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CRYOGENIC-SOLID COOLING TECHNIQUES

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by

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ABSTRACT

The technique evolved for solidifying liquid hydrogen and neon to the desired density is described herein as are the evaluation of a prototype model pressure-control valve and completion of the deliverable model of the cryogenic-solid cooler.

Approved:

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I. INTRODUCTION

The object of this program is to evolve the specific techniques for making a cryogenic-solid cooling system, and for measuring the physical and thermodynamic parameters of the operating device. The results of the third quarter of investigation are summarized in this report.

II. WORK ACCOMPLISHED

A. TECHNIQUES FOR SOLIDIFYING LIQUID HYDROGEN AND NEON

Hydrogen was the first of two gases which were solidified during this period.

The equipment used during experiments in solidifying liquid hydrogen was assembled in an outdoor test bunker due to the explosion hazard which did not permit tests to be made in the laboratory. The equipment consisted principally of a glass Dewar vessel, a large mechanical vacuum pump, weight-measuring equipment, pressure gauges, and temperature-measuring equipment. The same Dewar used previously in the nitrogen and methane solidification experiments was used for this experiment. The vacuum-insulated hydrogen container (glass Dewar) was marked with graduations for measuring the amount of solid produced. Additional thermal insulation was provided by wrapping the hydrogen container with aluminum foil. A narrow slit was made in the foil to permit visual observation of the solidification process.

The experiment was performed as follows. First, the empty Dewar vessel was weighed. It was then filled with liquid hydrogen and the vapor pressure over the liquid was reduced until, after a very short time, the hydrogen became solidified. The solid formed at the top and appeared to "grow" downwardly through the liquid at a fast rate until it was completely solidified. Although provisions were made for agitating the liquid hydrogen during the solidification process, the use of this technique was not required. The amount of solid produced was measured against the graduations on the side of the container. The test Dewar containing the solid hydrogen was disconnected from the pumping setup, sealed, and weighed. This experiment was repeated several times to obtain an average value of the solid density.

Measurements indicated that temperature of the solidified hydrogen was $11^{\circ}K$. Measurements of the vapor pressure over the solid also indicated that this temperature had been attained. The measurements gave an average value of 0.103 grams/cc as the solid hydrogen density. The Handbook of Chemistry and Physics lists the density of solid hydrogen as 0.08 grams/cc. The density of the solidified hydrogen produced in this experiment was approximately 25% greater than the handbook value. This difference is attributed to the presence of solidified air particles which formed when the Dewar was being filled with hydrogen and which are heavier than solidified hydrogen. These experiments indicate that liquid hydrogen can be solidified to the density levels discussed during the solid-cooler feasibility study. This is the density to which liquid hydrogen can be solidified in making it suitable for use in a cryogenic-solid cooler.

The liquid hydrogen did not present any handling problems. It was poured through a funnel into the test Dewar from a five-liter glass Dewar of the type used for storing liquid nitrogen. The standard five-liter storage Dewar was filled from a liquid hydrogen tank truck. As mentioned, liquid- and solid-air particles were formed on the outside of the funnel and in the liquid hydrogen. In filling the final model of the cryogenic-solid cooler, the liquid hydrogen would be transfered under pressure through insulated lines thereby minimizing the air-contamination problem. Filling of the test Dewar with liquid hydrogen was somewhat slower than with liquid nitrogen because of the lower density of liquid hydrogen. Solidification occurred more rapidly for liquid hydrogen, however, than for liquid nitrogen, probably because hydrogen has higher thermal conductivity. The solid hydrogen was visibly more compact and more uniform upon initial solidification than were nitrogen or methane.

Solidification of liquid neon was also investigated during this period. Experiments were performed with the same equipment used for solidifying liquid hydrogen. The liquid neon was transferred from a liquid-neon storage container into a one-liter glass Dewar. It was poured from this Dewar into the test Dewar and, again as with liquid hydrogen, solid air particles formed during the filling process. In this case, however, the density of the solidified neon was less than the value listed in the handbook because solidified air particles are lighter than solidified neon. The density of the solidified neon was from 1.18- to 1.35-grams per cc as compared to the handbook value of 1.44 grams per cc. Exclusion of the solidified air particles from the solidified neon would have resulted in the solid neon having the handbook density. The densities obtained, however, are satisfactory for use in the cryogenic-solid cooler. Liquid neon solidifies easily and is similar to hydrogen in this respect. No problems were encountered during the solidification of liquid neon, and the temperature-versus-pressure relationship agreed closely with the theoretical values.

