimeter. At this point, the bypass valve was closed, the test tank fill valve was opened, and the tank SLH_2 fill was started. For each pressurized expulsion, the test tank was filled with SLH_2 to approximately 5-percent ullage. Data on the transfer process were reported in Ref. 3.

After the test tank fill, the pressurized expulsion test conditions, including pressurant type and temperature, tank pressure, and outflow valve position, were set. Tests used either GHe or GH_2 throughout the pressurization and expulsion, or used GHe during pressurization and GH_2 during the expulsion. Prior to initiating the data recording system, the test tank mixer was brought to its starting speed of 600 rpm for each test with in-tank mixing. The test tank pressurization was started after the mixer reached operating speed. The tank pressurization rate for all tests was nominally 1 psi/sec. Once the desired tank pressure was reached there was a short hold period, then the outflow valve was opened and the SLH_2 was expelled. As the SLH_2 was expelled the mixer speed was decreased to levels to maintain SLH_2 solid suspension at all liquid levels, based on fluid mixing calculations. Pressurant gas was added to the test tank through the closed-loop control system to maintain a constant tank pressure during the expulsion. The expulsion continued until the tank ullage reached approximately 95 percent. Following expulsions using GHe or GHe/GH_2 pressurant, the helium concentration in the tank ullage was measured.

Experimental Test Results

During this test series 40 pressurized expulsions with SLH_2 were completed. Eleven tests used only GH_2 pressurant gas and twelve tests used only GHe pressurant gas during pressurization and expulsion. The remaining seventeen tests used GHe during pressurization and GH_2 during expulsion (GHe/GH_2). Pressurant gas was added during the expulsion process to maintain constant tank pressure. Measurements of tank pressure, ullage and tank wall temperatures, mass of pressurant gas added, and SLH_2 density were taken during each expulsion. The tests were conducted at pressures of 35 and 50 psia, with pressurant gas at 540 and 250 °R.

Tank Pressure Control

Figures 5(a), (b), and (c) show typical tank pressure profiles for the pressurization, hold, and expulsion processes with GH_2, GHe, and GHe/GH_2, respectively. In these figures, the pressurization profile was fairly linear as the tank was increased to the desired test pressure. The pressure was maintained during the hold period, then a pressure drop, generally less than 1 to 2 psi, was seen at the start of expulsion. Tank pressure was then maintained through the remainder of the expulsion. Tank pressure was maintained during SLH_2 expulsions over the range of test conditions, regardless of pressurant gas type, pressurant gas temperature, tank pressure, or in-tank mixing.

Pressurant Gas Requirements

An objective of these pressurized expulsion tests was to determine the pressurant requirements to maintain constant pressure during the expulsion of SLH_2 propellant. The pressurant gas requirements are affected by the mass transfer (condensation or evaporation) occurring between the liquid and ullage gas and condensation of ullage gas at the tank wall. They are also affected by the pressurant gas type and temperature and the distribution of energy in the system. Samples of pressurant requirement results are provided in Figs. 6(a) and (b). The data included in these figures are for expulsions with in-tank mixing of the SLH_2. The figures compare GH_2, GHe, and GHe/GH_2 at 35 psia with gas temperatures of 540 and 250 °R, respectively. At 540 °R helium had the highest pressurant requirements and helium/ hydrogen had the lowest. Because GHe is a higher density fluid, the GHe pressurant requirements would be expected to be greater than those for GH_2 or GHe/GH_2. However, at 250 °R, helium and hydrogen showed a similar amount of gas added, while the helium/ hydrogen requirements were again lower. Similar results were seen in cases at 50 psia, with GHe/GH_2 tests showing the lowest pressurant requirements. The concentration profiles obtained with GHe/GH_2 indicated that the GHe used in tank pressurization provided a layer between the SLH_2 and the GH_2 used for expulsion. The GHe, being more dense than GH_2, would tend to sink and form a layer close to the SLH_2 surface. This GHe layer may have reduced the amount of hydrogen condensing at the cold SLH_2 surface, thus reducing the total pressurant requirements in cases using GHe/GH_2.

