T H E   U N I V E R S I T Y   O F   M I C H I G A N

COLLEGE OF ENGINEERING
Department of Mechanical Engineering
The Heat Transfer and Thermodynamics Laboratory

Progress Report No. 14

PRESSURIZATION OF LIQUID OXYGEN CONTAINERS

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UMRI Project 2646

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EXPERIMENTAL DATA AND APPARATUS

During this period, the experimental work has been directed toward obtaining sufficiently accurate measurements of the pressurizing discharge process so that data can be collected on the amount of residual gas mass remaining in the tank following discharge. These runs all have been carried out with the 2-in.-thick styrofoam piston floating on the liquid nitrogen and separating it from the pressurizing gas. Previous data of this kind (see Progress Report No. 9) have been taken without the insulating piston in the system and with the pressurizing gas in direct contact with the liquid. Thus the runs being reported in this report may be compared with those previous runs to find the influence of the styrofoam interface on the quantity of residual gas remaining in the tank. The differences between these two sets of runs for equivalent final conditions can be attributed to the difference in the interaction between the gas and the interface. This comparison is found in Fig. 1 of this report. Upon reducing the data, it was found that considerable variation in the final gas pressure existed between the runs. Such a variation was not observed in the previous pressurized discharge runs without the separating piston. It is not known exactly why this should occur with these present runs but the phenomena are being studied further. It is possible that, in view of the increased surface area exposed to the pressurizing gas through the nature of the geometry of the piston and its surface texture, this could influence the system in the way observed.

In any event, for equivalent final conditions, both with and without the insulating piston, there appears to be no important difference in the quantity of residual gas for direct contact pressurized discharge systems and those with an insulating type of interface. What differences were observed, as shown in Fig. 1, appear to have occurred at the lower inlet temperature where those runs with the insulated piston appear to give a somewhat reduced mass of residual gas. On the other hand, temperatures in excess of approximately -40°F, the insulating piston appears to give somewhat increased mass of residual gas, although the difference in the effects is small.

More study will be given to the transient heat conduction effects between the pressurizing gas and the styrofoam piston for condensation on the piston. A preliminary study has indicated the surprising fact that the thermal diffusivity, which essentially controls the transient thermal processes in the piston, is approximately the same as that of the liquid nitrogen. The values of the thermal properties for styrofoam will be given a second check to improve their values, since the ones used were taken from the commercial literature of the Dow Chemical Company. The equivalence of the thermal diffusivities between these two materials indicates an equivalence in the transient temperature pattern within both the styrofoam and the liquid nitrogen for the condensing-type boundary conditions, which is assumed to exist. The principal thermal difference between these two materials, it seems is the difference in the enthalpy rise of each of the materials at any given time. This, in spite of equal thermal diffusivities, could be different since it is primarily a function of the volumetric heat capacities and this quantity is considerably different between liquid nitrogen and styrofoam.

In a transient system, such as this one, it may be necessary to re-define what is considered an insulating material during the discharge process. It appears that the simple criterion of the thermal conductivity is insufficient and that some cognizance must be made of the volumetric heat capacity as well. This is indicated on the analysis of the quantity of condensed gas at the gaseious liquid interface, as shown in Progress Report No. 9, page 12, Eq. (28). More study will be deovted to this problem.

During the experimental runs mentioned above, measurements also have been taken of liquid and gas temperatures, wall temperatures, and liquid level. The liquid level measurements have been made in two ways: one with the floating piston through the voltage divider network, previously reported, and the other using the load cell. In general, a difference was found between these two independent types of measurements, although in some runs they indicated exactly the same. From the measurements obtained, greater confidence is placed on the data from the floating piston than on those from the load cell. Since the load cell measures net vertical force on the tank and system, it is felt that a component of this force is made up of an effect from elastic moments placed on the system owing to temperature changes in the connecting lines. This effect is very difficult to correct for, owing to its variability. Fortunately, however, the piston makes this correction unnecessary. The liquid level data and wall thermocouple measurements, both as a function of discharge time in seconds, are shown in Fig. 2.

