A STUDY OF THE NUCLEATE BOILING HEAT TRANSFER COEFFICIENT OF DICHLORODIFLUOROMETHANE (FREON-12) OVER A HORIZONTAL SURFACE

by

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ABSTRACT

The heat transfer coefficients for oil-free liquid dichlorodifluoromethane (Freon-12 or Genetron-12) in nucleate boiling over a horizontal copper surface were measured at saturation temperatures of 0°F and 25°F and at heat flux densities between 6,000 and 63,000 Btu/hr-ft^2. The heating surfaces were finished with 400-A emery paper in two different patterns before each series of test-runs, while the geometric arrangement and the other parameters of the apparatus remained unchanged. Profilometer measurements of roughness and photomicrographs of the surface were taken. All the boiling curves calculated and plotted from the experimental results were of "S" shape, revealing a pronounced deviation from the conventional (normal) boiling curve, especially at lower saturation temperatures. The deviation of the boiling curve was probably due to the unpredictable nucleating characteristics of the heating surface and of the bubble population [1, 2]. This makes it impossible to correlate the experimental data by any of the existing empirical equations formulated by Zuber [3, 4, 5], Rohsenow[6, 7], Levy[16] and others.

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LIST OF SYMBOLS

Nomenclature:

A = heating surface area

$C = C_p$ = specific heat at constant pressure

C_{sf} = coefficient of Equation (3)

C_1, C_2 = constants of Equation (9)

d = diameter of heating surface

D_b = diameter of bubble

G_b = mass velocity of bubbles

$h = H$ = boiling heat transfer coefficient

k = thermal conductivity

K_{sf} = coefficient of Equation (7)

Nu_b = bubble Nusselt number

Nu_{br} = bubble Nusselt number defined by Equation (4)

Nu_{bz} = bubble Nusselt number defined by Equation (6)

P = pressure

P_v = pressure in vessel above liquid

Pr_L = liquid Prandtl number = $\frac{C_L \mu_L}{k_L}$

P/Q = percentage difference between Q and Q_w

Q = heat transfer rate from heating surface

Q_w = QW = heat input rate by wattmeter

Q/A = the rate of heat transfer per unit area of heating surface

R = bubble radius

Re_b = bubble Reynolds number

Re_{br} = bubble Reynolds number defined by Equation (4)

Re_{bz} = bubble Reynolds number defined by Equation (6)

T = temperature

T_1, T_2, T_3, T_4 and T_5 = temperatures of thermocouples 1, 2, 3, 4 and 5 respectively

T_7 = room temperature, temperature of thermocouple 7

$T_s = T_b = T_6$ = mixed bulk temperature or saturation temperature of liquid

T_w = temperature of heating surface

ΔT = DELT = $T_w - T_b$

W = power input by wattmeter

x_1, x_2, x_3, x_4 and x_5 = distances to thermocouples 1, 2, 3, 4 and 5 respectively from surface

ρ = mass density

μ = dynamic viscosity

Subscripts:

L = liquid

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I. INTRODUCTION

The nucleate boiling region is of great practical interest because a high heat flux density can be accommodated at a small temperature difference between the heating surface and the boiling liquid. Practical applications of boiling heat transfer theory are found in high power density systems, such as nuclear reactors, rocket engines, space power plants, etc.

A considerable amount of research on boiling heat transfer has been conducted and the results have been published, but few of these were carried out on boiling of the refrigerant dichlorodifluoromethane (Freon-12 or Genetron-12). Since Freon-12 is a common widely used refrigerant for air-conditioning and refrigeration systems, the investigation of the boiling of such a refrigerant is of practical interest. Also, the experimental results may be used for the design of evaporators or heat exchangers.

There are a large number of parameters which will affect the heat transfer rate. In the experimental work described here the intention was to concentrate upon the investigation of a few of these factors, namely, (1) the effect of surface finish texture on the heat transfer, (2) the effect of surface roughness on the heat transfer rate.

