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PRESSURIZATION OF LIQUID OXYGEN CONTAINERS

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ABSTRACT

During the period January 1, 1958, to February 15, 1958, approximately 300 man hours were spent on the project. The major effort involved the experimental work and calculations associated with measuring the actual amount of pressurizing gas required to discharge the liquid nitrogen from the tank. Several runs were made, and each time a number of factors were uncovered, which, if changed, would yield better results. The experimental results of the last run, which is the best run to date, have not yet been reduced, and will be reported in the next progress report. The results presented in this report are a sample of the results of the first tests, and are presented here to outline the general procedure being followed and to indicate some preliminary results.

In addition to this work, the doctoral thesis work of Mr. Herman Merte and Mr. Saul Fenster is being carried on. The equipment cost and operating expenses for this work are being met by this project, but both of these men have their financial support from fellowships. A summary of their progress is included in this report.

I. EXPERIMENTAL WORK AND PROCEDURE

Figure 1 shows a line diagram of the experimental equipment as it has been modified to measure the amount of pressurizing gas to discharge the liquid nitrogen from the tank.

The surge tank is first pressurized to 80 psig. This gas is then used for the initial pressurization (to 35 psig) of the liquid nitrogen tank. The amount of gas required for this initial pressurization is determined by measuring the initial and final pressure and temperature in the surge tank. After the initial pressurization of the liquid nitrogen tank, the quick-acting liquid discharge valve is opened and the liquid is discharged at a constant rate. The rate of discharge is measured by a propeller-type flow meter. The amount of pressurizing gas required during discharge is measured by the gas meter, which has been modified so that the rate of flow is recorded on the Sanborn. The rate of liquid discharge is also recorded on the Sanborn by means of the load cell. The pressure of the pressurizing gas is maintained constant at 35 psig by the pressure regulator.

The temperature of the pressurizing gas is varied by passing the gas through a heat exchanger, which may utilize either liquid nitrogen, solid carbon dioxide and alcohol, ambient air, or boiling water. The temperature of the pressurizing gas is recorded on the Sanborn. The temperatures at various points in the liquid nitrogen tank and in the tank wall are measured by thermocouples and recorded on a recording oscilloscope.

In the first runs it was found that a very precise correlation of the time-base for all the readings was necessary, and therefore an automatic timer has been added. It was also found necessary to conduct all runs on the same time schedule. For example, the amount of time between the initial pressurization and the opening of the discharge valve has been fixed at 20 sec. The discharge time of the liquid nitrogen has been fixed at 2 min. The tank is filled to approximately 100 lbm before discharge, and all results are adjusted to 100 lbm for purposes of comparison.

The check-off list for the Pre-test Check and Test Procedure are included in Tables I and II as supplementary information.

II. RESULTS

The results included in this report are only a sample of results from a preliminary test. Figure 2 shows some temperatures, pounds of pressurizing gas required, and pounds of nitrogen in the tank, all as a function of time. In this case the pressurizing gas was at ambient conditions. Figure 3 shows only the data during discharge (after 160 sec) for this same test. Consider the curve marked "Nitrogen in Tank" in Fig. 3. On this curve various thermocouples are marked: e.g., Tc-6, Tc-18, Tc-7, etc. These points indicate when the level of the liquid nitrogen is at the given thermocouple. Thus one notes the rapid increase in the temperature indicated by Tc-6 as soon as the liquid level drops below this thermocouple. The location of the various thermocouples is indicated in Fig. 2. One also notes that the wall temperatures, Tc-19 and Tc-18, for example, rise much more slowly after the liquid level drops below them. Figure 4 shows the rate of liquid discharge and the rate of pressurizing gas during discharge.

It should be emphasized that in this test (26B) the correlation of the time indicated by the various instruments was not very satisfactory, and this has been remedied on successive tests. It should also be noted that the period between the initial pressurization and beginning of discharge was much longer than is being utilized on later tests.

Table III shows the results of a number of these preliminary tests as regards the amount of gas required for the initial pressurization. Also indicated is the fraction of this initial pressurizing gas which condenses. It is quite evident that this varies with the period of time that the valve is left open before discharge. This has been standardized at 20 sec in the subsequent tests to study more effectively the influence of the variation of the temperature of the pressurizing gas.