Data were also plotted to evaluate pressurant requirements at each pressure for mixed and unmixed expulsions. . Figure 7, which shows results of GH_2 expulsions at 540 °R, indicates that more gas was required as operating pressure and expulsion time were increased. This trend was also seen with GHe and GHe/GH_2 pressurant gases. In addition, it appears that in-tank mixing of the SLH_2 increased the pressurant gas required when using hydrogen. Mixing probably increased the surface motion, causing more condensation of gaseous hydrogen and therefore higher pressurant requirements. In similar tests with helium, mixing was not found to be significant in increasing pressurant requirements as was observed in the hydrogen cases. Because helium will not condense at the triple point of hydrogen, the motion of the fluid should not significantly affect pressurant requirements. In similar tests with GHe/GH_2, mixing the SLH_2 did impact pressurant gas requirements. Mixing of the SLH_2 increased the pressurant gas required in GHe/GH_2 tests at 540 °R, but the increase was not as significant as seen in the GH_2 only cases. At lower gas temperatures, mixing did not appear to significantly affect gas addition during expulsion with GHe/GH_2. The fluid motion can affect the pressurant requirements when gaseous hydrogen is used during an expulsion.

Mass Transfer

Sample mass transfer results for the SLH_2 pressurized expulsions with in-tank mixing of the SLH_2 are plotted in Figs. 8(a) and (b). The mass transfer was calculated by a mass balance procedure based on the mass of gas added and the mass of gas in the ullage at the beginning and end of expulsion. The figures include the data for the different pressurant gas types at a particular pressure and gas temperature. It is clear from the data that for expulsions with GHe pressurant, regardless of tank pressure and gas temperature, evaporation of hydrogen occurred. This result is reasonable because the temperature of SLH_2 is not cold enough for condensation of the helium pressurant gas to occur, but the energy being added to the system by the pressurant can result in evaporation of hydrogen at the SLH_2 surface. In all expulsion tests with GH_2 pressurant, condensation mass transfer occurred, with from 50 to 70 percent of the gas added during the expulsion condensing at the tank wall and the SLH_2 surface. In the tests with mixing, where GHe was used during the pressurization and GH_2 was used during the expulsion, evaporation occurred in tests with gas at 250 °R with expulsion times under 300 sec and condensation occurred in the remaining GHe/GH_2 tests. The condensation mass transfer was less in the GHe/GH_2 tests than in the GH_2 only cases. This reduction in condensation for the GHe/GH_2 cases was probably the result of the helium layer, as previously described. Similar results were obtained in the tests at 50 psia.

Energy Balance

The energy balance is an accounting of the energy coming into the tank because of the pressurant gas and environmental heating and results in the determination of the distribution of the energy to the SLH_2, the ullage gas, and the tank wall.

Figure 9 shows several cases representative of the distribution of the total energy entering the tank. Data are presented for GH_2, GHe, and GHe/GH_2 pressurized expulsions at 35 psia, with nominal gas temperatures of 540 and 250 °R. In the figure the reading number refers to the number assigned to each run by the data recording system. In general, as indicated in Fig. 9, the energy gained by the ullage gas was lowest for the GH_2 cases. Because high rates of condensation occurred during expulsions with hydrogen as indicated in the mass transfer data, less energy remaining in the ullage gas might be expected. In general the gain in tank wall energy was highest for GHe cases. The total energy entering the tank which was lost to the tank wall was 20 to 30 percent higher with 540 °R pressurant gas than it was with the same pressurant gas at 250 °R. Although the wall energy was higher for the 540 °R cases, the wall energy remained approximately constant regardless of pressurant gas type. The energy to the SLH_2 was highest in the tests with the GH_2 pressurant gas. The data indicate that use of the GHe/GH_2 pressurant gas reduced the energy to the slush hydrogen when compared to expulsions where only GH_2 was used.

The energy balance results were also affected by SLH_2 mixing and the expulsion time. In general, the energy change in the ullage gas, the tank wall, and the SLH_2 increased as the expulsion time increased. Unmixed SLH_2 expulsions had higher ullage gas energy than similar mixed expulsions. This was likely due to a stratified liquid layer above the SLH_2 in the unmixed tests, reducing the energy exchange at the SLH_2 surface. The unmixed SLH_2 expulsions also had more energy lost to the wall, but less energy lost to the SLH_2 than similar mixed tests. This was again due to reduced energy exchange with a stratified liquid layer at the SLH_2 surface.