In order to arrive at a more quantitative understanding of the boiling phenomena, the effects of ageing of the heating surface and of hysteresis were also observed throughout the investigation.

II. THEORY

2.1 GENERAL

In 1934, Nukiyama [10]* made a simple experiment by submerging a thin platinum wire in water and heating the wire electrically to produce boiling. Later, numerous similar experiments on boiling heat transfer for different kinds of liquids were conducted by many investigators. According to Farber and Scorah's investigation [21], boiling proceeds in several distinct regimes which will be discussed later.

Boiling heat transfer may be investigated in two ways: (1) by experimental methods and (2) by analysis. Most investigators have used experimental methods in which the coefficient of heat transfer is obtained as a function of temperature difference between the heating surface and the boiling liquid with little attention being paid to obtaining fundamental information of the phenomenon. Thus little information is obtained which is generally valid for a particular solid-liquid combination at a specific saturation temperature.

Contributions of a more fundamental nature by Jakob [20] and his co-workers are of great significance. They searched for the mechanism of boiling of a liquid by observing photographically the generation of bubbles on the heating surface and the characteristic features of the bubbles rising through the liquid mass.

Virtually all attempts at analysis of the nucleate boiling phenomenon proceed semi-empirically. The problem in its entirety is of a complexity such that a reasonably general analytical model, even if it could be developed, would not lead to useful and lucid

* Numbers in square brackets refer to numbered references in the Bibliography.

results. All models proposed aim at the reproduction of a boiling curve, i.e. a plot of the heat transfer coefficient (h) versus the temperature difference between the heating surface and the saturation temperature of the liquid, of a general shape shown in Fig. 1 [21] .

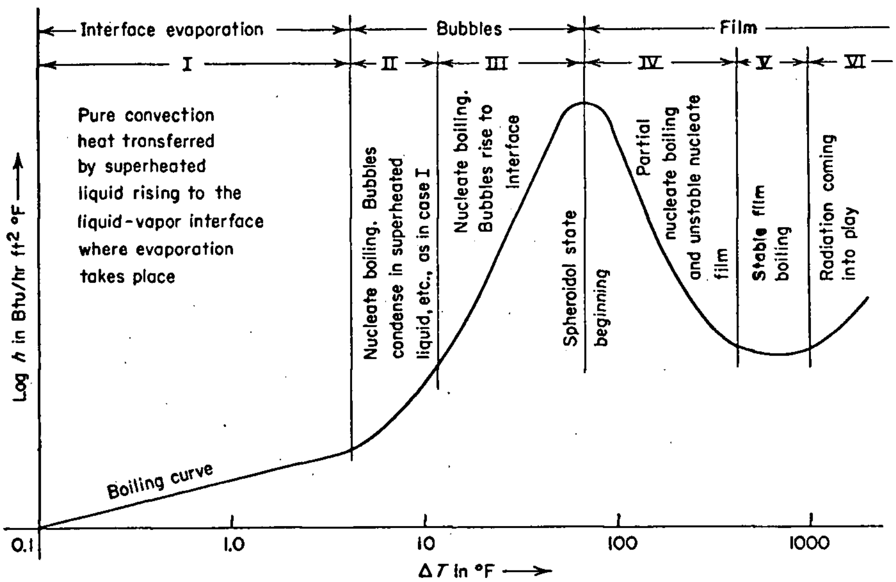


Fig. 1. Analysis of boiling curve (after Farber and Scorah [21]).

Generally, boiling processes take place in three types [7, 9, 11, 12]:

a. Nucleate boiling.

b. Transition.

c. Film boiling.

The boiling curve suggested by Farber and Scorah [21] generalizes the boiling phenomenon into six regimes as indicated in Fig. 1:

Regime I: Interface evaporation - Liquid is being heated by natural convection. Heat is transferred by pure convection, and vaporization without boiling occurs only at the vapor-liquid interface. The onset of convective heat transfer in this region is essentially a classical instability problem.

