ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
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Progress Report No. 8

PRESSURIZATION OF LIQUID OXYGEN CONTAINERS

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ERI Project 2646

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ABSTRACT

During the period February 15, 1958, to April 1, 1958, approximately 460 payroll man-hours and 560 nonpayroll man-hours were spent on the project. The principal effort was directed towards modifying the system to insure a constant and known inlet condition in the pressurizing gas and the collection of data for pressurizing discharge runs. The modifications made and the results obtained are discussed herein.

In addition, Ph.D. thesis work of Mr. Herman Merte and Mr. Saul K. Fenster continued on a full-time basis.

At the close of this period Mr. Phillip L. Jackson left the project for a new job.

MODIFICATIONS IN APPARATUS

It was observed that the inlet-gas temperature was not being established at the desired level by the heat exchanger. This was caused by heat transfer between the inlet gas and the inlet line attached to the tank and heat-capacity effects in the gas line from the heat exchanger to the tank.

This effect was considerably increased when two 90° elbows were added to the pressurizing gas line inside the tank better to simulate actual missile pressurizing conditions.

Two effects were noted in this sytem: first, the maximum attainable temperature of the inlet gas was too low to determine adequately the influence of the temperature of the pressurizing gas on gas residue; and second, the transient character of the inlet-gas temperature prevented analysis of the residual effects at any particular pressurizing gas temperature.

Curve B of Fig. 1 shows the difference in temperature between the gas at the heat-exchanger exit line and at the inlet to the pressurizing tank prior to modifications discussed below.

To eliminate this effect, the revisions shown on Fig. 2 were introduced. These revisions are listed in Appendix I.

Three thermocouples were added to the system—[(B) and (D)] at the elbow as indicated in Fig. 2, and one (A) on the deflection plate. The thermocouple at the elbow, (D), was used to record the temperature of the pressurizing gas leaving the heat exchanger. Thermocouples (A) and (B) were used to measure the temperature drop from the elbow to the deflection plate.

The line from the heat exhcnager to the quick-acting valve (Fig. 2) was insulated with styrofoam 3 in. thick. This enabled the system from the heat exchanger to the valve to be preheated prior to a test run by circulating gas through it at the desired temperature. Below the valve a small insulated brass container was mounted with an agitator and immersion heater. By controlling the temperature of the bath in this container, the temperature of the inlet line from the quick-acting valve to the tank was controlled.

To eliminate further any transients of the inlet-gas temperature, the two 90° elbows mentioned above were removed and a thin aluminum plate was inserted. This plate has a very low heat capacity and served the purpose of deflecting the inlet gas parallel to the roof of the tank.

After these changes the gas temperature was found to approach more closely a constant value throughout the run. The temperature difference of the gas between the heat-exchanger discharge line and the tank inlet then becomes comparatively small and constant throughout the run with a fast initial transient. Curve A of Fig. 1 shows this effect for boiling water in the heat exchanger. This change in temperature as well as the gas temperature at the inlet to the tank may be seen on Figs. 3 and 4.

THERMOCOUPLE RESPONSE

The (66%) response time of thermocouples to a step change in temperature was measured for two conditions: (a) plunging from gas to liquid, and (b) plunging from liquid to gas. The results are somewhat inconclusive as far as the system thermocouples are concerned but probably do provide qualitative data. As would be expected a sudden change from gas to liquid gave a high rate of response; the time constant was less than one second. On the other hand, a change from liquid to gas indicated a much larger time constant and showed an effect of evaporization of a residual liquid. This contributed largely to an increased time constant. It is difficult to generalize on these results as far as the system thermocouples are concerned, owing to the difference in gas turbulence and other effects, but it appears that a time constant for a liquid-gas transition could be as large as 10-15 seconds.

EXPERIMENTAL OPERATION

With the apparatus as shown in Fig. 2, four pressurization and discharge runs were made using nitrogen gas. The four runs were with liquid nitrogen, solid carbon dioxide and methyl alcohol, ambient air, and boiling water, respectively, in the heat exchanger.

Three pressurization and discharge runs were made using helium for pressurization. These runs were made with solid carbon dioxide and methyl alcohol, ambient air, and boiling water in the heat exchanger. It was felt that, with the available experimental set-up and technique, it would be simple and meaningful to take these data for comparison with the nitrogen data.

