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Liquid Methane Conditioning Capabilities Developed at the NASA Glenn Research Center's Small Multi-Purpose Research Facility (SMiRF) for Accelerated Lunar Surface Storage Thermal Testing

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September 2011

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Abstract

The NASA Glenn Research Center's Creek Road Cryogenic Complex, Small Multi-Purpose Research Facility (SMiRF) recently completed validation/checkout testing of a new liquid methane delivery system and liquid methane (LCH_4) conditioning system. Facility checkout validation was conducted in preparation for a series of passive thermal control technology tests planned at SMiRF in fiscal year 2010 using a flight-like propellant tank at simulated thermal environments from 140 to 350K. These tests will validate models and provide high quality data to support consideration of LCH_4/LO_2 propellant combination option for a lunar or planetary ascent stage.

An infrastructure has been put in place which will support testing of large amounts of liquid methane at SMiRF. Extensive modifications were made to the test facility's existing liquid hydrogen system for compatibility with liquid methane. Also, a new liquid methane fluid conditioning system will enable liquid methane to be quickly densified (sub-cooled below normal boiling point) and to be quickly reheated to saturation conditions between 92 and 140 K. Fluid temperatures can be quickly adjusted to compress the overall test duration. A detailed trade study was conducted to determine an appropriate technique to liquid conditioning with regard to the SMiRF facility's existing infrastructure. In addition, a completely new roadable dewar has been procured for transportation and temporary storage of liquid methane. A new spherical, flight-representative tank has also been fabricated for integration into the vacuum chamber at SMiRF. The addition of this system to SMiRF marks the first time a large-scale liquid methane propellant test capability has been realized at Glenn.

This work supports the Cryogenic Fluid Management Project being conducted under the auspices of the Exploration Technology Development Program, providing focused cryogenic fluid management technology efforts to support NASA's future robotic or human exploration missions.

Introduction

Background

NASA is currently developing propulsion system concepts for future robotic and human exploration missions. Studies have identified high performance, cryogenic methane (LCH_4) and oxygen (LO_2) as a propellant combination for consideration on the main engines and reaction control system (RCS) for exploration propulsion systems. To support this, a number of tests will be conducted at the NASA Glenn Research Center's (GRC) Creek Road Cryogenic Complex (CRCC) (Fig. 1) Small Multipurpose Research

Figure 1.—The Creek Road Cryogenic Complex (CRCC) located at Glenn Research Center.

Facility (SMiRF) (Ref. 1) from April to July 2010 to baseline the passive thermal control technology of a flight-representative, spherical LCH_4 propellant tank at simulated thermal environments from 140 K to 350 K. The tank size (1.2 m, 4 ft diameter) selected is representative of the LCH_4 tank required for a human lunar ascent propulsion system and can be accommodated in the SMiRF thermal-vacuum chamber. The selected thermal environments are representative of LCH_4 propulsion system storage during lunar transit (TLI), for a lunar pole stay and for a lunar equatorial stay.

The test series, named the Methane Lunar Surface Thermal Control (MLSTC) test will document the as-built performance of a high performance, variable density multilayer insulation (MLI) system in the various lunar environments a human lunar ascent stage may be exposed to. (Ref. 2)

For a lunar outpost exploration mission at the lunar South Pole, a surface stay of up to 210 days for a crew module and ascent propulsion stage has been assumed. NASA system trade studies and contracted lunar ascent studies have shown that LCH_4 ascent stage propellant tank venting can be eliminated for a 240 day mission. Of the overall mission time frame, the first 30 days will include loiter in low Earth orbit (LEO) and transit time to the lunar surface. The remaining 210 days would actually be time on the lunar surface. Eliminating propellant venting of LCH_4 during this time can be accomplished via:

- A passive MLI system consisting of at least 60 layers to protect the propellant tanks from the lunar surface and solar environmental heating;
- Loading the LCH_4 propellant tanks with densified LCH_4 at 92 K and starting with tank ullage of approximately 15 percent at the KSC launch pad.
- Using the higher thermal capacity of LO_2 by thermally strapping the LCH_4 propellant tank to the LO_2 propellant tank.

To support this effort, a complete methane infrastructure has been put in place at SMiRF to support testing with large quantities of liquid methane. This new infrastructure is capable of supplying and quickly sub cooling or warming the bulk liquid methane stored in a test tank installed in the SMiRF vacuum chamber.

- A spherical, flight-representative tank has been fabricated for integration into the vacuum chamber at SMiRF.

- A cryogenic fluid conditioning system has been integrated within the SMiRF test facility that can both densify (cool) or heat the bulk liquid methane to saturation temperatures lower or higher than normal boiling point (NBP) to support testing at various liquid condition test points.
- A 15,100 liter roadable Dewar has been procured for transportation and temporary storage of liquid methane.

An integrated system checkout of all components of the methane infrastructure occurred September through early October 2009.

Experimental Capabilities

The CRCC is located at the GRC in Cleveland, Ohio. Part of the Research Combustion Laboratory (RCL), the CRCC complex is comprised of three separate test cells of which the SMiRF shown in Figure 2 is the largest test cell. Among its many capabilities, SMiRF can evaluate the performance of thermal control systems required to provide long term storage of cryogenic propellants in space. Newly constructed in the fall of 2003, the CRCC is a $28 million state of the art facility using the latest in instrumentation, controls and data acquisition. SMiRF provides the ability to simulate space or high altitude thermal-vacuum environments and launch pressure ascent profiles. SMiRF can safely handle purge and pressurant gases (H_2, CH_4, He, N_2 and O_2) and cryogenic fluids such as liquid hydrogen (LH_2), LCH_4, LO_2 and liquid nitrogen (LN_2). Located in a valley on the GRC campus, SMiRF was designed in accordance with appropriate quantity-distance requirements in the event of an explosive failure of a flight weight test tank.

