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COLLEGE OF ENGINEERING
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PRESSURIZED DISCHARGE OF LIQUID NITROGEN FROM AN UNINSULATED TANK

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INTRODUCTION

Work has recently been completed on the discharge of liquid nitrogen from an uninsulated tank which is subjected to heating from the atmosphere. The objective of this investigation was to determine how various factors influence the mass of gas in the tank when the discharge process has been completed, and to determine how this amount of residual gas can be reduced to a minimum. This paper deals with two aspects of the investigation, namely, a study of temperature transients and boiloff rate without discharge, and secondly, the influence of the temperature of the pressurizing gas on the mass of gas in the tank when discharge is completed.

DESCRIPTION OF EQUIPMENT

Figure 1 shows a schematic layout of the equipment used in this investigation. The tank (1 foot in diameter, 3 feet long with 1/8-inch sidewalls) from which the liquid nitrogen was discharged was made of 5052 aluminum. Wall temperatures were measured longitudinally at five points with thermocouples which were peened into the tank wall and with 15 thermocouples suspended from a rack inside the tank. The latter were used to indicate temperatures inside the tank. A 50-channel Consolidated Engineering recording galvanometer was used to record these temperatures.

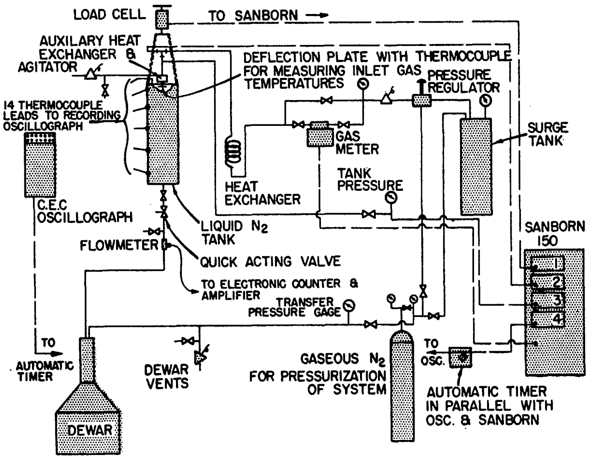

Fig. 1. Schematic arrangement of apparatus.

The amount of pressurizing gas used was measured in two ways. The first method utilized the surge tank, which was initially charged with the pressurizing gas. The amount of pressurizing gas used was determined from initial and final pressure readings and temperature measurements in the surge tank. A positive displacement gas meter was utilized in the second method. In practice the mass of gas required for initial pressurization was determined from the surge tank and the amount of gas required during discharge was measured by the gas meter. A pressure regulator was installed to maintain constant pressure in the tank. In all the tests reported in this paper, the liquid nitrogen was pressurized to 35 psig.

The investigation involved variation of the inlet temperature of the pressurization gas. The temperature of the pressurizing gas was varied by passing it through a heat exchanger, which, for different tests, contained boiling water, water at atmospheric temperature, methyl alcohol and dry ice, and liquid nitrogen. Considerable heat transfer to the pressurizing gas took place as it flowed from the heat exchanger to the tank, causing variations in inlet gas temperature. This was rectified by installing a small auxiliary heat exchanger containing the same fluid as the main heat exchanger at the inlet of the tank. Equilibrium temperature conditions, prior to testing, were established by bleeding pressurized gas through the lines. Once steady-state conditions were achieved, the temperature of the inlet gas was measured and recorded.

A strain-gage load cell was used to measure the mass in the tank. This with the gas-meter reading was recorded on a Sanborn 4-channel recorder. The rate of discharge was measured by a Waugh propeller-type flowmeter in conjunction with an Ellis amplifier and a Hewlett-Packard electronic counter. The primary function of this instrument was to enable an operator to manually control the liquid discharge rate at a predetermined rate. The discharge time for all the tests reported in this paper was two minutes.