WORK DURING THE NEXT PERIOD

During the next period, analysis of the pressurized discharge runs with the floating insulating piston will be completed. In addition, the design studies will be started on a new system, the principal purpose of which will be to make measurements of the volume of vapor and quantity of liquid present in a closed tank undergoing bulk boiling. This apparatus will exploit the use of the floating piston to make liquid and liquid vapor level measurements. It is anticipated that it will be necessary to conduct certain pilot studies on the proper design of the floating piston, before the construction of new research apparatus, in order that under conditions of boiling the piston truly represents the level of the two-phase system. This will require careful piston design which will enable it to float on the boiling fluid surface and still permit the venting of the vapor through holes properly placed in the piston.

CONTRACTUAL EXTENSIONS OF CURRENT RESEARCH PROGRAM

During this period, negotiations have been completed with the contracting agency to extend the research work currently being undertaken by this Laboratory. The scope of work is to include, in addition to the work previously assigned, the following:

1. The effect of vehicle acceleration on a boiling process, including maximum heat flux and surface orientation.

2. Transient free convection to a liquid both constant and varying level, in a closed container.

3. Vapor volume measurement from a boiling liquid in a closed container as a function of surface heat flux.

4. The dynamics of vapor-bubble collapse in a pressurized liquid.

5. Optimization of vapor pressuriation requirements.

PERSONNEL CHANGES DURING THE PAST PERIOD

During the past research period, there have been certain changes in project personnel. Mr. Hannes B. Kristinsson, who had assisted in the experimental program, left the project to accept a graduate fellowship in the Department of Chemical and Metallurgical Engineering. This fellowship will allow him to devote his full-time efforts to his Ph.D. thesis research. Dr. Saul K. Fenster completed his Ph.D. thesis research on this project and has left the University to take a job with industry.

H. MERTE'S THESIS

"A Study of Pool Boiling in an Accelerating System"

CURRENT STATUS OF THE WORK

Subsequent to the failure of the heating element in the flat plate heater, two rewirings were necessary before an operational unit was obtained. It was found that the failures occurred where the heater ribbon emerged from a slot and made two 90° bends before entering the adjacent slot. The mica insulation is on the order of .002 in. in thickness, and in making a sharp bend some of the laminations were broken. The higher temperature of the ribbon at these bends, due to the external face being in effect an adiabatic surface, caused the mica to break down completely. With the heater block at ground potential, the large surge of current melted the ribbon. In the present heater, the temperature of the ribbon at the corners was reduced by installing current shunts of gold foil .001 in. thick.

Tests are presently being made at $q/A \cong 25{,}000$ Btu/hr-ft^2. Thermocouples encased in stainless-steel tubing have been installed to measure the temperature of the water. Also, at this low flux rate, it has been found necessary to reduce the flow of cooling water considerably in order to prevent subcooling of the water at the higher accelerations. It appears that the rate of heat transfer between the surface of the water and the cooling coils located about 2 in. above is greatly increased by the acceleration. To keep the cooling coils filled with water at the reduced flow rate, a metering orifice was installed at the discharge end and calibrated.

WORK DURING THE NEXT PERIOD

Upon completion of the series of tests at the flux of $q/A = 25{,}000$ Btu/hr-ft^2, the data will be reduced and reported. Tests will continue at other flux rates.

S. FENSTER'S THESIS

During this period, the Ph.D. thesis entitled "The Transient Thermal Response of a Step Pressurized Boiling Liquid Nitrogen System" by Dr. Saul K. Fenster has been completed and submitted to the sponsoring agency for review and approval. As reviewed from the standpoint of national security and proper recognition of the Army Ballistic Missile Agency, the thesis was found acceptable in all respects. This thesis has been recast with the same title and is being issued as Technical Report No. 1. Copies have been mailed to the sponsoring agency. This research work is being continued under the provisions of the contract extension. At the moment, efforts are being made to find a qualified person to work on this aspect of the program.

