LIQUID TO GAS LEAK RATIOS WITH LIQUID NITROGEN AND LIQUID HELIUM

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ABSTRACT

To predict the leak rates of liquid helium and liquid nitrogen containers at operating conditions we need to know how small leaks (10^{-8} to 10^{-5} atm-cm³ air/s), measured at standard conditions, behave when flooded with these cryogens. Two small leaks were measured at ambient conditions (~ 750 Torr and 295 K), at the normal boiling points of LN₂ and LHe, and at elevated pressures above the liquids. The ratios of the leak rates of the liquids at ambient pressure to the gases (G) at ambient pressure and room temperature were:

GN ₂	LN ₂	GHe	LHe
1	18	1	172

The leak rate ratio of LN₂ at elevated pressure was linear with pressure. The leak rate ratio of LHe at elevated pressure was also linear with pressure.

INTRODUCTION

There are 42 LHe cooled, superconducting magnets in the Magnetic Fusion Test Facility-B (MFTF-B) under construction at Lawrence Livermore National Laboratory (LLNL). The magnets, along with the supply piping system and liquid helium cooled cryopumping panels, comprise a surface area of about 2200 m². Also, since all of this liquid helium cooled surface must be shielded against thermal radiation there are about 4000 m² of liquid nitrogen cooled surfaces all of which is contained in the 4 x 10⁶ liter volume of the MFTF-B vacuum chamber.

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The volumes containing the liquid cryogens must be leak hunted at or near standard conditions and the integrated leak later measured under similar conditions. To meet the allowable leak rates specified for operating conditions requires that the leak rate ratios of the two cryogens (LHe and LN₂) at standard conditions and at their normal boiling points be known within reasonable limits.

Workers in cryogenics and high vacuum have long been aware of what are commonly referred to as "cold leaks." (The system appears vacuum tight at room temperature but leaks profusely when filled with LN₂ or LHe.) An investigation of the behavior of small leaks at liquid helium temperature was recently reported by Sinharoy and Lange. They made two leaks, both having leak rates on the order of 10^{-7} atm-cm³/s (air) one with a short L/R ratio and one very long. Both leaks showed a significant increase in leak rate when in contact with LHe at 4.2 K. In this paper, since we needed data on both LN₂ and LHe, we repeat the investigation with both cryogens, a larger leak and somewhat different experimental procedure.

EXPERIMENTAL LEAK GEOMETRY

Leak #1 was made by drilling a 0.015 in. (381 μ m) hole in a 0.5 in. o.d. x 0.65 in. wall stainless steel weld cap. The hole was then peened until it indicated a stable leak rate of 2.4×10^{-6} atm-cm³/s air equivalent as measured with a calibrated helium mass spectrometer leak detector. The approximate geometry of the leak is shown in Fig. 1. Leak #2, made in the same way in the side of the 11 liter test volume, had a leak rate of 6.9×10^{-6} atm-cm³/s. With the system configured as shown in Fig. 2 we first measured the background gas load. This was done by evacuating the 11 liter test volume to about 10^{-3} Torr and with the 1200 liter vessel pumped

to its base pressure ($\sim 5 \times 10^{-8}$ Torr). The turbomolecular pump was isolated and the rate of rise recorded on a strip chart. Next the 11 liter volume was filled with the test gas (N_2 or He) at ambient conditions and the rate of rise recorded. The final step was to fill the 11 liter volume with the test liquid (LN_2 or LHe) and the rate of rise measured at ambient pressure over the liquid and elevated pressure up to 60 psig. Knowing the volume of the vacuum chamber and rates of rise determined the background gas load and leak rate of the test leak under the various test conditions. A number of measurements (3 to 5) were made at each test condition and the leak was remeasured at ambient conditions after each set of tests.

Fig. 1. The geometry of the two leak used in the test.

Fig. 2. The experimental setup used for the leak measurement.

RESULTS

Three runs were made with nitrogen and one run was made with helium on leak #1. All the data were normalized to the leak rate of the test gas at ambient conditions. Figure 3 shows the results for nitrogen. In run #1 the leak ratio for LN_2 at ambient pressure was 18 and that ratio, on the average, increased at a rate of 1.38 greater than the pressure above the liquid. The leak ratio for LN_2 at ambient pressure in run #2 was 4 and 12. Between the 4 and 12 readings the 1/2-in. tube cap containing the leak was agitated with a long 3/16 o.d. thin, stainless tube. The tube was inserted through the LN_2 fill line and into the one-half o.d. tube at the bottom of the 11 liter test chamber (full of LN_2) and bounced on the tube cap. Between run #2 and #3 the 11 liter chamber was removed from the system and the leak rate of 2.4×10^{-6} atm-cm³ air/s re-verified. Run #3 gave an LN_2 ambient pressure leak ratio of 14.

Fig. 3. Nitrogen ratio versus pressure leak.

The one run made with helium was on leak #1. Figure 4 shows the results for helium. The leak ratio of liquid helium at ambient pressure to gaseous helium at ambient pressure and temperature was 172:1. The leak rate ratio of liquid helium increased directly with the pressure above the liquid.

Leak #2 was made to reduce the probability of contamination from our LN_2 supply line. Figure 3 shows the results of a run on leak #2. The leak ratio of LN_2 at ambient pressure to N_2 gas at ambient pressure and temperature was 15.5.

Fig. 4. Helium leak ratio versus pressure.

However, the leak ratio increased at a rate of twice the pressure above the liquid.

DISCUSSION AND CONCLUSIONS

It is clear from these measurements, and those made by Lange, that the leak rates for liquid cryogens is significantly greater than

that measured at standard conditions. The increased rate measured for LHe falls between the limits one would predict from the changes in temperature, viscosity, and density for fully developed molecular or viscous flow. Further, liquid helium leak rates increased directly with pressure which tends to imply single phase, viscous flow. Fully developed molecular flow would predict a leak ratio of about 90:1 while viscous flow would give about 4000:1. We measure 172.

The liquid nitrogen measurements fall below what one would predict for either molecular or viscous or any combination of flow. We would predict a ratio of $\sim 360:1$ for molecular flow and about 74 for viscous flow. We measured as high as 18:1. Also, the leak ratios increase up to twice the rate as the pressure above the liquid. Since we believe leak #2 eliminated the plugging possibility from the LN₂ fill line, no explanation can be offered for the behavior of LN₂ under these conditions. Changes in the liquid to gas phase ratios due to pressure may play a part.

REFERENCES

1. S. SINHAROY and W. J. LANGE, Journal of Vacuum Science and Technology 20, 4 (April 1982).