Included in this report are two of the experimental results of the seven runs completed. Reproduction of the oscillograph and Sanborn charts for these runs are shown in Figs. 3 and 4.

The experimental data for nitrogen gas pressurization with solid carbon dioxide and methyl alcohol in the heat exchanger are shown in Fig. 3. The experimental data for nitrogen pressurization with boiling water in the heat exchanger are shown in Fig. 4. Initial pressurization is shown by the simultaneous abrupt inflection of thermocouple 3,inlet-gas temperature thermocouple, the gas meter reading, and the pressure in tank. Discharge is shown by the straight negative slopes on the flow curves of Figs. 3 and 4.

Preliminary estimates indicate the following effect of inlet-gas temperature on residual gas mass.

Inlet-Gas Temperature, °F	Residual Gas Mass, lbm
111	1.056
- 30	1.095
- 200	1.362

SOME RESULTS USING HELIUM AS PRESSURIZING GAS

Prior to the changes in the system discussed above, two runs were made which differ only in the type of pressurizing gas used. Both were done with ambient temperature in the heat exchanger; pressurization was accomplished with nitrogen in one case, and helium in the other. The mass of the residual gas is considerably less when helium is used, as shown by the following results:

Pressurizing Gas	Mass of Residual Gas
Nitrogen	1.11 lbm
Helium	0.546 lbm

PROGRAMMED HEAT FLUX

To carry out runs with a programmed heat flux, electrical resistance wire has been wound around the tank. The assembly is made in the following way.

Mylar tape 0.001 in. thick was wrapped on the tank. This tape insulates adequately electrically, but only negligibly thermally. Helical coils with a pitch of 3.5/in. of chromel A ribbon (1/8 by 0.0159 in) were then placed over the mylar type. A jacket of styrofoam 3 in. thick is to be placed over the coils. The heater will provide approximately 3500 watts for heating the tank.

ACTIVITIES DURING THE NEXT PERIOD ON RESIDUAL GAS APPARATUS

During the next period, effort will be directed towards (a) reducing the experimental data, (b) collecting data for a programmed wall heat flux, and (c) collecting data for pressurization with a floating piston made of an insulating material separating the liquid and gas.

The primary objective of the reduction of the experimental data will be the evaluation of the effect of inlet-gas temperature on the amount of residual gas. Other observations such as those pertaining to condensation and/or boiling at the interface as may be obtained from the oscillographic charts will be made.

The effect of programmed heat flux will be measured for these inlet-gas temperatures (ambient, boiling water, CO_2, alcohol) for a heat flux at the wall of approximately four times that in the existing apparatus.

The collection of data with a floating piston in the pressurizing tank will acquire considerable modification of the apparatus. It also presents a problem of thermocouple mounting which has not yet been solved but is under study. At the present a float made of 1- to 2-in.-thick stryofoam is contemplated.

FENSTER'S THESIS "AN INVESTIGATION OF THE TRANSIENT THERMAL RESPONSE OF A STEP-PRESSURIZED BOILING LIQUID NITROGEN SYSTEM"

To this date the boil-off and pressurizing apparatus has been received and found to be satisfactory by pretest inspection. Electrical equipment including primary power variacs, guard-heater control variacs, galvanometers, wattmeters, and miscellaneous heater equipment has been ordered. This equipment will permit the supply, control, and measurement of heat fluxes up to 12,000 Btu/hr ft^2 through the primary boil-off cyclinder walls. The Mechanical Engineering Department has made approximately $1000 available for these electrical purchases.

The primary boil-off cylinders will be heated by chromel-A ribbon. The ribbon circuit will be arranged so as to permit either uniform heating across the wall throughout the entire cylindrical area, or allow only a particular region or regions to be so heated. The total cylindrical surface area will be divided into five such regions.

Currently the problem of liquid-level measurement is being studied. Magnet-bearing floats and capacitance methods are being examined.

An analytical study of phenomena at the liquid-vapor interface is underway. This is related to the interfacial condensation or boiling, which may occur upon pressurization of the liquid nitrogen.

The next period will be devoted to making mechanical connections to the test cylinder for pressurization, filling, pressure regulation, and liquid-level indication. In addition, electrical circuits will be provided for primary test cylinder heating, guard-heater input, power-input measurement, wall and internal cylinder temperatures, and heater controls. It is anticipated that pretest checking will be started by the end of the next period.