Regime II: Nucleate boiling - Bubbles begin to form at active nuclei on the heating surface and grow larger as the temperature difference (ΔT) increases. When the buoyant force of the bubble overcomes the adhesion force to the heating surface, bubbles break off and rise through the pool inducing a convection current. As bubbles rise, some combine into larger bubbles, and others rise individually, but all disappear in the superheated liquid before they reach the liquid-vapor interface. Bubbles continue to form on the same sites. In this nucleate boiling region the ebullition is not vigorous.

Regime III: Nucleate boiling - Vigorous boiling takes place. A great number of larger bubbles ascend through the superheated liquid and rise into the air as vapor at the liquid-vapor interface. The stirring action produced by rising bubbles in turn increases the heat transfer rate. This is the most efficient heat transfer region, and is therefore the condition aimed at in design.

Regime IV: Transition - An unstable film forms over the heating surface but periodically collapses and forms again. Since the heat flux rate decreases with further increase in surface temperature, this part of the boiling curve is essentially unstable.

Regime V: Film boiling - The film of vapor over the heating surface does not collapse but becomes stable. Due to the rapid formation of large bubbles, the outside surface of the vapor film is continuously agitated and moves rapidly in wave form.

Regime VI: Film boiling - A stable vapor film remains over the heating surface. Bubbles appear to form at the surface of the <u>film</u> instead of at the nuclei on the heating surface. In this range, heat is transferred through the vapor film by conduction and radiation.

2.2 FACTORS AFFECTING NUCLEATE BOILING

There are numerous variables which will affect the boiling heat transfer coefficient. McAdams [12], Westwater [9] and Hsu [7] compiled many of the previous investigations. The predicted parameters are as follows:

a. Physical Properties of the Liquid - Surface tension, thermal conductivity, density, viscosity, latent heat, impurities, etc., are the parameters affecting the heat transfer rate.

b. Condition or Texture of Heating Surface - The rate of heat transfer is higher for rough and clean surfaces than for smooth and old surfaces.

c. Material of Heating Surface - According to a sdries of experiments conducted by Agarwal and Hsu [7], copper gives better "h" than chromium, platinum, nickel or zinc.

d. Temperature of the Liquid - Generally, the boiling film coefficient increases with the temperature of the liquid.

e. Pressure - The temperature difference necessary to maintain a given heat flux decreases as pressure increases.

f. Geometric Arrangement - The equations of Rohsenow [6] and of Forster and Zuber [14] do not predict the influence of the geometric arrangement - which may be of some consequence.

g. Agitation - Agitation induced by rising bubbles or by mechanical means will increase the heat transfer rate at any given temperature difference.

h. <u>Short-Wave Irradiation</u> - The rate of nucleation is affected strongly if the liquid is easily ionized or the liquid is a poor conductor.

2.3 CORRELATIONS OF BOILING HEAT TRANSFER DATA

a. Concepts

In the past few decades, research on boiling heat transfer has been conducted by many investigators. The models of boiling proposed are summarized as follows:

(1) Jakob [20] proposed that the vapor bubble of boiling originates in a thin highly superheated layer of liquid near the heating surface. A bubble cannot originate from zero radius and boiling will not start unless curvatures are present, such as are formed by wall roughnesses or by gas bubbles and other impurities in the liquid. The degree of superheating of a boiling liquid will depend upon the statistical mean of the radius of curvature of wall roughnesses or of bubbles of gas adhering to the walls on which the liquid can evaporate. The process of originating and growing of vapor bubbles causes some motion of the liquid and therefore promotes the heat transfer on the heating surface.

(2) Gunther and Kreith [22] showed the existence of a highly superheated film next to the heating surface. The high thermal resistance of this film is removed by the growth and collapse of vapor bubbles. Radial velocity of growing vapor bubbles and superheated film thickness next to the heating surface can account for the heat transfer rate.