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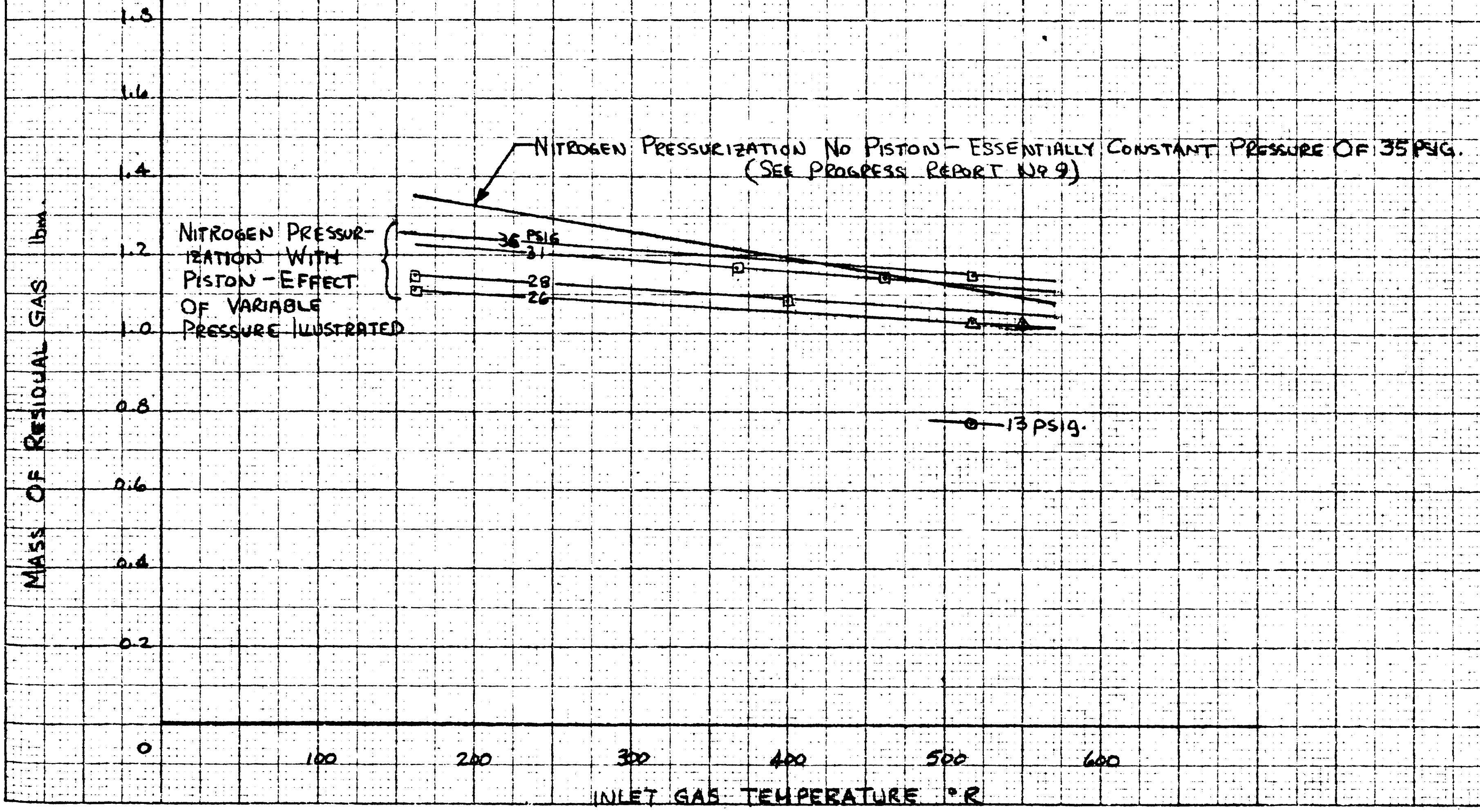
MASS OF RESIDUAL GAS
VS.
INLET GAS TEMPERATURE

FIG. 1



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Liquid Level Vs. Time

Wall Temperatures Vs. Time

Run 43B

Inlet Gas Temperature -298°F.