III. FUTURE WORK

As indicated, some experimental work has been completed, and these data are in the process of being reduced. Additional experimental work will be performed as necessary.

Professor John Clark has taken over the direction of this project from February 1, 1958, to June 15, 1958, while Professor G. J. Van Wylen is on sabbatical leave.

IV. MR. HERMAN MERTE'S THESIS WORK, "A STUDY OF POOL BOILING IN AN ACCELERATING SYSTEM"

Following submission of the thesis proposal (December, 1957), five weeks have been utilized in making the necessary design calculations for the experimental apparatus. These calculations have resulted in the following, in part:

1. It is extremely difficult to obtain heat-transfer rates large enough to approach the peak heat flux necessary for water at 1 atmosphere with a flat plate heated indirectly by electric power. In order that the effect of acceleration may be studied over a wide range of boiling, two different heating surfaces will be used. A flat plate parallel to the liquid surface will be used as the heating surface in the nucleate boiling range. The influence of acceleration upon convection heat transfer may also be studied with this heating surface. A platinum wire will be used as the heating surface to study the peak and film boiling ranges.

2. It has been found that by using a radius arm of 15 in. from the heater surface to the center of rotation, the difference in slope between the liquid and heater surface is no more than 4° with the liquid depth of 3 in. under 10-g acceleration.

3. In order that the experimental runs be of adequate duration, it is necessary that the vapor be condensed. At high heat fluxes a water-cooled condenser is the only practical means of accomplishing this.

4. Consideration is being given to using pure silver as well as copper for the heating surface since it has both higher thermal conductivity and thermal diffusivity.

The design of the rotating vessel assembly has been completed, and it is expected that the design of the remainder of the apparatus will be completed within a week, after which detail drawings will be made.

Figure 5 is a reproduction of the sketch of the experimental apparatus submitted with the thesis proposal.

V. MR. SAUL FENSTER'S THESIS WORK, "AN INVESTIGATION OF THE THERMAL TRANSIENT RESPONSE OF A STEP PRESSURIZED BOILING LIQUID NITROGEN SYSTEM

To this date the boiloff and pressurization apparatus has been designed, and fabrication work has been assigned to Ronan and Kunzl Co., Marshall, Michi-

gan. The apparatus was designed to permit rapid pressurization to pressures up to 50 psi. Heat fluxes through the container walls will be controllable, and can reach values up to three times those achieved in previous tests where heat input was governed by the temperature of ambient air only. Thermocouples will measure temperatures at various points in the liquid nitrogen and the walls of the primary liquid container.

The apparatus was designed to permit accurate measurement of heat input and the increase of energy of the nitrogen. This was done by surrounding the primary liquid test container by an evacuated, electrically controlled, isothermal shield, which is in turn surrounded by a liquid nitrogen annular container. Control of heat input to primary container and isothermal shield will be accomplished using 230-volt variacs which have been obtained from the Mechanical Engineering Department.

The contemplated test program will permit tests to be conducted at varying levels of heat flux and varying degrees of pressurization.

Pressurization will be accomplished using gaseous nitrogen and possibly gaseous helium. At constant pre-determined values of heat flux, the transient thermal response to said pressurization will be studied as a function of initial pressure, final pressure, and heat flux. Gas flow leaving the primary container will be measured immediately after rapid pressurization and studied as a function of aforementioned variables.

The Ronan and Kunzl Co. was selected through bids on the basis of their experience in the manufacture of cryogenic liquid containers and the satisfactory results obtained in previous work for this project. The delivery date for this apparatus is approximately March 7.