Testing includes a wide variety of cryogenic fluid management (CFM) technology including: various storage techniques for Thermodynamic Vent System (TVS) (Ref. 3), low gravity Mass Gauging (Refs. 4 to 6), Zero Boil Off (Ref. 7) and calorimeter testing of prototype MLI insulation systems. Various liquid supply testing has also been conducted using Liquid Acquisition Devices (LADs) (Ref. 8) as well as the ability to perform rapid fill and chill of various storage tanks. The SMiRF test facility serves as a low-cost, highly configurable small-scale screening test bed for concept and component testing with a wide variety of existing support and test hardware.

Figure 2.—Small Multi-purpose Research Facility (SMiRF) test cell.

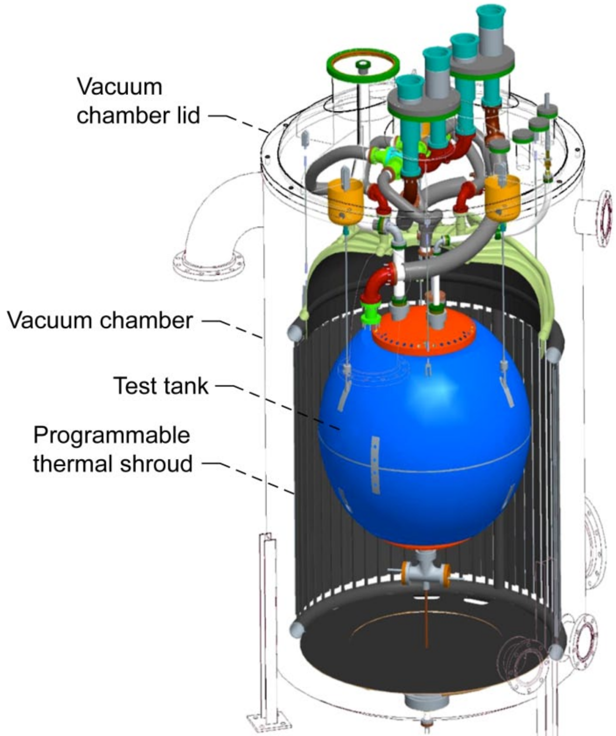

Figure 3.—Small Multi-purpose Research Facility (SMiRF) programmable thermal shroud.

The center of the SMiRF test cell is a vertical cylindrical space simulation vacuum chamber. The 7400 L vacuum chamber can accommodate test articles as large as 1.8 m in diameter and 2.3 m high. The SMiRF vacuum system includes a first stage mechanical pump, a second stage mechanical pump with Roots type blower, and a third pumping stage comprised of three diffusion vacuum pumps. The ultimate vacuum level can be maintained at 6.7×10^{-4} Pa in the chamber. The vacuum pumping system also allows the chamber to be evacuated to match a specific pressure pump down profile simulating a launch vehicle ascent pressure profile (from atmospheric pressure to 1.33 Pa in 2 min). Chamber pressure can be maintained at intermediate values as required by research programs. An optically dense programmable thermal shroud shown in Figure 3 is available for use in the vacuum chamber. The thermal shroud limits the dimensions of the test article to a maximum diameter of 1.12 m. The shroud can simulate lunar or Martian diurnal temperature profiles and operate over a temperature range of 110 to 360 K with a ramping capability of 3.3 K per minute during cooling and a ramping capability of 0.83 K per minute during warming over the entire range. Gas composition in the vacuum chamber is continuously monitored using a mass spectrometer based residual gas analyzer (RGA) that detects species in the 0 to 100 atomic mass units (amu) range. Outputs from the RGA controller can signal alarms or shutdowns as necessary during unattended operations.

Facility operations are typically performed in a remote control room located 150 m from the test cell. Operations are accomplished using programmable logic controller (PLC) providing hardwired signals for safety in operation. Wonderware (Invensys Systems, Inc.) HMI (human machine interface) software is used for facility control. Programmed alarms, shutdowns and component or signal interlocks protect the facility and research hardware. Data acquisition is through the use of LabView (National Instruments Corporation) software with input available from up to 456 channels at a nominal 1 Hz recording rate. Operator control of various systems via open loop processes provides greater testing flexibility. The control system is independent from the data system, but data is readily shared between the two through standard communication protocols.

Results and Discussion

Trade Study

To conduct the MLSTC test series at SMiRF within an acceptable resource allocation (test personnel cost and facility schedule time duration), a LCH_4 test fluid conditioner system was required to provide a pre-determined, variable temperature supply of LCH_4 to the test tank located in the SMiRF vacuum chamber using only NBP LCH_4 supplied from a facility supply dewar. The LCH_4 conditions desired in the test tank ranged from a highly densified 92 K state (liquid saturated at 13.8 KPa) to a 140 K state (liquid saturated at 606.7 KPa.) To accomplish this level of liquid conditioning, one system would be needed to chill the LCH_4 below its NBP temperature of (112 K), and a second system would be required to warm the LCH_4 well above its NBP temperature. Controllability of liquid temperature was desired to be held within ± 1 K at any target temperature within the above described range.