MERTE'S THESIS
"A STUDY OF POOL BOILING IN AN ACCELERATING SYSTEM"

Design of the experimental apparatus has been completed and the drawings have been let out for construction bids. The two main assembly drawings showing the salient features are included herewith. System acceleration is obtained by rotation of the test section.

Preliminary bids have indicated that the material and labor costs for construction of the apparatus will be about $3000, and the time required, about 8 weeks. Approximately $1000 has been made available by the Mechanical Engineering Department for the purchase of necessary instrumentation and equipment of a permanent nature.

The flat-plate heating surface and associated electrical apparatus will be capable of furnishing a heat flux up to 600,000 Btu/hr ft^2. Approximately 80 in. of 1/4 by 0.002-in. heater ribbon is to be insulated with mica and cemented into 0.008-in. slots milled in one end of a short copper cylinder. Provision is made for maintaining an adiabatic wall at this end of the cylinder using a guard heater. The heat flux is measured both by the power input and the temperature gradient in the cylinder.

For the peak heat flux and film boiling regions, a unit containing a horizontal platinum wire will be inserted within the inner container, and the plate heating element will be used to maintain the fluid at saturation temperature.

A variable-speed hydraulic transmission driven by a 1-hp electric motor will rotate the assembly. With a Hewlett-Packard tachometer generator and electronic counter the speed of rotation can be measured within ± 1 rpm.

While the apparatus is under construction, efforts will be directed in the following channels:

1. calibration of electric meters and thermocouples;

2. construction of platinum-wire holder;
3. construction of platinum-wire welding apparatus;
4. the assembly of sub-assemblies as available;
5. provide for making de-aerated water; and
6. continuation of study of theroretical effects of acceleration on boiling.

APPENDIX I

MODIFICATIONS IN APPARATUS

1. A small heat exchanger has been added to inlet line.

2. Inlet gas has been diverted using a metal (aluminum) plate 1/32 in. thick by 1-1/2 in. square below the inlet pipe. The aluminum deflection plate was placed in the system so that the gas flow in the missile would be simulated. The deflection plate was made of thin aluminum to achieve low heat capacity to reduce the temperature transient time of the inlet gas.

3. Thermocouples have been added to measure the instantaneous difference between the temperature of the gas from the heat-exchanger exit line and the actual temperature of the gas entering the tank.

4. A thermocouple was inserted in the heat-exchanger line to measure the temperature of the gas leaving the heat exchanger.

5. To measure more accurately the amount and the rate of the pressurizing gas used, a voltage dividing-type transducer was installed on the gas meter and was recorded on the Sanborn oscillograph.

APPENDIX II

TEST PROCEDURE
(Refer to Fig. 1, Progress Report No. 7, March 1958)

1. Record temperature, barometric pressure, humidity in test cell.

2. Unless toxic fumes are present, turn off blower and shut cell doors.

3. Close valve in line to heat exchanger and vent tank, through gate valve on tank.

4. Close vents to Dewar.

5. Pressurize Dewar (12-15 psig). See procedure no. 11.

6. Open values in line from Dewar to tank.

7. Fill tank to 105 lb. (Allow it to boil off to 100 lb for a test. This time allows a pretest check to be made.)

8. Close quick-acting tank valve.

8a. Close gate valve, then open to 1-3/8 rev.

9. Release pressure from gaseous N_2 bottle to Dewar.

10. Vent Dewar.

11. Run gas through heat-exchanger lines to bring them up to equilibrium temperature of gas. Then close line vents, tank inlet solenoid, and pressurize surge tank to 70-80 psig.

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.

15a. Open valves to pressure regulator.

16. See 8a.

17. Record surge tank pressure.

18. Close main line vent, open solenoid line vent.

19. Close gate valve vent on liquid N_2 tank.

20. Open quick-acting valve on inlet line, allowing tank to vent through line solenoid vent.

21. Close line solenoid vent, open tank inlet solenoid valve (simultaneously).

22. Ten seconds after tank reaches 35 psig, record surge tank pressure.

23. Open valve from gaseous N_2 bottle to surge tank.

24. Ten seconds after surge tank reading, start discharging of tank by opening quick-acting valve.

25. Check for open Dewar vent.

26. Regulate outlet for 205 cps on electronic counter using tank outlet gate valve.

27. 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).