TABLE I

PRE-TEST CHECK

1. Available liquid nitrogen
2. Available bottled gas
3. Pressurization
4. Thermocouple connections—ends soldered correctly, reference junctions OK, shorting on tank surface, response to ΔT
5. Available heat-exchanger materials
6. Electrical circuits loading
7. Electrical equipment—fuses, bulbs, motors
8. Time-synchronizing device
9. Gas-meter indicator device
10. Response and zeroing of galvanometers
11. Oscillograph recording
12. Electrical devices warmed up for at least 1/2 hour
13. Liquid level and temperature of heat exchanger
14. Paper in Sanborn and oscillograph
15. Full bottle of gas
16. Full Dewar of liquid N_2
17. Connection of load cell, thermocouples, pressure gage, remote indicators and timers
18. Calibration for weight, temperature, pressure on Sanborn
19. Indication of calibration voltages and deflections
20. Full baths for reference junctions

TABLE II

RAPID PRESSURIZATION AND DISCHARGE OF TANK
Test Procedure

1. Record temperature, barometric pressure, humidity in test cell.
2. Unless toxic fumes are present, turn off blower and shut cell doors.
3. Vent main tank.
4. Close vents of Dewar.
5. Pressurize Dewar (6 to 9 psig). See procedure No. 11.
6. Open values in line from Dewar to tank.
7. Fill tank to 100 lb (tank holds 108 lb).
8. Close quick-acting tank valve.
9. Vent Dewar.
10. Turn off pressure from N_2 bottle.
11. Pressurize surge tank to 70-80 psig (this may be done simultaneously with Nos. 5 to 9).
12. Close valve from surge tank to N_2 bottle.
13. Adjust recording devices for test speeds.
14. Synchronize with respect to time.
15. Read gas meter and mark quantity on Sanborn record.
16. With quick-acting tank valve shut, set tank regulating valve.
17. Open all inlet valves to tank except tank inlet solenoid.
18. Bypass gas meter.
19. Turn lever on panel to tank regulation.
20. Open valve to pressure regulator.
21. Close hand main tank vent, leaving solenoid valve open.
22. Record surge tank pressure.

TABLE II (Concluded)

23. Simultaneously close solenoid tank vent and open tank inlet solenoid valve.

24. Close tank inlet solenoid valve when tank pressure is 35 psig.

25. Record surge tank pressure.

26. Open pressure line to surge tank.

27. Check for open Dewar vent.

28. Adjust valves for flow through gas meter.

29. Open quick-acting tank valve.

30. Regulate outlet flow for proper cps on electronic counter using tank outlet gate valve.

31. If necessary, increase pressure in surge tank by regulating valve on N_2 bottle—this will be necessary when tank pressure drops appreciably below 35 psig.

32. Turn off quick-acting tank valve when flow-meter indication suddenly triples.

33. Turn off pressure from N_2 bottle.

34. Vent tank.

35. Turn off oscillogrph.

36. Record oscillograph number.

37. Write oscillograph number, run number, heat-exchanger material, pressurization used, attenuations, on Sanborn graph.

The following should be recorded in data book:

Date
Time
Ambient temperature, pressure, humidity
Pressurizing gas used
Heat-exchanger material
Initial gas-meter reading
Surge tank pressure before pressurization
Surge tank pressure after pressurization
Run number
Oscillograph number
Flow-meter readings

TABLE III

AMOUNT OF GAS REQUIRED FOR INITIAL PRESSURIZATION AND FRACTION CONDENSED
Test 26B

Run No.	Mass of Gas Transfer, lbm	Time Inlet Valve Open Before Discharge, sec	Heater Medium	Weight of N_2 Tank, lbm	Amount Cond., lbm	Amount Cond. per 100/lbm Liquid N_2	% Condensed
26-B	0.281	80	Ambient	103.0	0.134	0.138	49.0
26-C	0.287	94	Ambient	103.6	0.152	0.157	52.9
26-D	0.291	116	Ambient	107.0	0.151	0.161	51.8
27-B	0.280	23	Ambient	100.25	0.084	0.084	30
27-D	0.279	50	Ambient	96.7	---	---	--
27-E	0.408	74	CO_2 and Alcohol	99.5	0.206	0.205	50.3
27-F	0.363	39	CO_2 and Alcohol	99.0	0.153	0.152	42.1
27-G	0.387	55	Hot Water	95.0	0.167	0.158	43.2
27-H	0.340	53	Hot Water	99	0.158	0.157	46.5
27-J	0.350	65	Hot Water	99	0.167	0.165	47.7
27-K*	0.047	55	Ambient	98.5	---	---	--

*Run 27-K was pressurized with gaseous helium.