These capabilities would allow SMiRF to simulate a 240 day lunar exploration storage mission in which liquid is well mixed during storage, conservation of mass (no venting) is maintained, and tank ullage volume decreases from an initial 15 percent to an approximate final 5 percent value. Other requirements included a 3028 liter per hour test tank load rate, a test tank maximum expected operating pressure (MEOP) of 1.72 MPa (250 psig), and an instrumentation and controls compatible with the facility. NFPA 70 National Electric Code (NEC) Class I, Division II, Group B; ASME B31.3 Process Piping and ASME Boiler & Pressure Vessel Code Section VIII Division I compliance was also required. Assumptions for the design include a test tank volume of 875 liter test tank, a heat leak of 300 to 800 W, and initial chill down of piping consuming 197 liter of liquid methane in 18 min.

A series of trade studies were performed at the start of this project to determine the optimal path for achieving the desired capabilities. These studies were conducted considering the available SMiRF facility resources, whether the system should be skid mounted or permanently located, as well as the performance of each system in achieving the desired liquid temperatures. It was determined that two new sub-systems would be required to generate the full range of specified LCH_4 temperatures: One for sub-cooling or densification of the LCH_4 below its NBP temperatures, and a second system to warm the LCH_4 above its NBP.

For chilling the LCH_4 below its NBP, the following two types of systems were analyzed:

1. Evaporative cooling using a vacuum pump
2. Inter-media liquid heat exchanger

The first option evaluated the evaporative cooling of propellant already loaded in the SMIRF test tank and would require repurposing an existing facility vacuum pump and piping that was originally used for vacuum purging. It also required the purchase of an in-line heater to warm the cold ullage gas prior to entering the vacuum pump inlet as well as the addition of an oxygen sensor on the vacuum pump exhaust. The concept is illustrated in the top section of Figure 4. Advantages included infinite temperature tuning, utilization of current SMiRF infrastructure, and in-situ test tank processing. The disadvantages included sub-atmospheric operation and loss of LCH_4 that would require a makeup system.

The second option, illustrated in bottom section of Figure 4, involved prechilling the LCH_4 before it entered the test tank. This option would require the installation of an inter-media inline heat exchanger using a liquid argon (LAr) bath or Cryo-cooler to cool the liquid prior to tank loading. It had the advantage of operating at positive pressure without CH_4 venting. In addition, a similar system had been designed and utilized in a nearby test facility with positive results. This type of heat exchanger could also be easily skid-mounted, making it both removable and transportable. However it is not an in-situ process, and there was no temperature tuning capability (fixed outlet temperature) without an additional warming heat exchanger. Finally a recirculation pump or drain might have been required to process the LCH_4 if the test tank was filled from a warm condition.

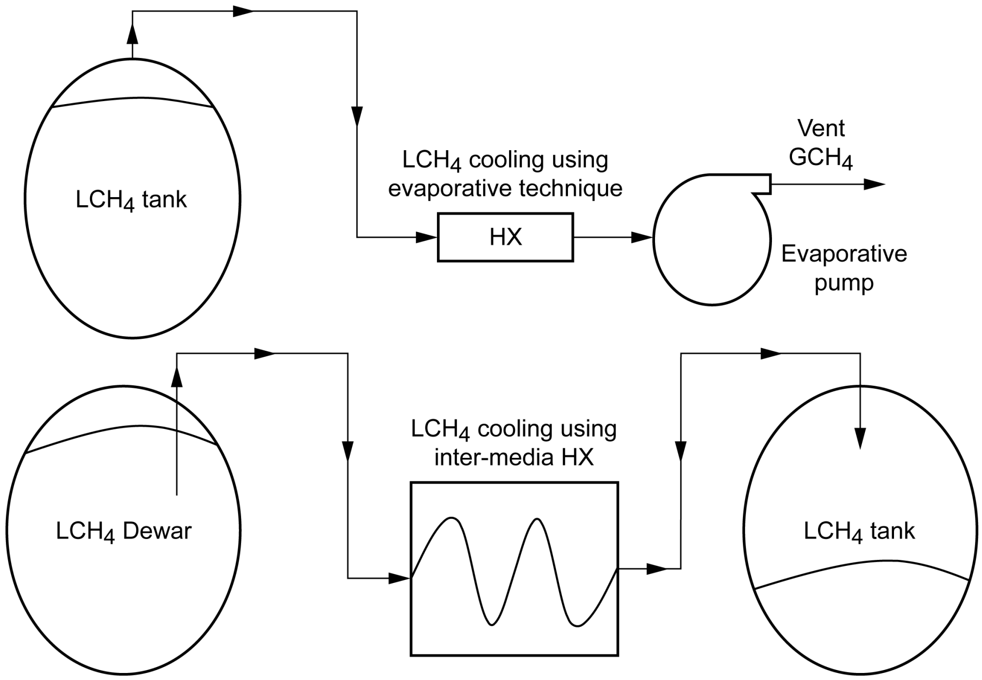

Figure 4.—LCH_4 cooling concepts.

After careful evaluation with regards to cost, overall size, performance and available facility infrastructure, the evaporative cooling option was chosen and will be described in detail in following sections.