28. Turn off quick-acting tank valve when flowmeter indication suddenly triples.

29. Turn off pressure from N_2 bottle.

30. Vent tank.

31. Close valve in line from tank inlet to heat exchanger.

32. Turn off oscillograph.

33. Record oscillograph number.

34. 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
flowmeter readings

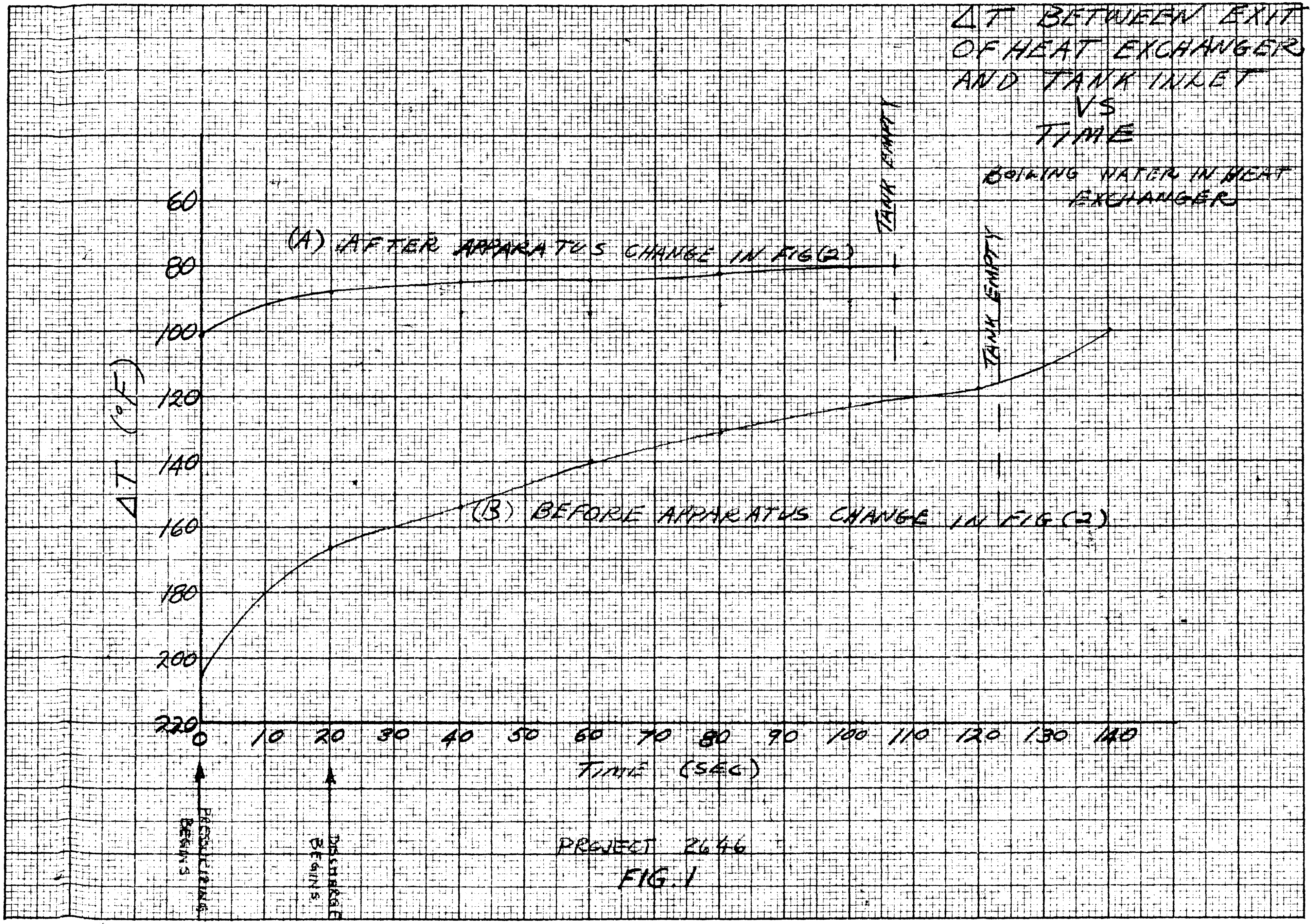

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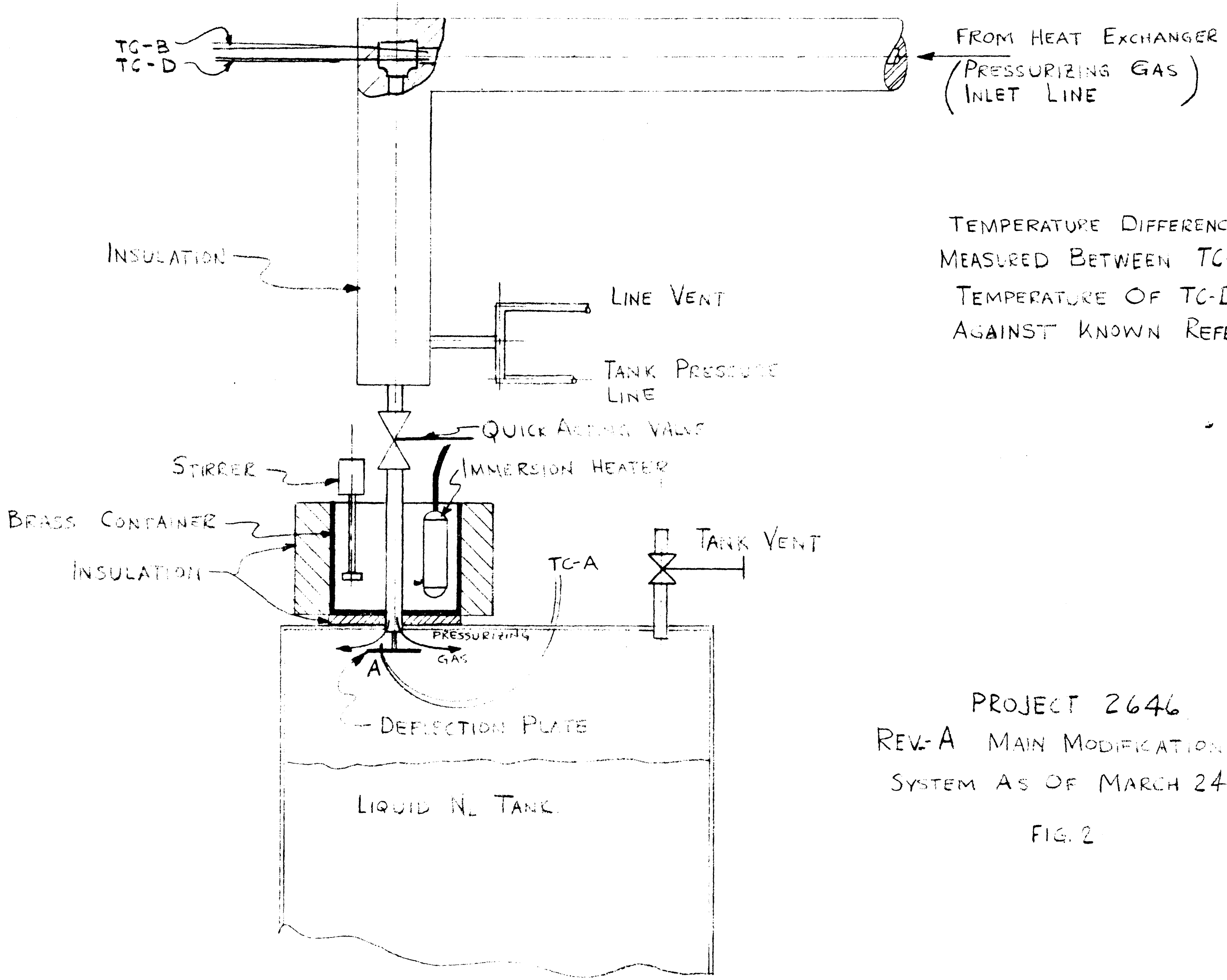
FIG. 1