TEMPERATURE TRANSIENTS AND BOILOFF RATE WITHOUT DISCHARGE

One series of tests involved pressurization without discharge. In these tests liquid nitrogen, which was boiling at atmospheric pressure in the uninsulated tank, was rapidly pressurized to 35 psig with 300°K nitrogen. Immediately after pressurization, data were taken on one wall thermocouple, which was well below the liquid surface, one liquid temperature, also well below the liquid surface and the boiloff rate. Figure 2 shows the results of one such run. The inside heat-transfer coefficient in the liquid and the fraction of total heat transfer which was transferred to the liquid were calculated, and these are also shown in Fig. 2.

There are several interesting things to note from these data:

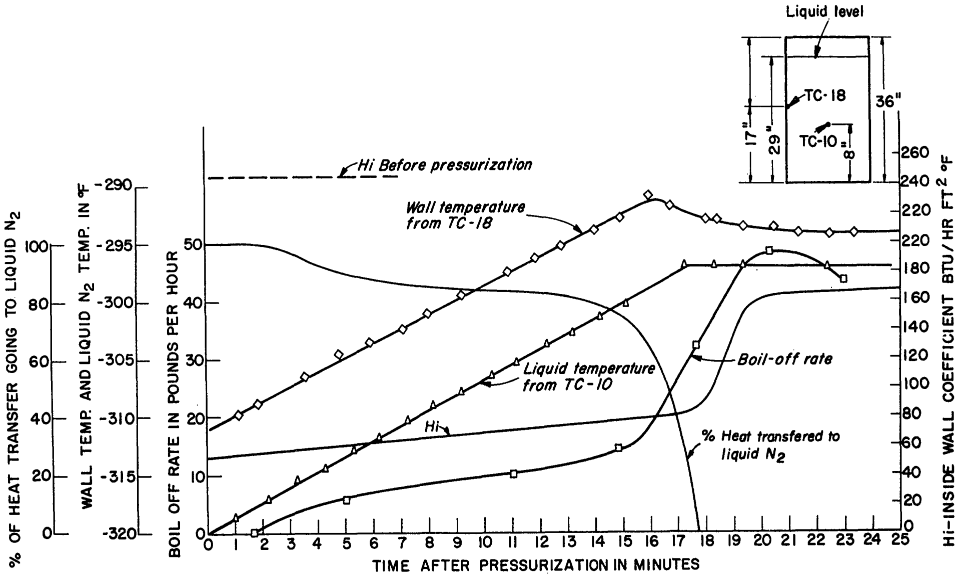

Fig. 2. Pressurization without discharge.

(1) Boiloff ceases immediately after pressurization, but after approximately two minutes boiloff is re-initiated. The rate of boiloff increases steadily until the 16-minute point is reached. After this the boiloff rate increases very rapidly. It should be noted that boiloff begins well before the wall temperature reaches the new saturation temperature. It appears that this boiloff is the result of heat transfer from the wall to the liquid near the liquid surface. From other data we have found that the wall temperature above the liquid is significantly higher than the wall temperature below the liquid surface. Thus there will be both longitudinal and radial heat flow in the wall at the liquid surface.

(2) The peak in the wall-temperature curve at the 16-minute point is particularly interesting. This occurs at the same time that there is a rapid increase in the boiloff rate, and just prior to the time that the liquid reaches the new saturation temperature. A reasonable explanation for this appears to be that a considerable amount of superheat is necessary to cause boiling when a quiescent liquid is heated above its new saturation temperature. Once boiling is initiated, there is considerable agitation at the surface and much less superheat is necessary to maintain boiling. Thus it is evident that at the 16-minute point the large temperature difference between the wall and the liquid causes boiling to be rapidly initiated throughout the entire tank. As soon as this takes place, the wall temperature drops because less temperature difference is then necessary to maintain boiling.

(3) During the period between the initial pressurization and the time the wall reaches the new saturation temperature, about 85% of the heat transferred across the wall is used to raise the temperature of the liquid.