For heating the LHC_4 above its NBP temperature, another analysis was performed comparing the benefits and draw-backs of two additional types of systems with concepts shown in Figure 5:

1. Warm GCH_4 bubbling
2. Electric heater

Bubbling warm gaseous methane gas (GCH_4) shown in the top section of Figure 5, through the LCH_4 already in the test tank would require both a gaseous methane supply and a bubbler distribution system mounted inside the test tank. A vaporizer would need to be added to the LCH_4 supply to provide the gaseous methane. Advantages for this option included in-situ conditioning, infinite temperature tuning, and a LCH_4 supply already available for vaporization. The bubbler could also take advantage of an existing flow and back pressure control system. Negative impacts for this type of system includes the required cost and effort of purchasing and installing a vaporizer and control panel as well as the required dedication of additional test tank space to add a distribution manifold

The in-line electrical heater option shown in the bottom section of Figure 5 would also provide infinite temperature tuning. The critical factor with this type of component would be the ability of the unit to warm the liquid without any localized boiling. Like the inter-media liquid heat exchanger mentioned previously, this type of electric heater was also in use at a nearby test facility and could again be remotely mounted on a separate skid for easy removal and transport. This in-line-heater method is not an in-situ process and would require additional electrical power and space. In addition, a re-circulating pump and associated piping and tank penetrations would be required.

Again, after careful evaluation with regards to cost, overall size, performance and available facility infrastructure, the bubbling concept was chosen as discussed in the following sections.

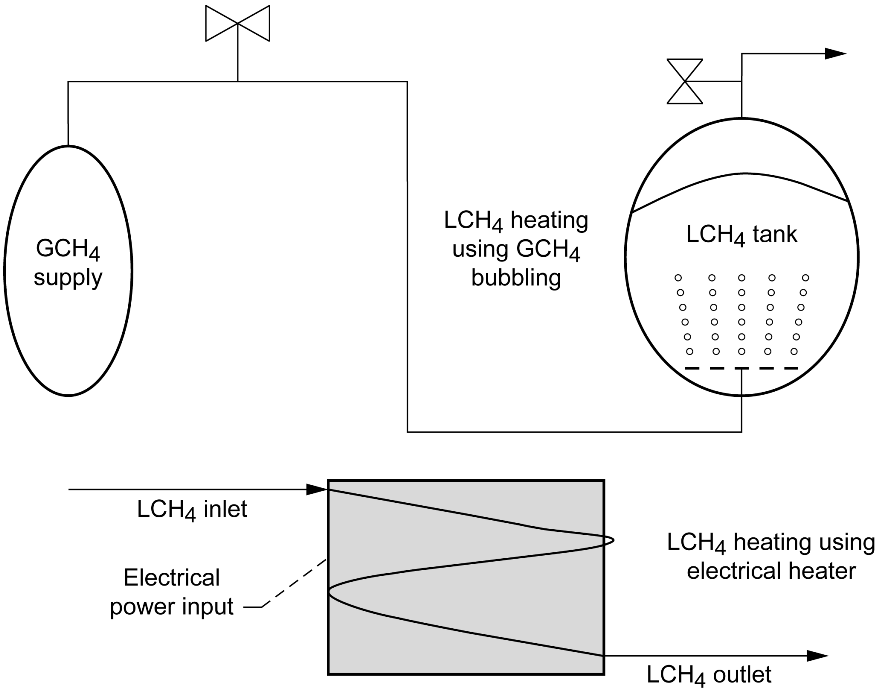

Figure 5.—LCH_4 warming concepts.

Facility Modifications

An overview of the completed methane conditioning system infrastructure upgrade including LCH_4 supply, GHe pressurization and the closed loop cold wall is shown in Figure 6. The highlighted lines show the Bubbler lines and Evaporative Cooling lines. The Bubbler lines run from the bulk LCH_4 storage tank through the vaporization heater and into the bottom of the tank with the bubbles being dispersed through the sparger. The Evaporative Cooling lines run from the ullage space inside the test tank, through a heater to warm the cold LCH_4 gas and to the mechanical roughing pump.

Evaporative Cooling System

To chill down the available NBP liquid to reduced temperatures within the test tank, an evaporative cooling system was added using one of the three existing vacuum pumps currently being used to evacuate the vacuum chamber. Piping already existed to vacuum purge the test tank, so flow to this pump was isolated from the vacuum chamber and left connected only to the test tank. This allows the LCH_4 in the test tank to be chilled from its NBP of 112 K down to a saturation temperature of 92 K. This required the installation of a heater to warm the cold vented methane gas before it entered the vacuum pump and a new vacuum pump discharge line to safely vent the methane gas into the atmosphere. This chill-down process was designed to take 1 hr (assuming a 300 W heat leak and no make-up liquid) for a full tank (875 liter) of liquid methane.

The existing facility pump utilized for this process was an Edwards/Stokes model 212J Microvac rotary piston vacuum pump. This unit is powered by a 5.6 kW, 230/460 V electric motor and has a pumping capacity of $250 m^3$/hr at 500 rpm. Since this pump was initially intended to pump only air out of the vacuum chamber, the manufacturer was consulted for this pump’s use with cold methane gas. They provided two recommendations. The first was to ensure that the gas at the pump inlet was sufficiently warmed, and the second was to add an external oil purification reservoir to the pump. The oil purifier would provide added security in the unlikely event that a small oil leak occurred into the methane flow stream as well as providing additional oil cooling under elevated pumping loads. Under this scenario, the oil purifier would provide a 13.2 liter source of additional pressurized oil as an added back-up to prevent

