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Supplemental Multilayer Insulation Research Facility

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SUPPLEMENTAL MULTILAYER INSULATION RESEARCH FACILITY

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SUMMARY

The Supplemental Multilayer Insulation Research Facility (SMIRF) provides a small scale test bed for conducting cryogenic experiments in a vacuum environment. The facility vacuum system is capable of simulating a Space Shuttle launch pressure profile as well as providing a steady space vacuum environment of 1.3×10^{-4} N/m^2 (1×10^{-6} torr). Warm side boundary temperatures can be maintained constant between 111 K(200 R) and 361 K(650 R) using a temperature controlled shroud. The shroud can also simulate a typical lunar day-night temperature profile. The test hardware consists of a cryogenic calorimeter supported by the lid of the vacuum chamber. A 0.45 m^3(120 gal) vacuum jacketed storage/supply tank is available for conditioning the cryogen prior to use in the calorimeter. The facility was initially designed to evaluate the thermal performance of insulation systems for long-term storage in space. The facility has recently been used to evaluate the performance of various new insulation systems for LH_2 and LN_2 ground storage dewars.

INTRODUCTION

SMIRF is a unique facility for ground based liquid hydrogen, liquid nitrogen, and vacuum experimentation. Tests that require vacuum and cryogenic capabilities of all types can be performed in this facility. The facility was designed to evaluate thermal performance of cryogenic insulation systems for long-term storage in space. The facility can simulate the pressure history of a shuttle launch, the pressure and temperature history on the lunar surface, and the pressure and temperature of space. SMIRF has most recently been used to evaluate various ground based insulation systems to be used by a commercial dewar manufacturer. This paper describes the SMIRF test facility and its capabilities.

DESCRIPTION OF FACILITY

General

The test facility (figure 1) is located in building 204 of the South 40 area of NASA Lewis Research Center. The steel frame building consists of a control room, shop, test area, and a basement under the test area. The building is surrounded on three sides by 4.6 m (15 ft) earthen mounds. The control room is separated from the shop by a 0.4 m (1.3 ft) thick concrete wall. The shop in turn is separated from the test area by a 20.3 cm (8 in.) thick concrete block wall. The test area is 31 ft high and surrounded by thirteen 3.0 m by 3.7 m (10 ft by 12 ft) panel lift doors. A crane with a 1814 kg(4000 lb) 6 m (20 ft) lift capacity is located in the test area.

Vacuum System

A 304 stainless steel cylindrical vacuum chamber is located at ground level in the test area. The chamber is approximately 250 cm(98.3 in.) high by 181 cm(71.3 in.) in diameter with a dished lid and bottom (figure 2). A mezzanine level allows access to the chamber and lid. Three diffusion pumps and 5 mechanical vacuum pumps provide the required vacuum capability. Four mechanical pumps are used as roughing pumps to evacuate the chamber. The fifth pump is used as a backing pump for the diffusion pumps. The exhaust line from the pumps is outside of the building and 4.6 m(15 ft) above the roofline. The total capacity of the roughing pumps is 33.4 m^3/min(1180 ft^3/min).

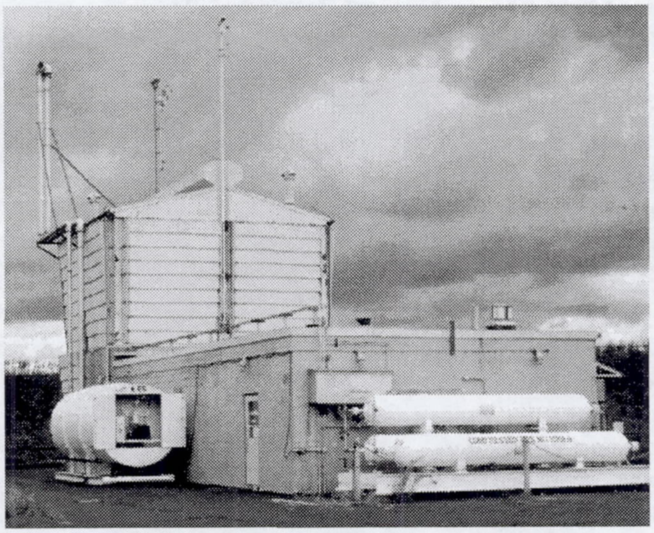

Figure 1.—Supplemental multilayer insulation research facility.

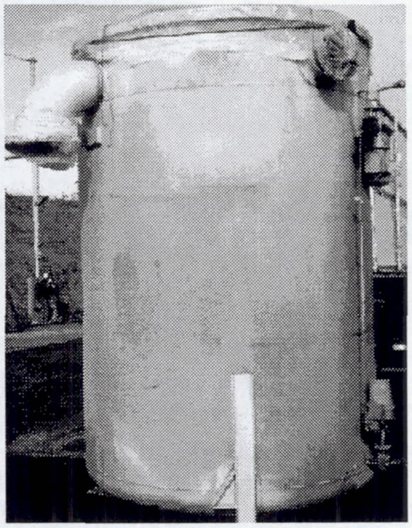

Figure 2.—Vacuum chamber.