SLH_2 Density Changes

The density of the SLH_2 was measured in the transfer line as the SLH_2 was transferred to and expelled from the test tank. The density in the transfer line was measured using an NRA densimeter with a 25-mCi cesium 137 source. The density in more than half the tests was also measured inside the test tank during expulsion using a bullseye capacitance densimeter. The density of SLH_2 during filling of the test tank ranged from 39 to 65 percent solid fraction, with the average density for all the test tank fills being 5.11 lb/ft^3 (52% solid fraction). The solid fraction at the end of expulsion was zero for the hydrogen expulsions, except in the unmixed cases. In the expulsions with helium, the solid fraction at the end of expulsion ranged from 3 to 53 percent. From the energy balance results, the total energy added to the tank was significantly lower in the helium tests than in both the GH_2 and the GHe/GH_2 cases. This was because helium has a much lower enthalpy than hydrogen. The total energy reduction was probably the most significant factor in having SLH_2 at the end of the helium expulsions. The expulsions with GHe/GH_2 at 540 °R and mixing had no solids at the end of expulsion, while those at 250 °R and the unmixed tests with 540 °R gas had solid fractions ranging from 0 to 39 percent. The unmixed SLH_2 expulsions had solids remaining for all tests regardless of pressurant gas type. As previously described, a layer of liquid existed above the SLH_2 in unmixed cases. This layer, as evident from the mass transfer and energy balance results, reduced the energy to the SLH_2 such that solids remained at the end of the unmixed expulsions. These results are similar to those in previous SLH_2 testing at the K-Site Facility.[2]

Concluding Remarks

Experiments were conducted at the K-Site Facility to provide data on tank pressure control issues associated with the pressurized expulsion of slush hydrogen. The tests were conducted in a 5-ft-diam. spherical test tank with GH_2, GHe, and GHe/GH_2 pressurant gases. The test results included evaluation of tank pressure control, pressurant gas requirements, system mass and energy balances, and SLH_2 density changes.

The issue of tank pressure control, and specifically ullage pressure collapse, was not found to be of major concern in this testing. Tank pressure was maintained during the expulsion process whether pressurized with only GH_2 or GHe and when using GHe during the initial pressurization and switching to GH_2 during the expulsion. This was found to be true regardless of tank pressure and pressurant gas temperature. Tank pressure was also maintained whether the SLH_2 was mixed or unmixed.

The pressurant gas requirements increased with tank pressure and with expulsion time for all pressurant gases. The pressurant gas required was generally higher with helium, which would be expected because it is a higher density fluid than gaseous hydrogen. The pressurant gas required was lowest in tests using GHe/GH_2. The GHe provided a buffer layer between the SLH_2 and the GH_2 during the expulsion. This layer effectively reduced condensation mass transfer occurring at the SLH_2 surface. It may be advantageous in terms of vehicle weight to use this pressurant combination during expulsion to reduce pressurant usage in a vehicle fuel tank.

These test results significantly expand the technology base on tank pressure control issues relating to pressurized expulsion of slush hydrogen. These data provide information necessary for using SLH_2 for NASP and other space propulsion applications.

References

[1]Kandebo, S.W., "NASP Team Narrows Its Options As First Design Cycle Nears Completion", Aviation Week & Space Technology, April 1, 1990, p. 80.

[2]Hardy, T.L., and Whalen, M.V., "Slush Hydrogen Propellant Production, Transfer and Expulsion Studies at the NASA K-Site Facility," NASA TM-105191, 1991 (Also, AIAA Paper 91-3550, 1991).

[3]Hardy, T.L. and Whalen, M.V.: Slush Hydrogen Transfer Studies at the NASA K-Site Facility, NASA TM-105596, 1992 (also, AIAA Paper 92-3384, 1992).

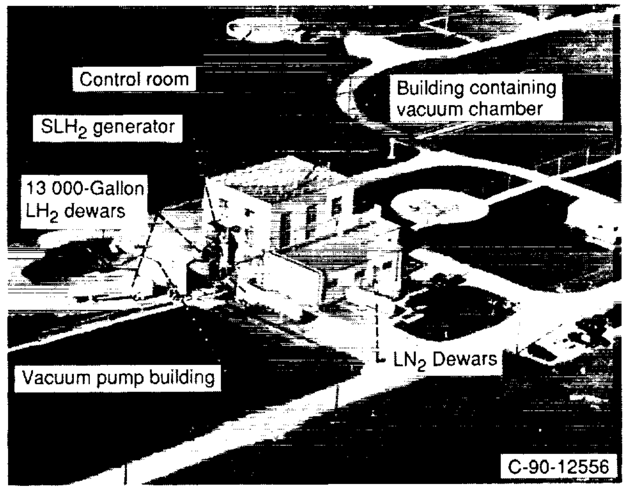


Figure 1.—NASA Plum Brook K-Site Facility.