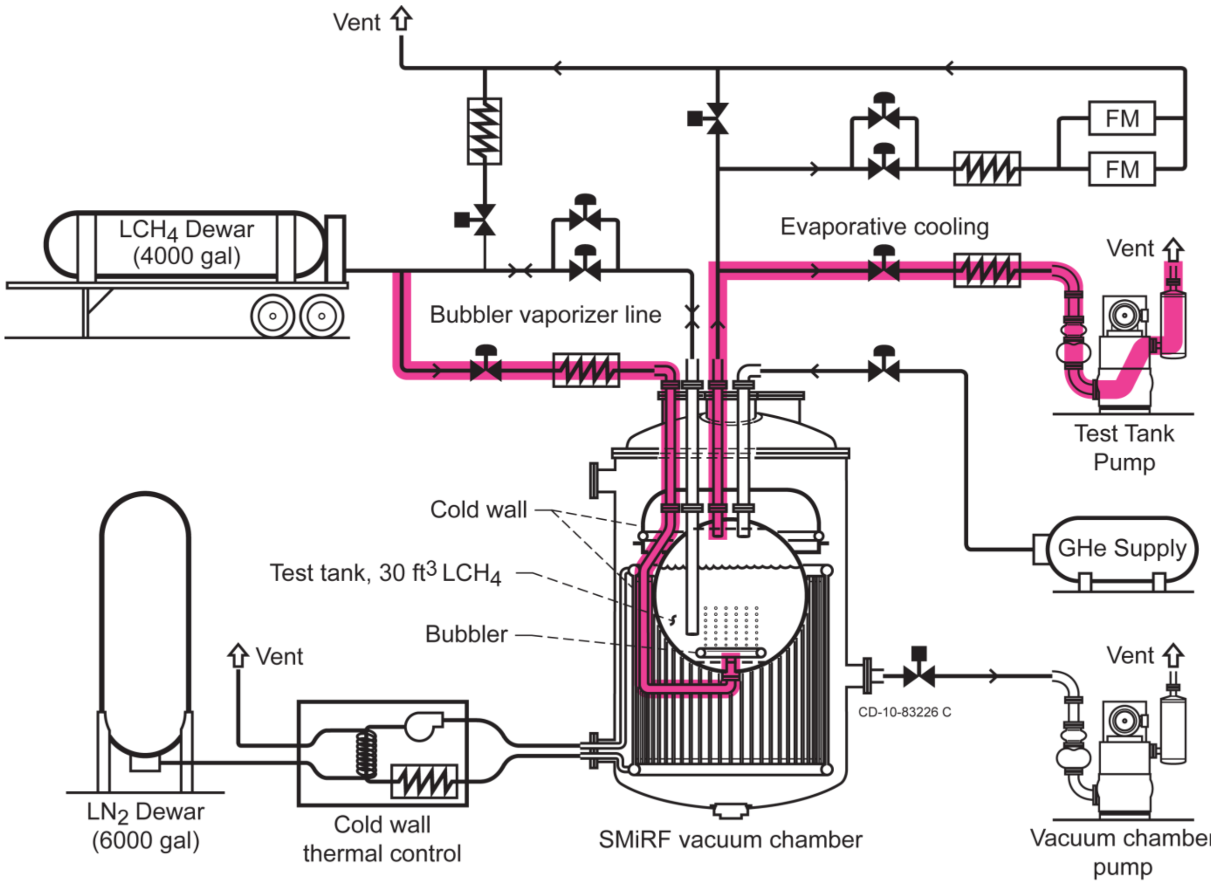

Figure 6.—Small Multi-purpose Research Facility (SMiRF) LCH_4 piping and conditioning system.

any chance of drawing air/oxygen into the main flow stream. The Edwards purifier unit selected was a model 339-030 providing a flow rate of 11 lpm, and is driven by a 0.37 kW, 230/460 V electric motor rated for Class 1 Division 1 Groups C and D suitable for methane service.

An electric heater was then added to the vacuum system to address the pump manufacturer's other concern of heating the cold methane gas before it entered the inlet of the vacuum pump. The electric heater was sized to warm the methane gas from its lowest saturation temperature of 92 K up to 300 K at the vacuum pump's maximum flow rate of 250 m^3/hr. Heater power is controlled by a silicon-controlled rectifier (SCR) electrical panel using a 480V-3Ph-30 kW circuit. Remote control through the HMI/PLC programs automatically controls the power to the heater as necessary to maintain the methane gas at the desired set-point temperature at the heater outlet. The heater is constructed using a 2.19 cm, 316 stainless steel tube chamber that will encompass nine, 1.87 mm diameter Incoloy elements to provide a 23 w/in^2 element watt density. It is insulated, has a stainless steel tube outer jacket, and is ASME certified to 1.90 MPa (275 psig).

Lastly, a dedicated vent was added to exhaust the vacuum pump discharge safely. An O_2 sensor system was installed in the discharge line to monitor the O_2 levels in the main flow stream. This will detect any air that may leak into the vacuum system at any point and provide a warning if the mixture of gases in the system begins to approach the Limiting Oxidant Concentration (LOC) that can support deflagration. According to NFPA 69, the LOC for oxygen in methane is 12 percent by volume. While this O_2 sensor will constantly display real-time measurements, it will also be set up with two limits. The first limit will be set at a four percent O_2 concentration and will provide a signal to an alarm in the control room. The second limit will be set at ten percent O_2 by volume and will send a signal to the facility PLC for an appropriate course of action.