(4) The average inside heat-transfer coefficient in the liquid varies significantly with the amount of boiling. During the first 16 minutes, when boiling takes place only at the wall near the surface of the liquid, the inside coefficient is about 70 Btu/ft^2 hr °F, whereas with steady-state boiling at the new saturation temperature, the inside coefficient has a value of about 160 Btu/ft^2 hr °F. This compares to a calculated value based on the relation*

$$\frac{h_c L}{k_f} = 0.13\left[\left(\frac{L^3 \rho_f^3\, g\beta\, \Delta t}{\mu_f^2}\right)\left(\frac{C_p \mu}{k}\right)_f\right]^{1/3} \qquad (1)$$

of 99 Btu/ft^2 hr °F. This relation applies to natural convection without boiling.

(5) The period of time to reach the new saturation temperature in this case was about 17 minutes. This, of course, depends on the size of the apparatus and the ambient conditions. It was evident, however, that in our case the discharge process, which was of two minutes duration, was completed well before the new equilibrium temperature was reached.

PRESSURIZING-GAS-TEMPERATURE INFLUENCE ON RESIDUAL GAS MASS

A series of experiments was conducted to determine the influence of the pressurizing-gas temperature on the mass of gas in the tank when the discharge of liquid has been completed. The inlet gas temperature was varied by using different cooling media in the heat exchangers shown in Fig. 1. The mass of residual gas was calculated utilizing the measured temperatures throughout the tank. These temperatures were measured with thermocouples and recorded with the Consolidated Engineering recording galvanometer. The inlet gas temperature, inlet gas volume rate, and tank pressure were recorded on the Sanborn recorder. The mass of gas in the tank at the end of the discharge process was calculated by graphical integration, using the recorded temperature and pressure at the moment the discharge process was completed.

In one series of tests, nitrogen was used for the pressurizing gas. Curve A-A of Fig. 3 shows the mass of nitrogen gas in the tank as a function of the pressurizing-gas temperature. The mass of residual gas can be decreased by 20% by increasing the pressurizing-gas temperature from 160°R to 570°R.

A second series of tests was made using helium as the pressurizing gas; these results are indicated by curve B-B in Fig. 3. In this case the ordinate

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*W. H. McAdams, Heat Transmission, 3rd Ed., McGraw-Hill Book Co., Inc., New York, 1954.

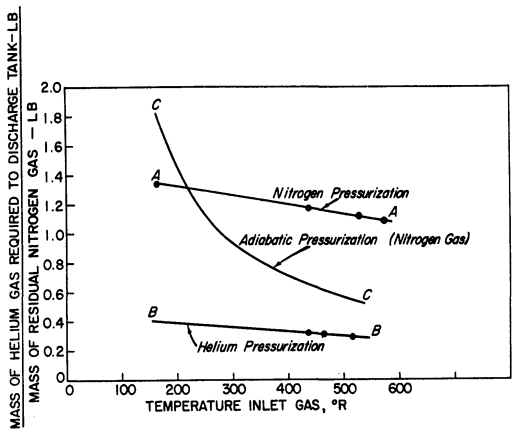

Fig. 3. Influence of pressurizing-gas temperature on the mass of residual gas.

indicates the amount of helium used in the discharge process rather than the residual gas mass (because an analysis of the residual gas was not made).

Curve C-C of Fig. 3 is a theoretical curve and indicates the residual gas mass as a function of temperature, assuming no heat transfer to or from the gas during the discharge process. From a comparison of curves A-A and C-C, one concludes that at high inlet gas temperatures there is a significant cooling of the gas during the discharge process, whereas at the lowest temperatures there is a significant heating of the pressurizing gas. This is no doubt due to heat transfer from the walls to the gas. This indicates that the heat transfer from the wall to the gas significantly influences the residual gas mass.

A few additional remarks may be made regarding the temperature measurements in the tank. Figure 4 shows some of the original records from the Consolidated Engineering recording galvanometer and the Sanborn recorder. As the liquid level passes a given thermocouple, the indicated temperature rises rapidly to the new saturation temperature and then indicates a constant temperature for a considerable period of time. It appears that this phenomenon is due to a drop of liquid that clings to the thermocouple as the level passes the thermocouple and evaporates at the new saturation temperature. When the drop has completely evaporated, the thermocouple indicates a temperature associated with the gas surrounding the thermocouple.

It is also interesting to note that the wall-temperature increases significantly during the discharge period and that there is a considerable temperature gradient in the wall at the time the discharge process is completed.