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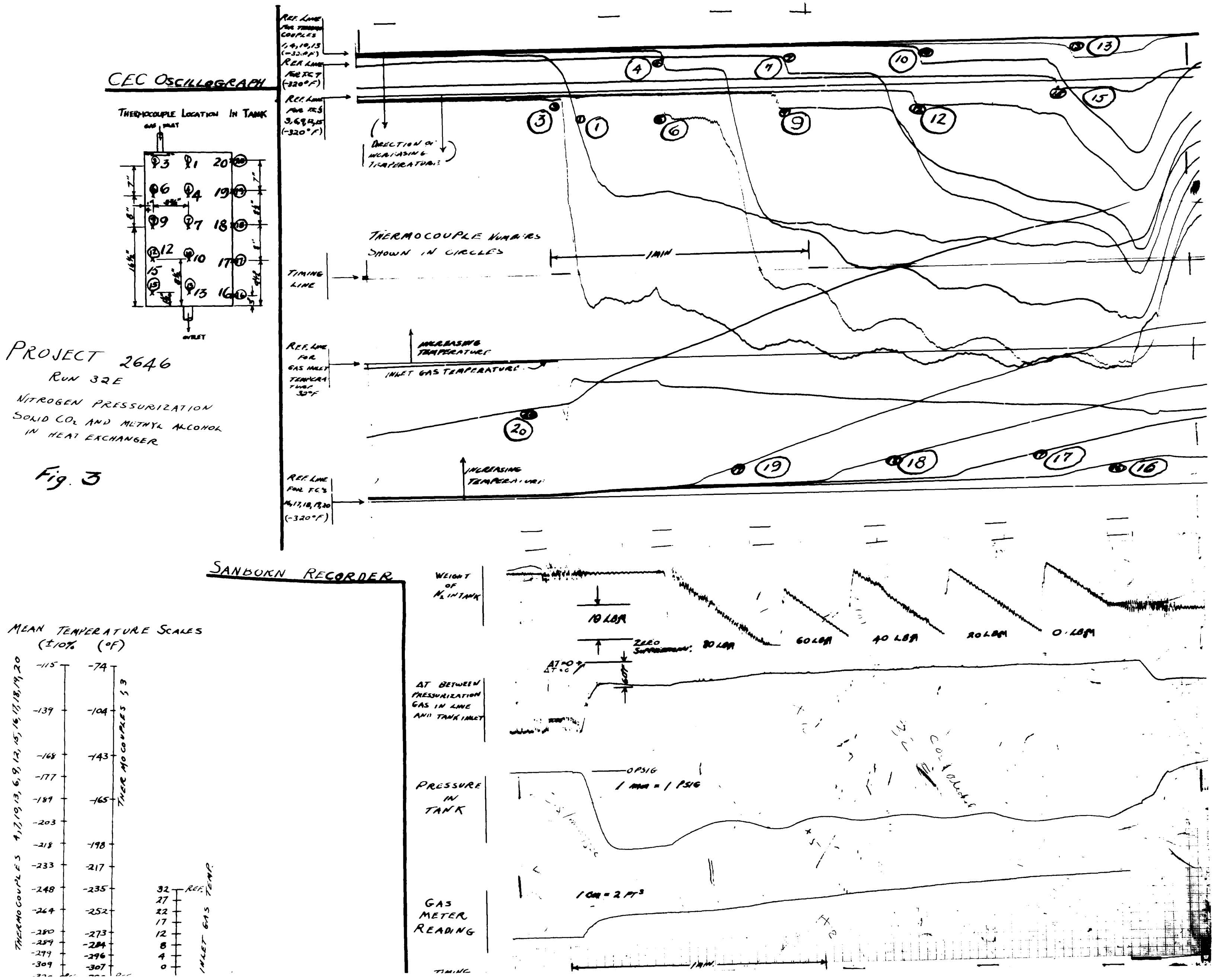
REV.-A MAIN MODIFICATIONS TO
SYSTEM AS OF MARCH 24, 1958