Bubbling System

To study the upper range of LCH_4 temperatures desired, an ambient temperature methane gas bubbler system was chosen. This system was designed to inject the warm gas into the LCH_4 at the bottom of the test tank warming the liquid to a saturation temperature of 140 K at 606.7 KPa (88 psia). The ambient temperature GCH_4 (300 K) was generated by flowing LCH_4 from the storage Dewar, though an electric vaporizer. The predicted warm-up time for a full load of NBP liquid in the test tank, to the 140 K maximum LCH_4 temperature, was approximately 1.5 hr using this bubbler heating system. The bubbling system was designed to handle flow rates of up to 3.8 lpm (2,124 slpm). Similar to the vacuum system heater described previously, the power for this vaporizer is controlled by an SCR electrical panel using a 480V-3Ph-30 kW circuit. Remote control through the HMI/PLC programs automatically controls the power to the vaporizer as necessary to maintain the methane gas at the desired set-point temperature at the vaporizer outlet.

The vaporizer consists of a coiled tube encompassed in cast aluminum. The eighteen heater elements are also encompassed in the same aluminum casting, but do not physically contact the propellant tubing. Heat is conducted from the elements, through the casting, and into the tube wall. Both the methane tubing and outer housing are constructed of 304 stainless steel tube and are designed, built, and certified to ASME code. Gaseous Nitrogen (GN_2) is used as the purge gas for the bubbler system and is provided by the existing facility. The gaseous methane is delivered to the bottom of the test tank through piping routed through the vacuum chamber. A control valve at the vacuum chamber boundary sets the flow and a sparger manifold mounted at the bottom of test tank distributes appropriately sized bubbles throughout the cross section of the tank to transfer heat to the liquid.

Methane Storage and Delivery

A new liquid methane transport trailer (Fig. 7) was purchased to supply bulk liquid methane to SMIRF. The new trailer, M-22, is a commercial liquefied natural gas (LNG) trailer, fabricated by Alloy Custom Products, Inc. The trailer has been designed, fabricated, and inspected to U.S. DOT MC-338 specifications. The maximum allowable working pressure (MAWP) of the 15,100 liter (4,000 gal) trailer is 827.4 MPa (120 psi) and a maximum unloading rate of 757 lpm (200 gpm). The transport trailer is connected directly to the SMiRF facility and self pressurized to deliver liquid methane to the test tank. A second and much larger transport Dewar, M-26, has been converted from hydrogen to methane use for

Figure 7.—15,100 liter liquid methane roadable Dewar (M-22).

greater storage capacity and longer term storage of methane at a nearby commercial industrial gas supplier. This larger 49,200 liter (13,000 gal) vessel will be limited to a capacity of 30,280 liter (8000 gal) to account for methane's greater density versus hydrogen. It is used to receive larger shipments and serve as the staging area and supply source for M-22.

Test Tank

A new test tank was designed to be representative of a pressure fed methane propulsion system propellant tank typical of a lunar ascent stage. The spherical tank is 1.22 m (4 ft) in diameter (outside) with a smooth outer mold line to accommodate installation of MLI (Fig. 8). The tank can be installed in the SMiRF facility vacuum chamber within the cryo-shroud. Side mounting brackets are recessed into the tank wall to maintain the smooth outer surface interface with the existing ground fixture for ease of access. Three 1.59 cm diameter support rod mounting bosses with threaded ends are positioned in the top hemisphere of the tank for facility integration. The tank lids are designed to allow interchangeable mounting at the top or bottom of the tank, and to provide human entry/access to the tank internal volume. The top lid has three 8.9 cm (3 in. sch 80 NPS) ports to accommodate a fill line, vent line (including instrumentation leads), and a gaseous helium line. The bottom lid has one 8.9 cm (3 in. sch 80 NPS) port for the bubbler bar line and a conduit line for a mixer pump cable.

The ASME code stamped tank was designed and fabricated in accordance with the current edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and other sections as applicable. The MAWP is 2.43 MPa for 77 K to 311 K. The tank, flanges, and bolting materials are made from type 304 stainless steel with all components compatible with cryogenic fluids and cold gases. After fabrication, the tank and all lid assemblies were cold-shock tested using liquid nitrogen and hydrostatic pressure tested per the ASME code. Finally, the tank was helium gas leak tested per ASTM E-493 or ASTM E-498 to insure a maximum allowable leak rate is 1×10–9 standard cubic centimeters per second. The MLI was provided by Ball Aerospace Technology Corporation under contract.

Figure 8.—Test tank covered in multilayer insulation (MLI).

Methane Conditioning System Performance Tests

Methane conditioning system performance tests were conducted to verify predicted performance for both the methane bubbler warming and evaporative cooling systems. These tests were performed using the 875 liter volume spherical test tank described in the previous section. The tank was suspended from the test facility vacuum chamber lid and had piping penetrations for liquid fill, vapor vent, warm methane vapor, and temperature instrumentation. The test tank was un-insulated. Tests were performed with the vacuum chamber at nominally ambient temperature (i.e., thermal shroud was not operating during tests).

LCH_4 Evaporative Cooling Testing

Two evaporative cooling tests were performed. The first test was performed by filling the test tank with approximately 335 Kg of LCH_4 at nominally NBP conditions (1 atmosphere pressure, 112 K liquid temperature). The liquid was chilled by reducing the tank pressure as described above in the section: Facility Modifications—Evaporative Cooling System. The liquid temperature and pressure change is shown in Figure 9. Note that during the chill down test, the evaporative cooling system was shut down between T=120 min and T=145 min to troubleshoot a facility heat exchanger issue. Test tank pressure and LCH_4 temperature remained essentially unchanged during this time, and once pumping resumed, the tank pressure and liquid temperature continued to drop to the final fluid condition of approximately 13.8 KPa and 92 K. Total elapsed time to chill down the liquid (not counting the 25 min shut down) was 67 min.