Analytical work is in progress on a wall-temperature-transient analysis, gas space and ambient heat-transfer coefficients, and liquid-gas interfacial condensation. These results will be reported later.

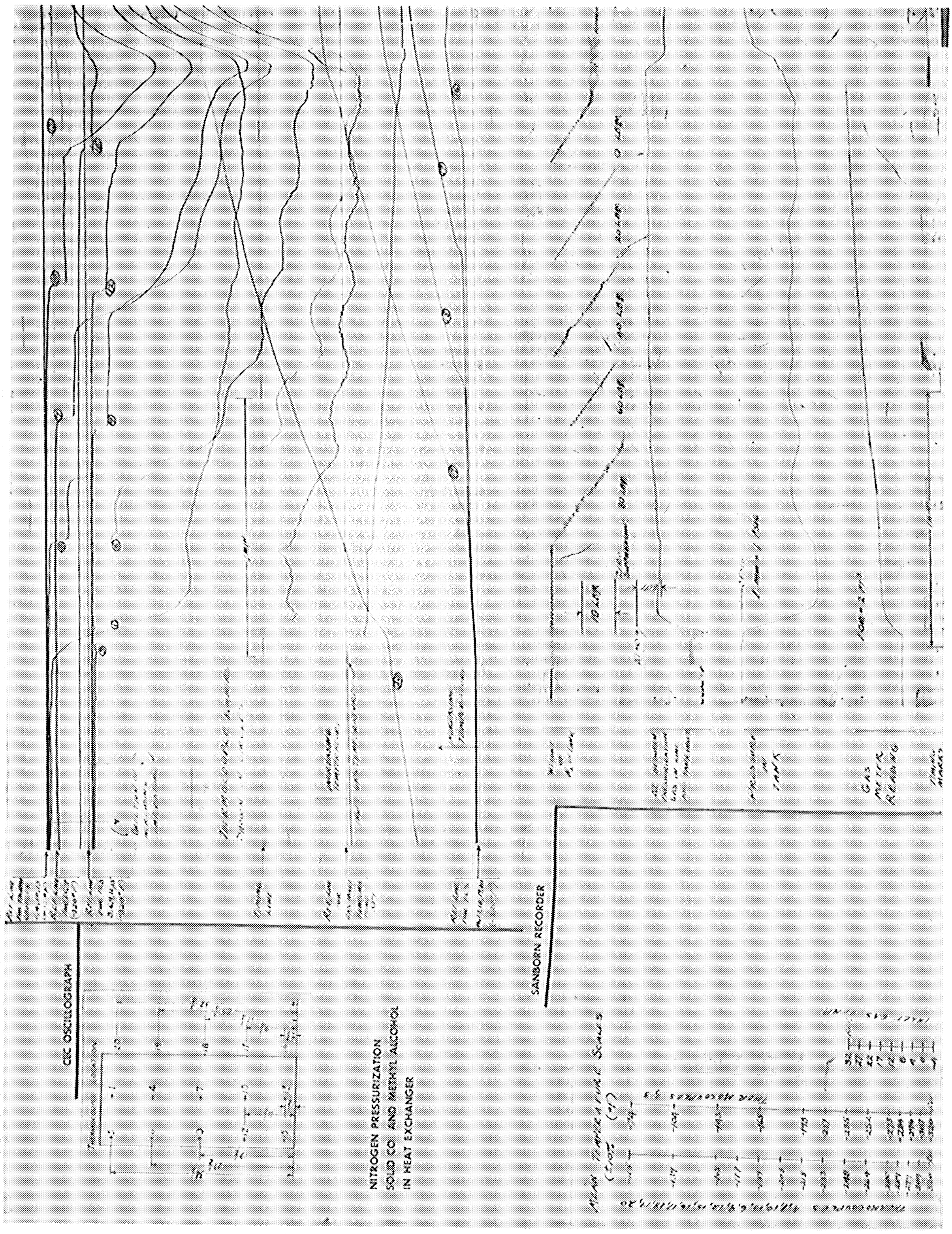

Fig. 4. Original data for pressurized discharge.

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