FIG. 2



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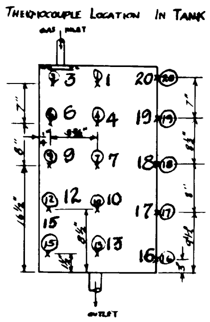
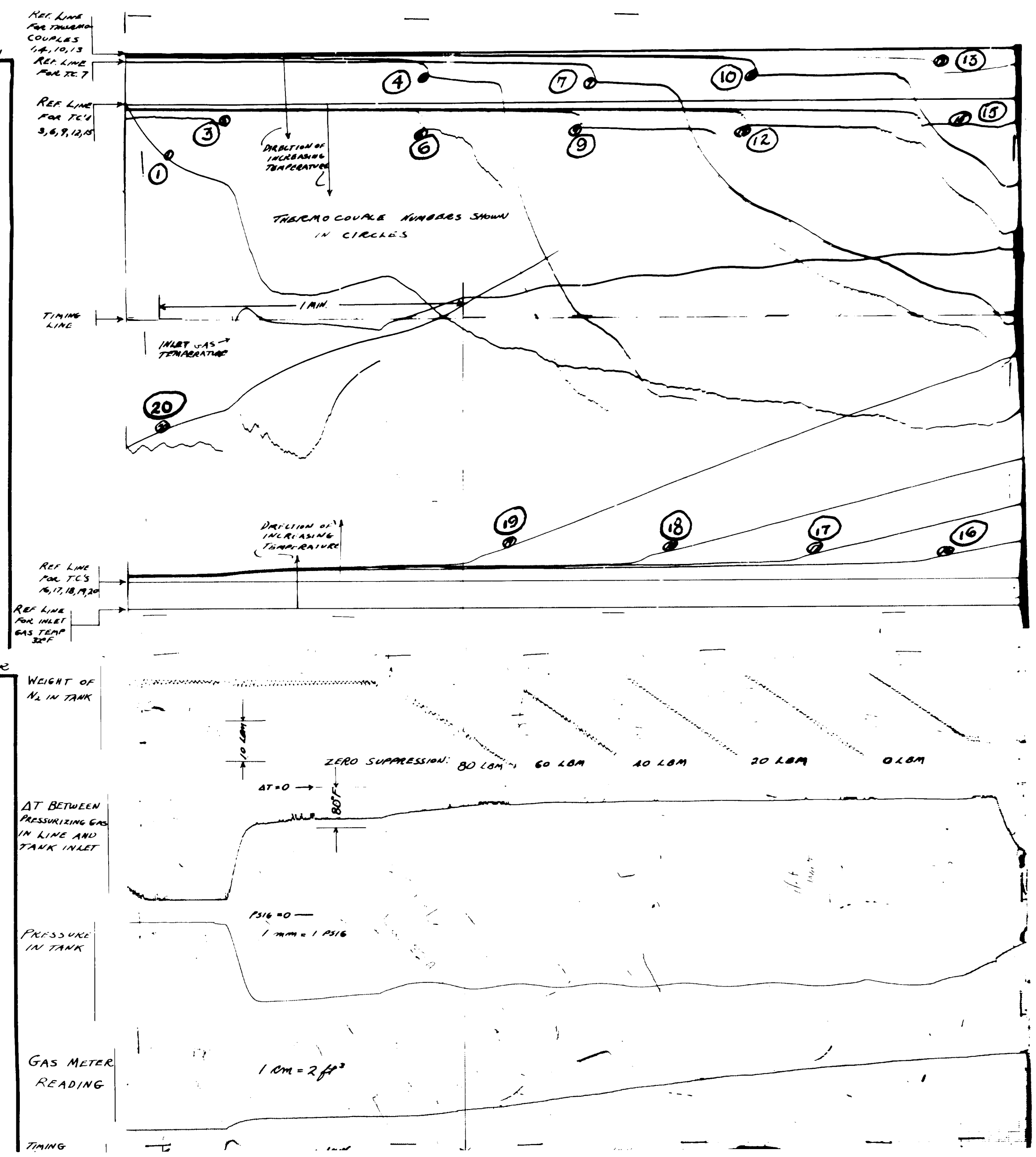
Run 32E

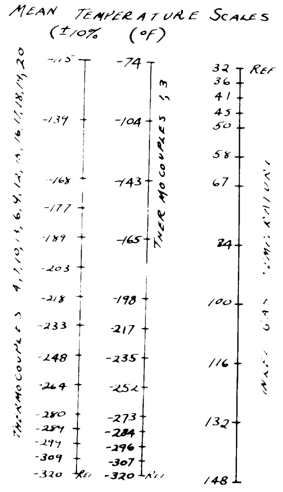
Nitrogen pressurization

Solid CO_2 and methyl alcohol in heat exchanger

Fig. 3







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RUN 32A

3-24-58

NITROGEN PRESSURIZATION

BOILING WATER IN HEAT EXCHANGER

Fig. 4