(3) Ellion [23] suggested that at higher superheats the diameter of a bubble at departure is governed by a mechanism which indicates the importance of the radial velocity of a bubble while it is still attached to the heating surface.

(4) Corty and Foust [13] demonstrated the importance of the size and distribution of the micro-roughness in determining the liquid superheat and boiling heat flux. This means that by changing surface characteristics the shape of the nucleate boiling curve can be changed.

In conclusion, these experimental findings seem to indicate that the large heat transfer rate associated with nucleate boiling is a consequence of the micro-convection in the super-heated sublayer caused by bubble dynamics.

b. Empirical Equations

Heat transfer data for pool boiling have been correlated using a bubble Nusselt number (Nu_b), a bubble Reynolds number (Re_b), and the Prandtl number (Pr_L) of the liquid. Upon application of the theory of similarity to the differential equations of heat transfer and fluid flow, a relation of the form

$$Nu_b = \phi\ (Re_b, Pr_L) \text{ ----------- } (1)$$

may be shown to exist for the heat transfer from a solid boundary to a fluid. An approximate form of the function ϕ may be obtained from experimental data, and for purposes of design, an empirical expression of the form

$$Nu_b = \text{Coeff.}\ (Re_b)^m (Pr_L)^n \text{ -- } (2)$$

is usually employed.

In 1951, Rohsenow [6] developed an equation expressed in the form of equation (3) by correlating experimental data from near inception of nucleate boiling to the maximum heat-flux values over a wide range of pressure and for various surface-fluid combination

$$Nu_{br} = \frac{1}{C_{sf}} (Re_{br})^{0.667} (Pr_L)^{-0.7} \quad \text{----------} \quad (3)$$

where

$$\left.\begin{aligned} Re_{br} &= \frac{(G_b)\ (D_b)}{\mu_L} \\ Nu_{br} &= \frac{(Q/A)\ (D_b)}{(T_w - T_s)\ (k_L)} \end{aligned}\right) \quad \text{----------------} \quad (4)$$

The coeefficient (C_{sf}) depends upon the surface tensions between liquid, vapor and solid for a particular surface-fluid combination. D_b is the diameter of bubble as it leaves heating surface and G_b is the mass velocity of bubbles at their departure from heating surface.

In 1955, another correlation employing Equation (2) was derived by Forster and Zuber [4, 14]. It takes the form of

$$Nu_{bz} = 0.0015\ (Re_{bz})^{0.62} (Pr_L)^{0.33} \quad \text{------} \quad (5)$$

where

$$\left.\begin{aligned} Re_{bz} &= \frac{2\dot{R}R\rho_L}{\mu_L} \\ Nu_{bz} &= \frac{(Q/A)\ (R)}{(T_w - T_s)\ (k_L)} \end{aligned}\right) \quad \text{------------} \quad (6)$$

Here R and $\dot{R}$ are the radius and rate of growth of the bubble respectively.

The exponents and coefficient of the Forster-Zuber Equation (5) were derived from peak-value data which cannot correlate the entire nucleate boiling regime. In order to make the equation valid over the entire heat flux range, Rohsenow [5] used the data previously taken in developing Equation (3) to re-evaluate the exponents and coefficient of Equation (5). The following form of correlation was found:-

$$Nu_{bz} = K_{sf}(Re_{bz})^{1.05}(Pr_L)^{-7} \quad \text{-----------} \quad (7)$$

where K_{sf} is also a function of the surface-liquid combination.

Table I lists magnitudes of C_{sf} and K_{sf} of Equations (3) and (7) for some surface-fluid pairs in pool boiling [5].

Table I Values of C_{sf} and K_{sf}

Fluid-heating surface	C_{sf}	K_{sf}
Water-platinum	0.013	...
Benzene-chromium	0.010	1
Ethanol-chromium	0.0027	300
n-pentane-chromium	0.015	0.30
Water-brass	0.006	...