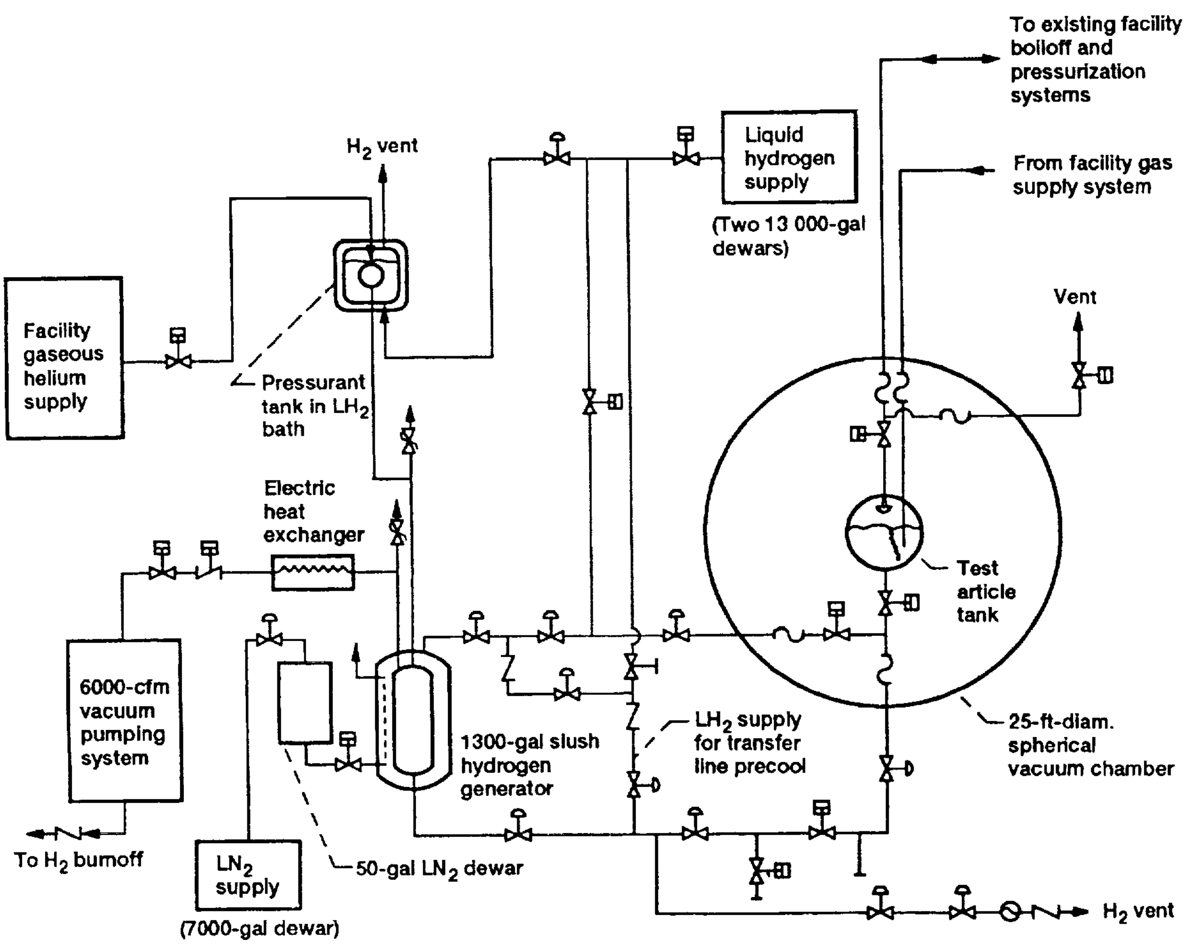


Fig. 2.—NASA Plum Brook K-Site Facility schematic.