Each of the mechanical vacuum pumps are isolated from the vacuum line by a remote operated vacuum gate valve. The vacuum system is configured such that one pump can be used to vacuum purge the test article and LH_2 supply lines. All four of the vacuum system pumps can be used to pump down the vacuum chamber. Thermocouple vacuum gages are installed on the inlet to the vacuum pumps to measure inlet pressure. A thermocouple is installed in the pump oil reservoir to measure oil temperature. Flow switches verify cooling water is supplied to the pumps.

A water chiller provides cooling water for the pumps. The water chiller is a self-contained unit consisting of a reservoir chiller and pump. The reservoir has a capacity of 0.053 m^3(14 gal) and contains a 50/50 water glycol solution. The chiller has a heat rejection capability of 53 kW.

Three NRC diffusion pumps are attached directly to the vacuum chamber. The displacement of each pump is 4000 liters/sec. Each diffusion pumps is isolated from the vacuum chamber by a 25.4 cm(10 in.) gate valve.

The diffusion pumps are equipped with cryotraps. The LN_2 filled cryotraps trap (by freezing) any oil from the diffusion pumps which may back stream into the vacuum chamber. The LN_2 level in the cryotrap is controlled by a closed loop level controller.

The three diffusion pumps are backed up by a mechanical vacuum pump located in the basement of the test area. A GN_2 gas ballast valve is used on the pump to prevent contamination of the oil reservoir. A thermocouple vacuum gage is installed on the inlet to the vacuum pump to measure inlet pressure.

Each of the diffusion pumps can be isolated from the roughing pumps. In the event of a failure of the roughing pump it is possible to switch to one of the other three mechanical pumps to back the diffusion pumps.

Flow switches on the diffusion pumps and mechanical backing pump verify sufficient cooling water is provided to the pumps. Thermocouples on the diffusion pump heaters indicate if the heaters malfunction. A thermocouple is also installed in the oil reservoir of the backing pump. If any of the temperature sensors or flow switches are outside the pump operating range, the pumps will automatically shutdown.

Shroud System

A temperature controlled shroud is located inside the vacuum chamber between the vacuum chamber wall and the research article. The purpose of the shroud is to provide a known radiative background temperature for the research article. The shroud can be controlled between 111 K (200 R) and 361 K(650 R). The shroud control system is also capable of producing a temperature profile over this range to simulate a lunar day. Temperature ramping capabilities are at least 0.17 K per minute over the entire range. Shroud temperature top to bottom can be controlled within ±3.0 K over the entire operating range.

The shroud is made of aluminum finned tubes that are attached to an upper and lower manifold. The shroud is shown on figure 3. The emissivity of the inner and outer surfaces of the shroud is less than 0.1. Two removable shields (one end attached to the shroud) are installed between the shroud and the test article. The shields are used to shield the test article from heat sources other than the shroud. The shroud is designed for operation at 1.3×10^{-4} N/m^2 (1×10^{-6} torr).

The temperature of the shroud is maintained by recirculating thermally conditioned GN_2 through the finned tubes. The shroud temperature is controlled at a desired value by a programmable controller which compares the input value from a thermocouple located on the shroud with the desired set temperature. Based on this temperature measurement, the GN_2 will either be heated or cooled. Heating is achieved by a 5kW electric immersion heater. The incoloy heater is enclosed in a stainless steel housing. The heater transfers heat by forced convection directly to the gas stream. Cooling is achieved by an LN_2 to GN_2 heat exchanger. A 14.2 m^3/min(500 ft^3/min) blower with a brushless motor is used to recirculate N_2. The blower is water cooled using the chilled water system.

Cryogenic Supply System

The cryogenic supply system consists of a roadable dewar, vacuum jacketed transfer lines, vent systems for the dewars, and a 0.45 m^3(120 gal) vacuum jacketed supply tank. The dewars are connected to the supply tank by a vacuum jacketed transfer line. Vacuum jacketed control valves control the flow to the supply tank. Dewar connections are made using bayonet fittings in the field. Each section of the vacuum jacketed piping is equipped with a combination pump-out, vacuum gaging, and pressure relief port.

A 0.45 m^3(120 gal) supply tank is used to supply cryogens to the test article. The tank is a double walled vacuum jacketed pressure vessel made of 304 stainless steel. The inside diameter is 0.6 m(2 ft) and the height is 2.4 m(8 ft). Reflective multilayer gettering materials are installed in the vacuum space. From the supply tank the fluid can enter the chamber through any or all of four separate fill lines.