The second evaporative cooling test was similar with the exception that make-up LCH_4 was added to the test tank during the test as the bulk liquid was being cooled by reducing tank pressure. The purpose of this test was to determine if the liquid mass could be maintained without significant increase in time to cool the bulk liquid. The liquid temperature and pressure is shown in Figure 10. The test began with approximately 263 Kg of LCH_4 at 107.5 KPa pressure and 112 K. The liquid was chilled as previously described, and liquid added intermittently during the chill down. Final fluid conditions of approximately 13.6 KPa and 92 K were obtained after 70 min.

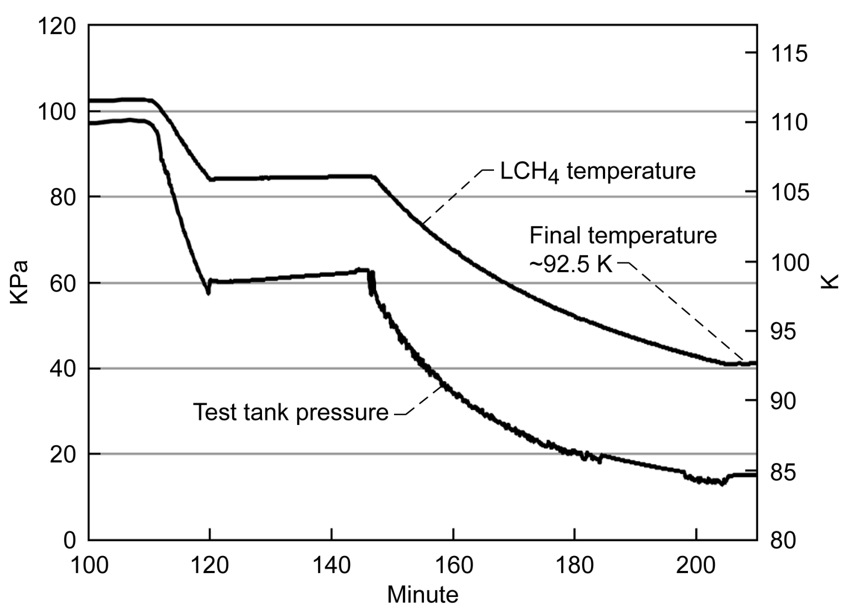

Figure 9.—Small Multi-purpose Research Facility (SMiRF) LCH_4 evaporative cooling test, without liquid make-up.

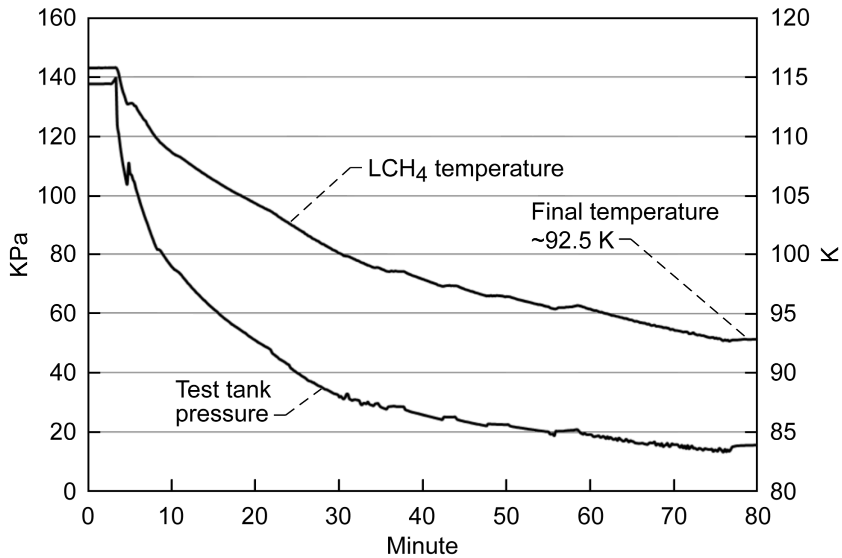

Figure 10.—Small Multi-purpose Research Facility (SMiRF) LCH_4 evaporative cooling test, with liquid make-up.

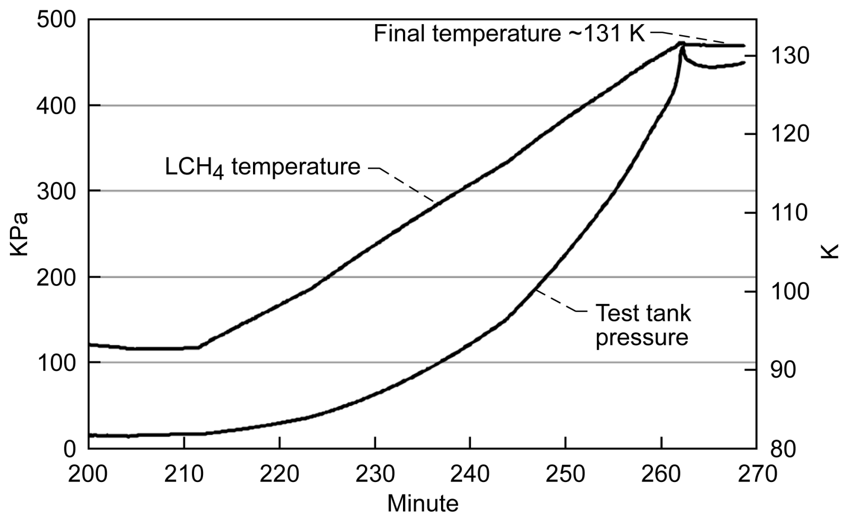

Figure 11.—Small Multi-purpose Research Facility (SMiRF) LCH_4 bubbler warming test.