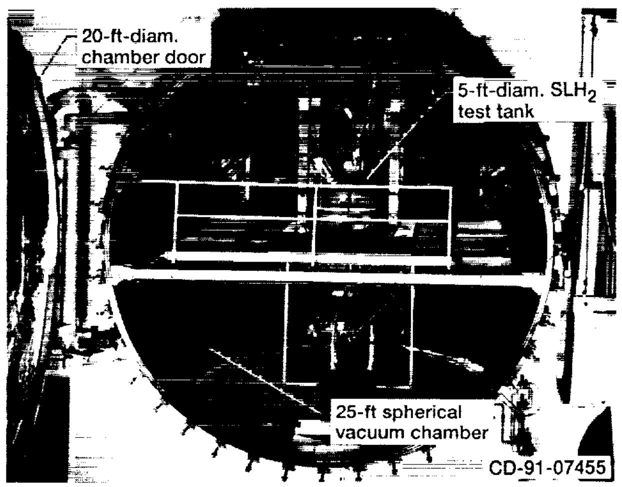


Figure 3.—K-Site 25-ft-diam. spherical vacuum chamber.

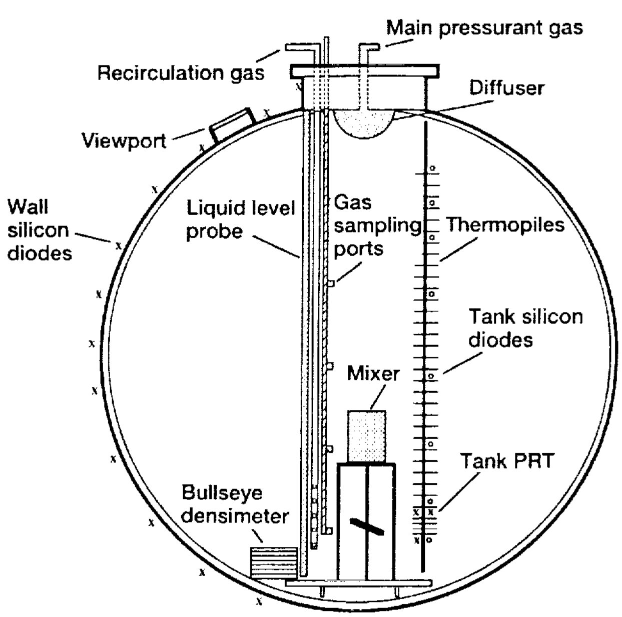
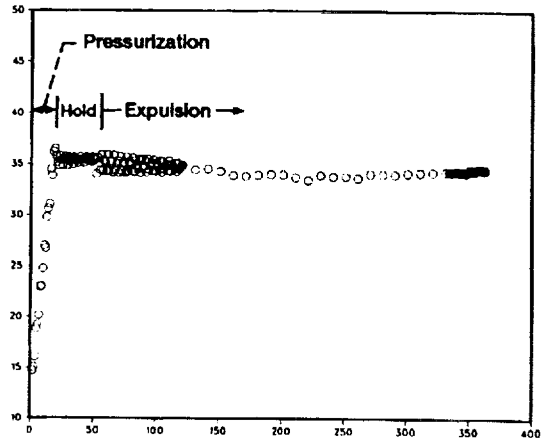
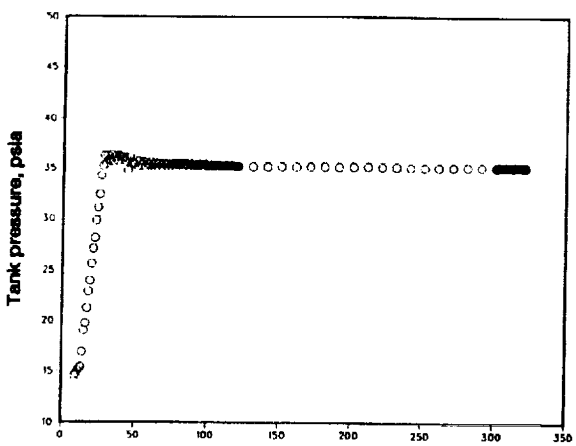


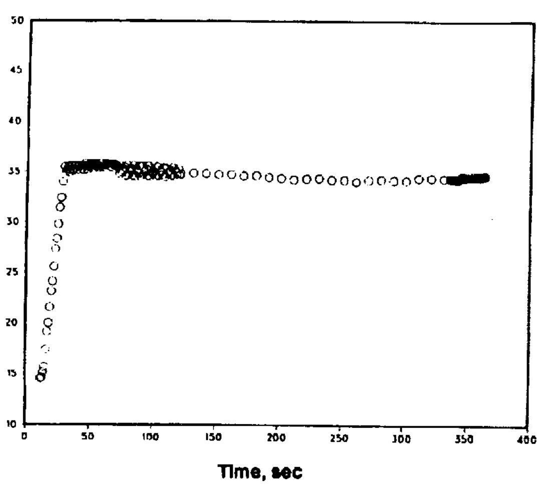
Fig. 4.—K-Site slush hydrogen test tank instrumentation.