Cryogenic Vent System

There are three vent lines available from the chamber, one 5.0 cm(2 in.) and two 2.5 cm(1 in.) lines. All three lines feed into a 7.6 cm.(3 in.) main vent which discharges 4.6 m (15 ft) above the roof. A separate test article vent path is required when evaluating insulation system thermal performance (boil-off). This is to prevent pressure disturbances in the other tanks from affecting the pressure controls system of the test tank.

Liquid Nitrogen System

The liquid nitrogen system consists of a 8 m^3(2100 gal) roadable dewar (N-65), flexible vacuum jacketed transfer lines and a vent system for the dewar. The dewar is equipped with a burst disc that relieves at 363 KPa(38 psig). The liquid nitrogen dewar is located on the west side of building 204. The main LN_2 vent discharges into a stainless steel drum with a level sensor installed in the top. If the level sensor indicates liquid nitrogen, the main LN_2 supply valve is automatically closed. This is to prevent a LN_2 spill in the area.

LN_2 is provided to the cryotraps on the diffusion pump inlet valves. The LN_2 level in the cryotrap is controlled by a closed loop level controller. LN_2 is also used in the shroud temperature control system.

Gaseous Helium System

GHe is used at SMIRF to purge the LH_2 system and the vacuum chamber. The facility is supplied by a 16,649 KPa(2400 psig), 1982 m^3(70,000 ft^3) tube trailer. GHe pressure is regulated to 170 KPa(10 psig) using two pressure regulators in series. If pressure of the main supply falls below 3549 KPa(500 psig), the supply automatically switches to two auxiliary 3.0 m^3(106 ft^3), 14,581 KPa(2100 psig) tubers.

Gaseous Nitrogen System

GN_2 is used for valve operator pressure, for the gas ballast supply, and for purging vent lines. GN_2 is also used to purge electrical boxes which contain components that are not rated for Class I, Division 2, Group B service per the NEC.

The main GN_2 supply is from a 8.8 m^3(310 ft^3), 16,649 KPa(2400 psig) storage tuber. If the supply pressure from this main tuber falls below 3549 KPa(500 psig), supply automatically switches to two auxiliary 3.0 m^3(106 ft^3), 14,581 KPa(2100 psig) tubers. The supply pressure is regulated down to 963 KPa(125 psig), 274 KPa(25 psig), and 170 KPa(10 psig) for the various operational usages.

Water System

A closed loop water chiller, operating at 289 K(520 R) supplies cooling water to the vacuum pumps, diffusion pumps, and shroud blower. The water chiller consists of a reservoir, a pump, and a heat pump type device for rejection of heat. The reservoir is filled with a 50/50 mixture of glycol and water to prevent freezing during winter months.

The chiller is equipped with temperature switches that shut down the compressor if the water temperature is less than 278 K(501 R) and shut down the entire unit if the water temperature exceeds 304 K(548 R). Pressure switches shut down the compressor and discharge fans if refrigeration pressure is less than 136 KPa(5 psig) and shut down the entire unit if refrigeration pressure is greater than 2790 KPa(390 psig). A pressure switch on the compressor shuts down the compressor and discharge fans if pressure is less than 163 KPa(9 psig).

Electrical Systems

All electrical components in the building are rated for Class I, Division 2, Group B service per the NEC or enclosed in nitrogen purged cabinets. Purge pressure is verified using a pressure switch that alarms if the pressure of a cabinet is less than 0.037 KPa(0.15 in. of H_2O).

Instrumentation cables run through the test area wall to signal conditioning in the shop area, then through an underground tray to the control room. Control cables run from the test area to the control room through the underground trays. Power cables run through the test area wall and control room wall. All penetrations are sealed at the test area eliminating any paths for the hydrogen to travel from the test area to the control room.

Hydrogen detectors are installed in the test area ceiling and basement. The H_2 detectors are set to alarm at 20% and 40% of the lower flammable limit (LFL) of H_2 in air. The hydrogen detectors alarm in the control room at 20%(LFL), in both the control room and fire station at 40%(LFL). Smoke detectors are installed in the control room and shop area. The smoke detectors alarm in both the control room and fire station when smoke is detected.

SMIRF operates with a Gould Modicon 984 programmable logic controller. The controller is used to control facility interlocks, permissives, and shutdowns.

Calorimeter

The calorimeter is used to provide a constant heat sink temperature during the evaluation of thermal performance of insulation systems. The boil-off from the calorimeter is used to determine the heat flux through the insulation.

The calorimeter, shown in figure 4, consists of three separate 76.2 cm(30 in.) diameter tanks. The center, or measure tank, is located between two guard tanks. The purpose of the guard tanks is to eliminate heat flow into the measure tank through its two ends. The tanks are constructed of 1.3 cm(0.5 in.) thick 1100 alloy aluminum.