B. EVALUATIONS OF PRESSURE-CONTROL VALVE

A pressure-control valve was obtained from Prosser Industries, Inc., Anaheim, California, and evaluated during this reporting period. This device, shown in Figure 1, is a diaphragm-type valve having a 7.25-in. diameter. It is 2.37-in. high and weighs about 5 lbs. Since this is a prototype model intended for experimental purposes, no special effort was made to obtain a lightweight valve. In a space application of the solid cooler, it should be possible to reduce the weight of this particular valve by 75%, simply by removing extraneous material without affecting the performance. The valve was evaluated during the sublimation of solidified nitrogen and carbon dioxide in a test Dewar. The valve is adjustable, such that the pressure over the solid coolant could be maintained constant within a range of 9- to 30-Torr. The valve maintained a constant pressure although it was subjected to a gas flow-rate from the Dewar which was higher than would be experienced when used with the cryogenic-solid cooler. The high flow-rate of nitrogen gas was due to the excessive heat-leak into the test Dewar which is many times more than expected from the cryogenic-solid cooler. Solidified carbon dioxide produced a lower flow-rate during sublimation than did solidified nitrogen. Thus, the valve was successfully evaluated with the test Dewar, having performed satisfactorily under abnormally high flow-rates. Even greater reliability is anticipated at the lower flow-rate produced by a crygoenic-solid cooler. This pressure-control valve will be used with the deliverable model of the cryogenic-solid cooler.

C. DELIVERABLE MODEL OF THE CRYOGENIC-SOLID COOLER

During this reporting period, the deliverable model of the cryogenic-solid cooler was assembled. This model consists of a coolant inner-container, heat-transfer rod, bellows-sealed exhaust-port, superinsulation, support members, and an outer container with various fittings. The inner and outer containers are shown in Figures 2 and 3, respectively, before being insulated and assembled. The outer container cover is shown in Figure 4. The bellows seal on the inner container is covered with a perforated metal protective shield as shown in Figure 2.

The inner container has a 7-in. diameter and is 7.25 in. long. It will hold approximately two liters of solid coolant. The combined weight of the heat-transfer rod and bellows is 4.75 lb. This unit is designed to operate for approximately one month using solid nitrogen ($48^{\circ}K$) or for three months using solid methane ($77^{\circ}K$). The supporting cords attached to the eyelets on the inner container can be seen in Figure 2. These cords are made from Dacron thread which is a high-strength and low thermal-conductivity material. These cords pass over pulleys mounted on the top of the outer container and are then tied to springs attached to the bottom of the outer container. The springs help to damp shocks which may result from the cooler being jarred or dropped and prevent the supporting cords from breaking. The four cords extending from the top and bottom of the inner container provide semi-rigid support for the inner container.

The heat-transfer rod is silver-soldered to the front of the container. At the rear where the gas escape port is located, the rod is attached with a heavy spring. This spring acts as an expansion joint between the container and heat-transfer rod. This is necessary due to the extreme ranges in the temperature to which the coolant container will be exposed. Also located at the back of the heat-transfer rod is a threaded fitting used for filling the inner container with cryogenic liquid from a pressurized source. Under these conditions, the container can be filled rapidly and with much less difficulty than was experienced with the experimental model of the cryogenic-solid cooler.

The space between the coolant container and outer container is filled with superinsulation. The superinsulation is 3-in. thick and has from 70- to 80-radiation shields per in. Previous experience with this type insulation indicates that this number of radiation shields is optimum. The coolant container is insulated as follows. First, both ends of the container are insulated with 2-in. thick pads having a diameter equal to that of the inner container. Superinsulation is then wrapped continuously around the container, covering the top and bottom pads as well. This insulation is 11 in. long (7-in. container plus both 2-in. end pads) and 3-in. thick. Two 1-in. thick pads, having a 13-in. diameter, are then placed at the top and bottom of the insulated container. Direct radiation paths between the inner and outer containers are eliminated by this insulation method.

The outer container has two flanges located on the top and bottom as shown in Figure 3. The bottom flange mates with the flange which holds a window directly over the heat-transfer rod, and will also hold an electrical feed-through for a cooled component. The top flange mates with another flange which holds the connections to the pressure-control valve. In order to fill the inner container with coolant, the pressure-control valve mounting flange has to be removed. Two reinforcing bands around the outer container provide an additional safety feature to reduce the danger of implosion of the outer container which, although remote, is a possibility worthy of the measure taken. Another feature that should be noted is the conical shape of the container ends. These were also designed to support the external pressure on the outer jacket.

One of the fittings shown on the photo of the container cover (Figure 4) is an evacuation port for the superinsulated chamber and the other is a safety valve. The safety valve prevents excessive buildup of pressure from rupturing the outer container in the event that a leak in the inner container destroys the insulating vacuum and causes a rapid evaporation of the coolant into the vacuum space.

Performance tests on the deliverable model of the cryogenic-solid cooler and pressure-control valve will be conducted during the remainder of the contract.

III. CONCLUSIONS AND RECOMMENDATIONS

The solidification techniques for hydrogen and neon have been investigated. No difficulty was experienced in solidifying either material to the density required for use in a cryogenic-solid cooler.

The pressure-control problem for the cryogenic-solid cooler has been solved with the acquisition of the commercial pressure-control valve. This valve has been evaluated and found to operate satisfactorily.

The deliverable model cryogenic-solid cooler has been fabricated and assembled. The remaining period of the contract will be used to perform tests on this model.