(a) Run number, 2302; mixed; pressure, 34.3 psia; gas temperature, 541 °R; pressurant, H_2; expel time, 312 sec; ullage volume, 2.2 percent; reading number, 614.

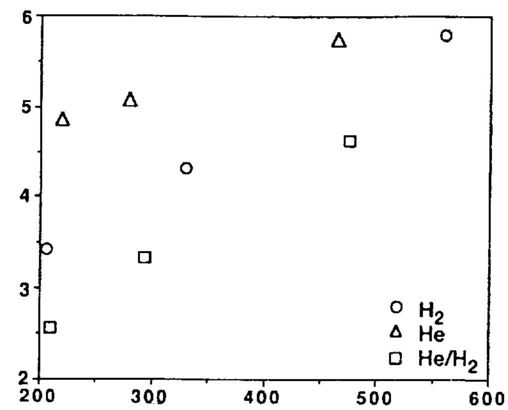


(b) Run number, 2332; mixed; pressure, 35.1 psia; gas temperature, 531 °R; pressurant, He; expel time, 279 sec; ullage volume, 3.3 percent; reading number, 678.

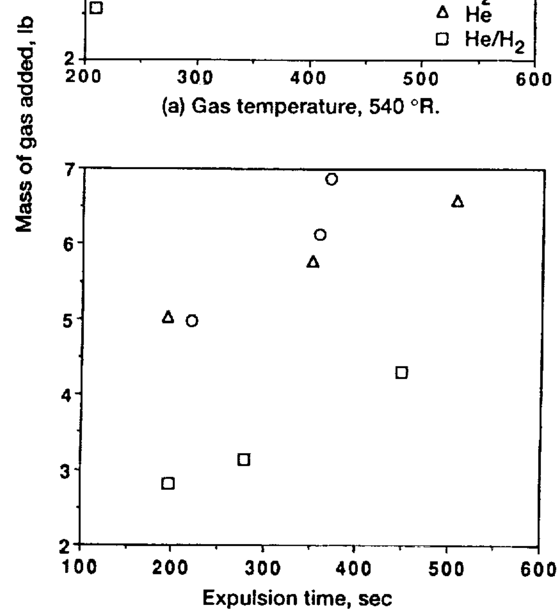


(c) Run number, 2342; mixed; pressure, 34.8 psia; gas temperature, 548 °R; pressurant, He/H_2; expel time, 293 sec; ullage volume, 3.2 percent; reading number, 707.

Fig. 5.—Tank pressure profile for SLH_2 pressurized expulsion.



(a) Gas temperature, 540 °R.



(b) Gas temperature, 250 °R.

Fig. 6.—Pressurant requirements for SLH_2 at tank expulsion pressure of 35 psia.

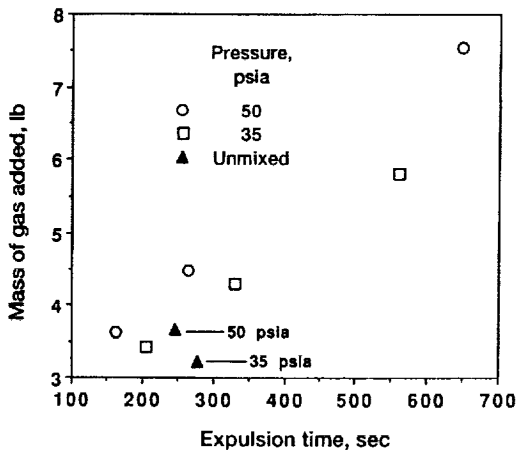


Fig. 7.—Pressurant requirements for SLH_2. Pressurant, H_2; gas temperature, 540 °R.