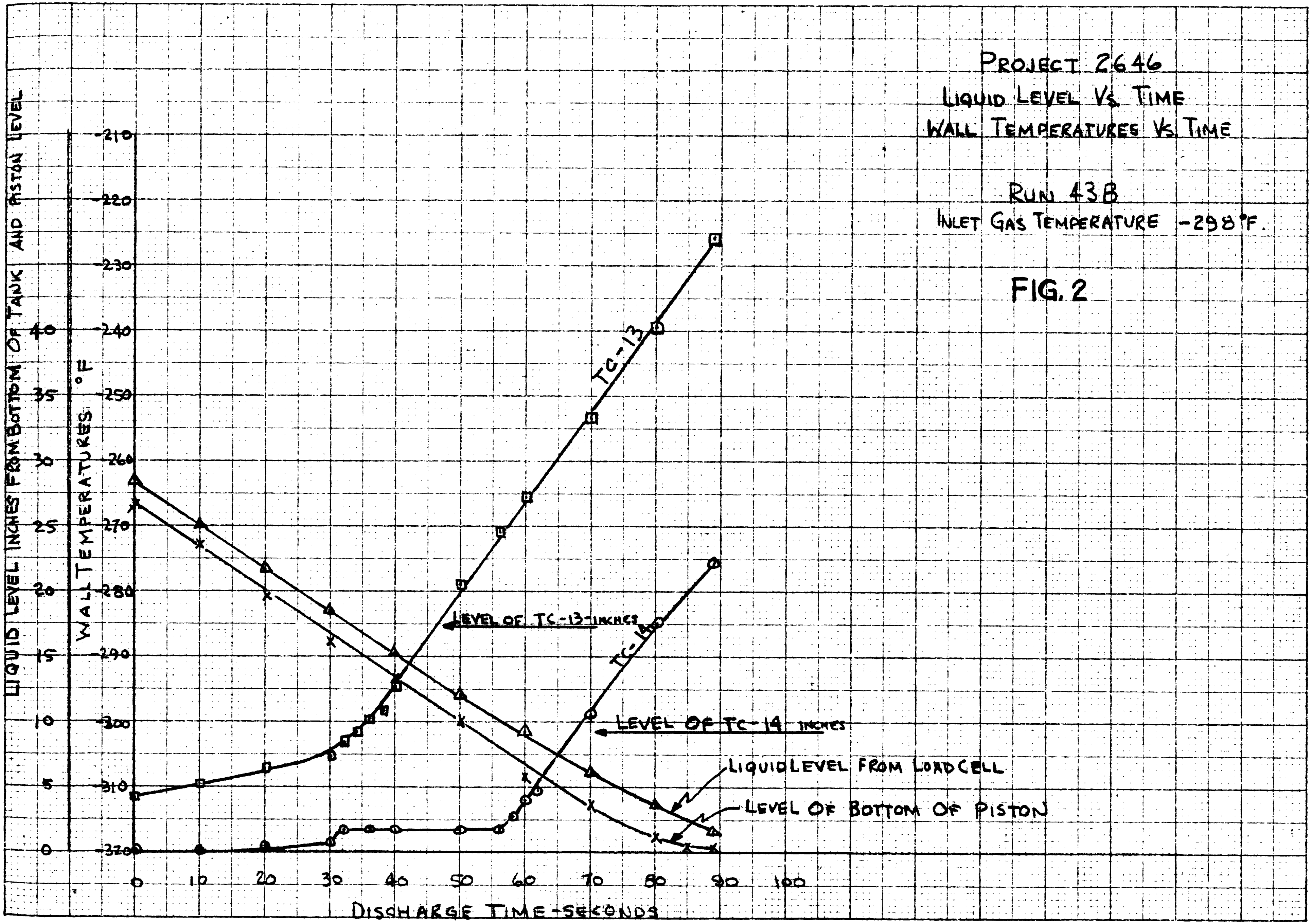

FIG. 2