LCH_4 Bubbler Warming Testing

One LCH_4 fluid warming test was performed using the methane bubbler system. In this test, liquid methane was warmed by bubbling warm gaseous methane through a diffuser in the bottom of the test tank as described above in the section: “Facility Modifications—Bubbling System”. This test was performed after the first evaporative cooling test. Initial mass of the LCH_4 was approximately 285 kg. Fluid initial conditions were 13.8 KPa and 92.7 K. Gaseous methane was bubbled into the liquid, warming it up to a final temperature of 131 K at 445 KPa. Fluid conditions are shown in Figure 11. Although the system is designed to warm the liquid to a maximum temperature of 139 K at 607 KPa, the test was terminated early since the maximum allowable liquid level in the test tank had been reached before the liquid had totally warmed. It is noted however that the system performed as designed.

Table 1 shows actual test data compared to design for the evaporative cooling operations. Table 2 shows actual test data compared to design for liquid bubbler warming operations. For both the evaporative cooling and bubbler warming systems, data from these checkout tests compared favorably with the design.

TABLE 1.—LCH_4 EVAPORATIVE COOLING—DESIGN AND ACTUAL PERFORMANCE COMPARISON

Subcooler	Design (no liquid make-up)			Actual (no liquid make-up)			Actual (with liquid make-up)		
	Start	End	Delta	Start	End	Delta	Start	End	Delta
Pressure (KPa)	101.3	13.8	87.5	97	13.6	83.4	107.5	13.6	93.9
Temperature (K)	112	92	20	111.5	92.5	19	112	92	20
Mass (kg)	350	308	42	334.8	284.8	50	263	243	20
Time (min)	------	-------	66	------	------	67	------	------	70

TABLE 2.—LCH_4 BUBBLER WARMING—DESIGN AND ACTUAL PERFORMANCE COMPARISON[a]

Bubbler	Design			Actual		
	Start	End	Delta	Start	End	Delta
Pressure (KPa)	101.4	607	505.6	101.4	445	343.6
Temperature (K)	112	139	27	111.4	131	19.6
Mass (kg)	295	323	28	312	345.8	33.8
Time (min)	------	----	90	------	------	51

[a]Initial actual fluid initial temperature and pressure were lower than shown in Table 2, as test began with subcooled liquid (reference Fig. 11). Actual data is shown for liquid between NBP and final condition for comparison with design.

Summary and Future Work

The SMiRF test facility within GRC's CRCC complex is a unique, world class cryogenic test facility capable of testing multiple cryogenic fluids including liquid nitrogen, liquid oxygen, and liquid hydrogen. Recently, test capabilities have been enhanced to add liquid methane to the inventory of test fluids including a conditioning system to readily reduce the bulk liquid methane saturation temperature to 92 K or warm the liquid to 140 K from NBP initial conditions. With the added capability of the new Liquid Methane Conditioner System, the SMiRF facility has the ability to quickly and efficiently change bulk fluid saturation properties to support a wide variety of cryogen testing. These capabilities have been experimentally demonstrated and will be used in an extensive upcoming lunar storage mission simulation.

Additional planned SMiRF facility upgrades will include a high outflow component to the LCH_4 system and a cryogenically cooled gaseous helium (GHe) pressurant system. The high outflow piping sub-system will increase the LCH_4 drain rate to a minimum 1.8 kg/sec simulating outflow requirements for typical main planetary lander and RCS engines. A cryogenically cooled GHe system will offer the ability to provide pressurant at temperatures as low as 83 K. This offers the benefit of simulating cold GHe storage temperatures.

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14. ABSTRACT Glenn Research Center's Creek Road Cryogenic Complex, Small Multi-Purpose Research Facility (SMiRF) recently completed validation / checkout testing of a new liquid methane delivery system and liquid methane (LCH4) conditioning system. Facility checkout validation was conducted in preparation for a series of passive thermal control technology tests planned at SMiRF in FY10 using a flight-like propellant tank at simulated thermal environments from 140 to 350K. These tests will validate models and provide high quality data to support consideration of LCH_4/LO_2 propellant combination option for a lunar or planetary ascent stage.An infrastructure has been put in place which will support testing of large amounts of liquid methane at SMiRF. Extensive modifications were made to the test facility's existing liquid hydrogen system for compatibility with liquid methane. Also, a new liquid methane fluid conditioning system will enable liquid methane to be quickly densified (sub-cooled below normal boiling point) and to be quickly reheated to saturation conditions between 92 and 140 K. Fluid temperatures can be quickly adjusted to compress the overall test duration. A detailed trade study was conducted to determine an appropriate technique to liquid conditioning with regard to the SMiRF facility's existing infrastructure. In addition, a completely new roadable dewar has been procured for transportation and temporary storage of liquid methane. A new spherical, flight-representative tank has also been fabricated for integration into the vacuum chamber at SMiRF. The addition of this system to SMiRF marks the first time a large-scale liquid methane propellant test capability has been realized at Glenn.This work supports the Cryogenic Fluid Management Project being conducted under the auspices of the Exploration Technology Development Program, providing focused cryogenic fluid management technology efforts to support NASA's future robotic or human exploration missions.					
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