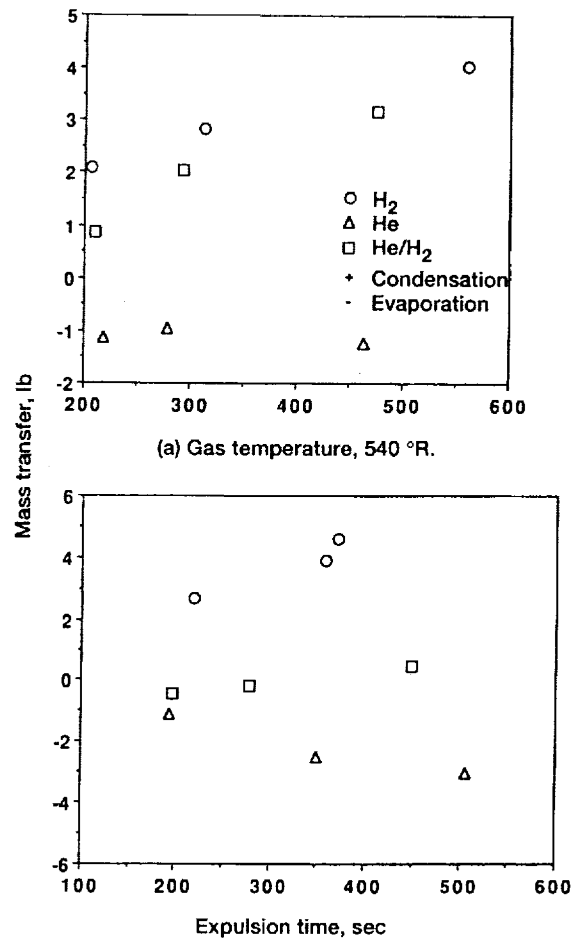
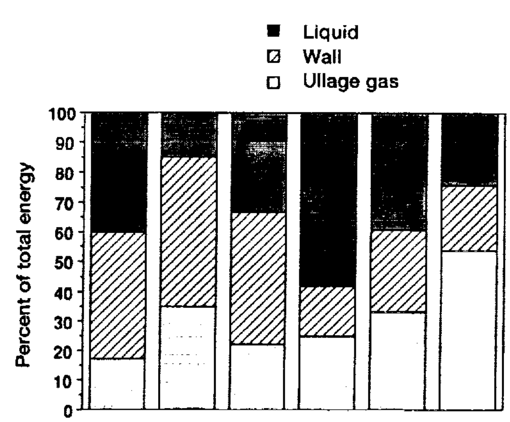


Fig. 8.—Mass transfer of SLH_2 at tank expulsion pressure of 35 psia.



Reading number	614	678	707	897	787	837
Gas	GH_2	GHe	GHe/GH_2	GH_2	GHe	GHe/GH_2
Temperature, °R	541	531	548	233	272	256
Time, sec	312	279	293	358	350	278

Fig. 9.—Slush hydrogen energy balance.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1992	Technical Memorandum

4. TITLE AND SUBTITLE

Slush Hydrogen Pressurized Expulsion Studies at the NASA K-Site Facility

5. FUNDING NUMBERS

WU-763-22-21

6. AUTHOR(S)

Margaret V. Whalen and Terry L. Hardy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-6933

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-105597
AIAA-92-3385

11. SUPPLEMENTARY NOTES

Prepared for the 28th Joint Propulsion Conference and Exhibit cosponsored by AIAA, SAE, ASME, and ASEE, Nashville, Tennessee, July 6-8, 1992. Responsible person, Margaret V. Whalen, (216) 977-7536.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 28

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

An experimental test series of the slush hydrogen (SLH_2) project at the NASA Lewis Research Center (LeRC) Plum Brook K-Site Facility has been completed. This testing was done as part of the characterization and technology database development on slush hydrogen required for the National Aero-Space Plane (NASP) Program. The primary objective of these experiments was to investigate tank thermodynamic parameters during the pressurized expulsion of slush hydrogen. To accomplish this, maintenance of tank pressure control was investigated during pressurized expulsion of slush hydrogen using gaseous hydrogen and gaseous helium pressurant. In addition, expulsion tests were performed using gaseous helium for initial pressurization, then gaseous hydrogen during expulsion. These tests were conducted with and without mixing of the slush hydrogen. Results from the testing included an evaluation of tank pressure control, pressurant requirements, SLH_2 density change, and system mass and energy balances.

14. SUBJECT TERMS

Hydrogen; Hydrogen fuels; Liquid hydrogen; Cryogenic fluids; Cryogenic fluid storage; Cryogenics; National Aero-Space Plane Program; Space exploration; Slush hydrogen

15. NUMBER OF PAGES

10

16. PRICE CODE

A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102