The measure and guard tanks are supported through their centers by a stainless steel tube. During a test this tube is filled with the same cryogen that is in the tanks. This is to prevent conduction or radiation from reaching the measure tank. Insulation systems are placed and supported between two G-10 rings near the ends of each guard tank.

Calorimeter Tank Pressure Control

The determination of insulation thermal performance (heat flux) by measuring the boil-off from the measure tank requires precise pressure control of the measure tank. The tank pressure, 114 KPa(16.5 psia), is controlled by regulating boil-off flow. The measure tank control system consists of four parallel pneumatic control valves, a controller, a 6.8 KPa(1 psid) pressure transducer, and a constant pressure reference. The control system is sized to measure flows

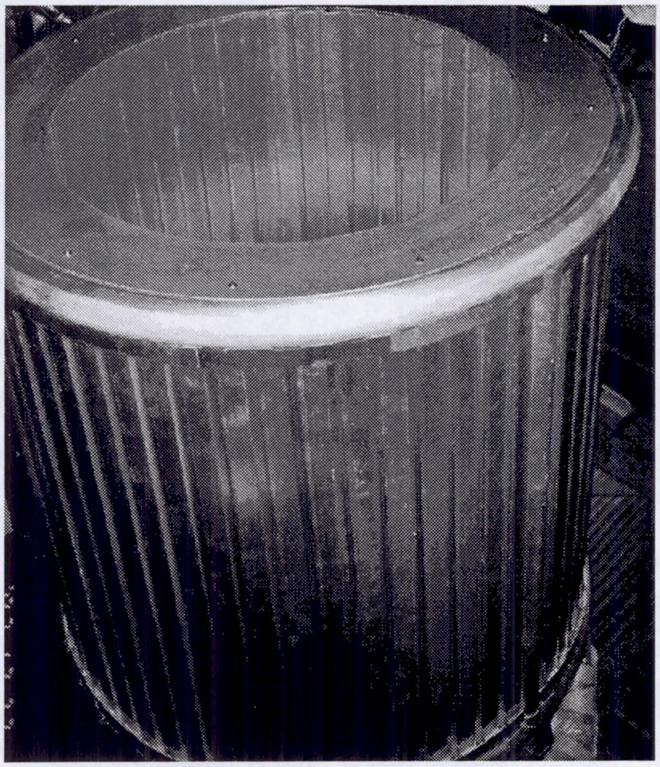

Figure 3.—Temperature controlled shroud.

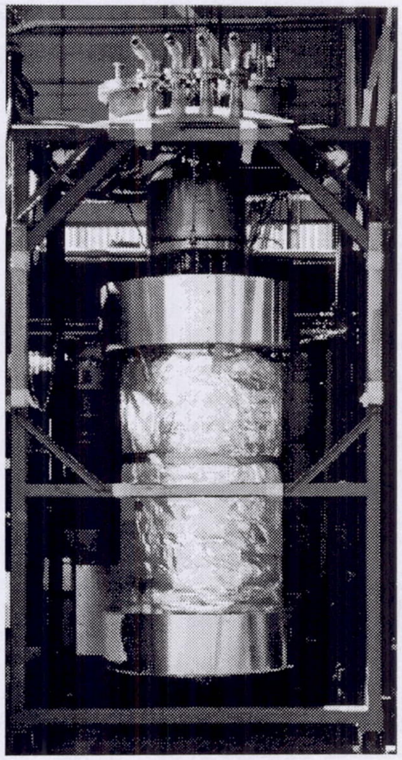

Figure 4.—Calorimeter.

from 0.00056 m^3/hr to 90.6 m^3/hr(0.02 ft^3/hr to 3200 ft^3/hr) and maintain measure tank pressure to within +0.14 KPa (+ 0.02 psia). The measure tank boil-off is measured by one or more of a series of five flowmeters.

The two guard tanks have to be maintained at a slightly higher temperature and therefore higher pressure of 117 KPa(17.0 psia) to prevent the condensation of the measure tank boil-off as it passes through the upper guard tank. This is achieved through another set of pneumatic control valves, controller, and a 34 KPa(5 psid) pressure transducer referenced to the same constant pressure volume as the measure tank. This guard tank pressure can be maintained to within +2.1 KPa(+ 0.3 psia).

Accomplishments/Plans

To date this facility has been used to evaluate the performance of seven different insulation systems. Three were evaluated using LH_2 in the calorimeter and four used LN_2. All tests were successful.

Future plans for this facility include; a program to evaluate the venting characteristics of MLI insulation systems during rapid pressure decays, developing concepts to minimize heat transfer through insulation penetrations such as tank feed and vent lines and tank support members, measuring the thermal permeability of composite material, and demonstrating a propellant liquefaction and storage system in a Mars environment.

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