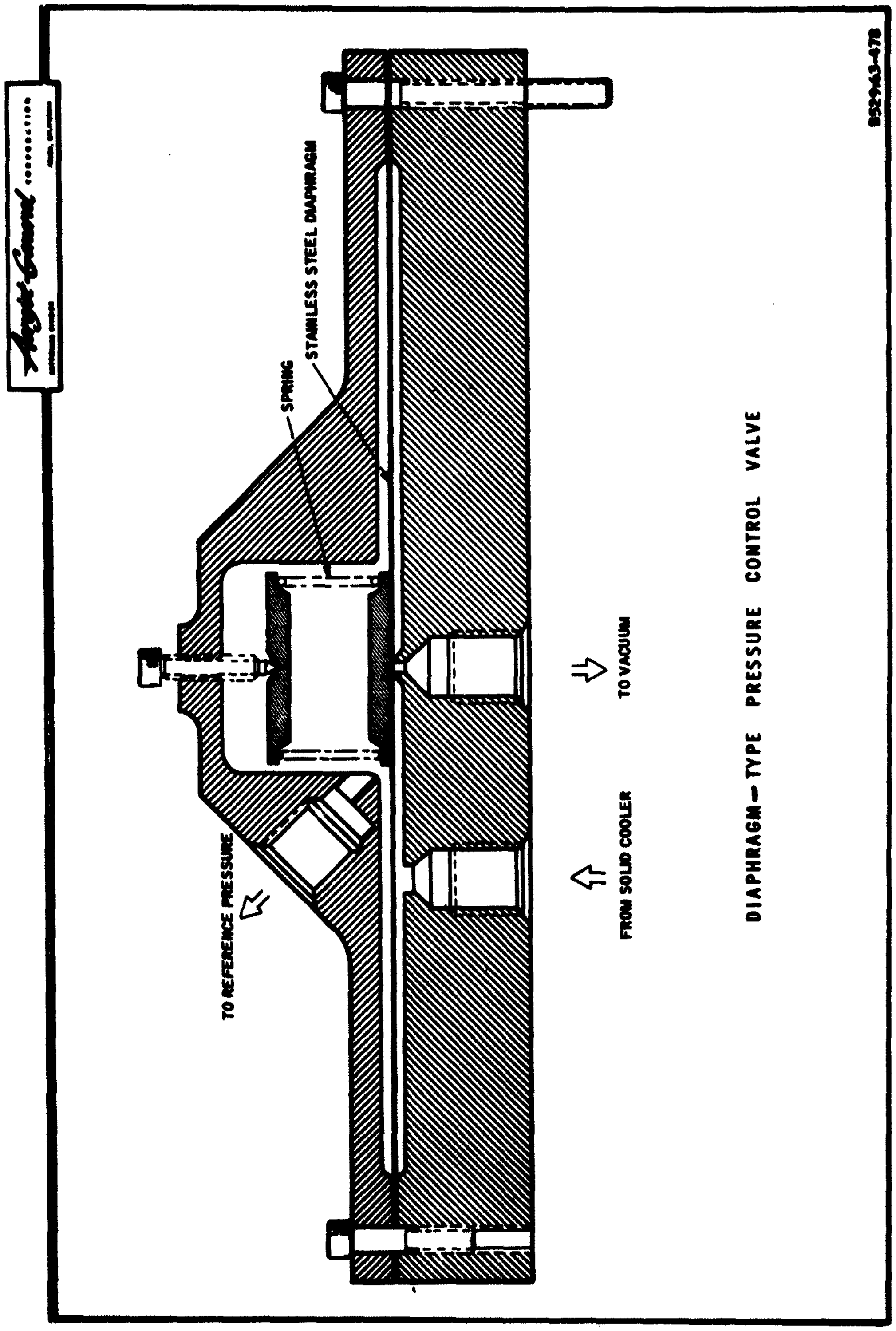
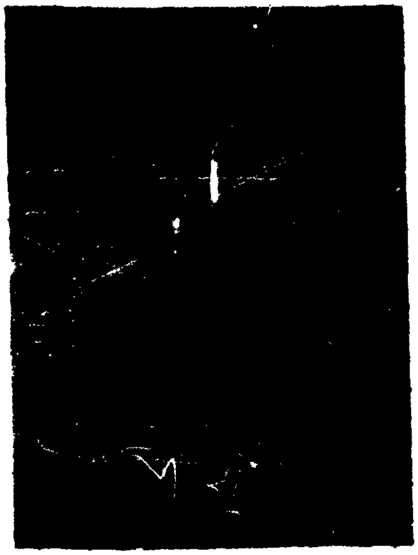

STAINLESS STEEL DIAPHRAGM
SPRING
TO REFERENCE PRESSURE
TO VACUUM
FROM SOLID COOLER
DIAPHRAGM—TYPE PRESSURE CONTROL VALVE

Figure 1



COOLANT INNER CONTAINER

FIGURE 2.

OUTER CONTAINER

FIGURE 3.

OUTER CONTAINER COVER

FIGURE 4.

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Figures 2, 3, and 4