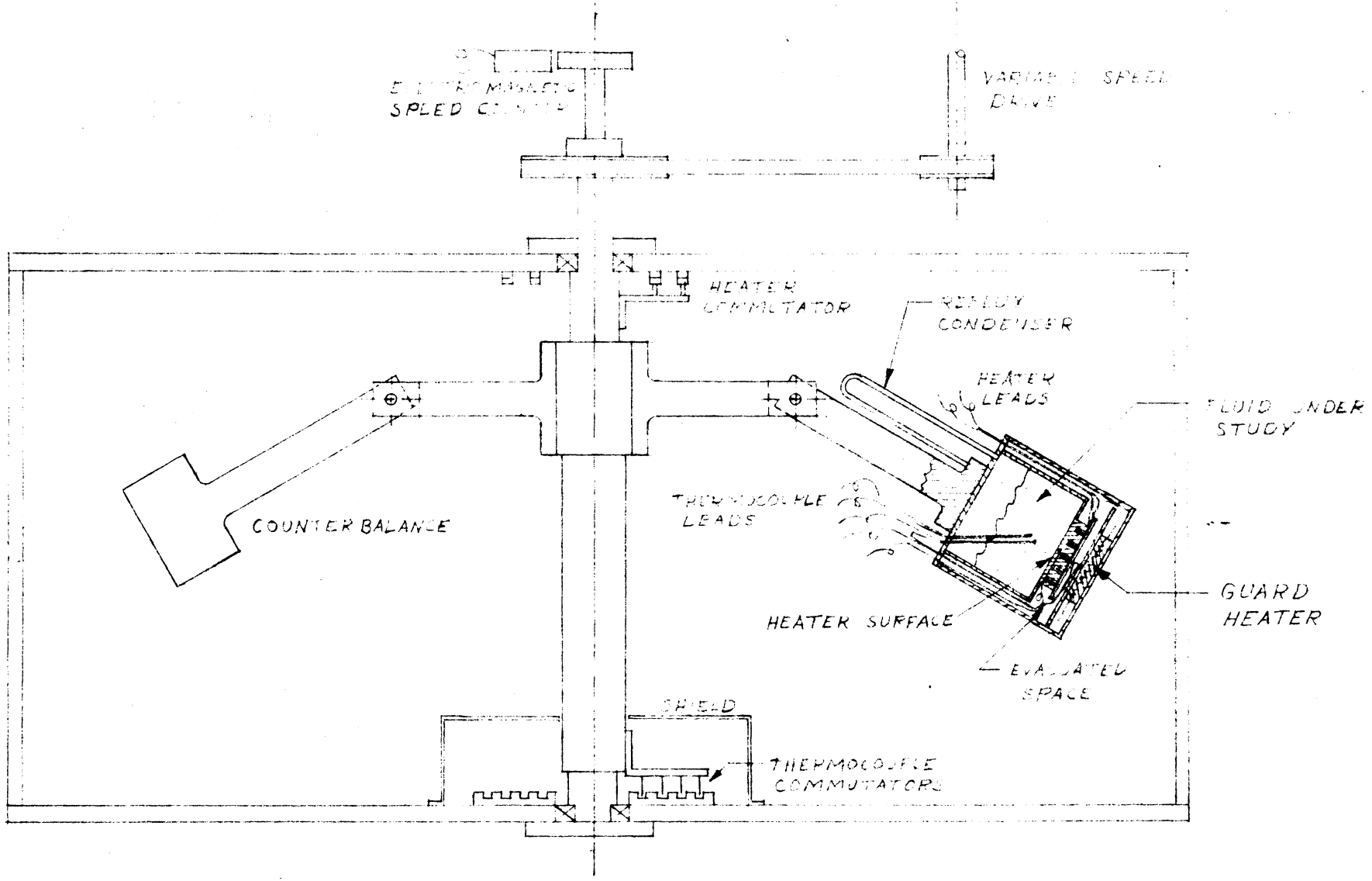

FIGURE 5

SKETCH OF EXPERIMENTAL APPARATUS FOR DETERMINING THE EFFECT OF ACCELERATION UPON BOILING HEAT TRANSFER.