Several other attempts at correlation of boiling heat transfer have been made, such as Levy's [16] . These all use similar methods but assume different physical models for the boiling process. Actually, they are not complete and should not be compared directly to each other since none of them has taken into account the nucleating characteristics of the heating surface. Besides, the various investigators do not even agree on the quantitative and qualitative effects of some of the important variables such as the temperature difference, surface tension, liquid viscosity, etc., in their derivations.

The correlation of the boiling heat transfer results of the present investigation will be discussed later in Section VII.

2.4 UNKNOWN FACTORS IN BOILING HEAT TRANSFER

At present, according to Westwater [2], we are still lacking a complete knowledge of nucleate boiling because there are some parameters which affect the heat transfer coefficient still in need of further investigation and understanding. These are:

a. <u>Shape of Nucleate Boiling Curve</u> - From the very beginning investigators conducting research in nucleate boiling have assumed that the nucleate boiling curve (Q/A vs. ΔT) should be a smooth curve with a positive slope at all points up to the maximum heat flux. However, some recent investigations showed that the curve could be of "S" shape, with a negative slope over part of its course. Westwater[2] and Rohsenow[6] suggested that the deviation of the boiling curve is due to the effects of acceleration, the nucleating characteristics of heating surface, and of the bubble population. If this is true, then all the existing equations for nucleate boiling such as those given by Rohsenow, Forster and Zuber, and others can only be a first approximation.

b. <u>Natural and Artificial Nucleation Sites</u> - Nucleation sites on the heating surface affect the heat flux. A great deal of further investigation is required to be conducted on:

(1) the best shape of nucleation sites,

(2) the best size and distribution of sites,

(3) the best material for the solid surface,

(4) an economical way to produce a large number of sites,

(5) the expected life of sites for different liquids

under various operating conditions, and

(6) the rejuvenation of deactivated sites.

c. <u>Bubble Growth</u> - Existing knowledge, data and theories, are still inadequate regarding the shape of the bubbles, the temperature profile of the liquid in the region near the bubble wall and near the solid wall, and the bubble growth rate.

d. <u>Bubble Frequency</u> - We are still lacking knowledge on the number of bubbles emitted per unit time and the bubble sizes as they break away from the heating surface. To predict nucleate boiling heat fluxes existing equations are not valid for any solid-liquid combination.

In the present investigation the effects of the surface finish pattern and surface roughness on the heat transfer coefficient received concentrated attention.

III. EXPERIMENTAL APPARATUS

The experimental apparatus (Fig. 2) was originally designed by Mr. F. G. Furse for measuring the boiling heat transfer coefficients of oil-free Freon 11 and Freon 12-mixtures [15]. It can be used to measure the boiling heat transfer coefficients for any solid-liquid combination within the pressure range from -5 to 100 psig. The principal components were a 6-in. ID, 6-ft. high steel pressure vessel, a 2-in. diameter electrically heated heating surface assembly, a pool of liquid refrigerant, a condensing coil in the vapor-filled space above the liquid, a temperature measurement circuit, and a piping system.

Heat was provided by three electrical heaters embedded at the lower end of the heating surface assembly. Heat input was regulated by a variable transformer and measured by a wattmeter.

A refrigeration plant supplied the cooling effect to the condensing coil in order to control the boiling temperature of the liquid inside the vessel. Copper-constantan thermocouples were installed at various locations to measure the temperature and heat flow during the course of test.

A complete list of equipment and instrumentation is shown in Appendix III and the principal components are explained in detail as follows:

a. Steel Pressure Vessel (PV) - the geometry of the vessel is shown in Fig. 3. The vessel was made of 3/4" steel and could sustain safely a boiling pressure of 100 psig. The 12-mesh bronze screen (BS) installed half way between the liquid surface and the condensing coil

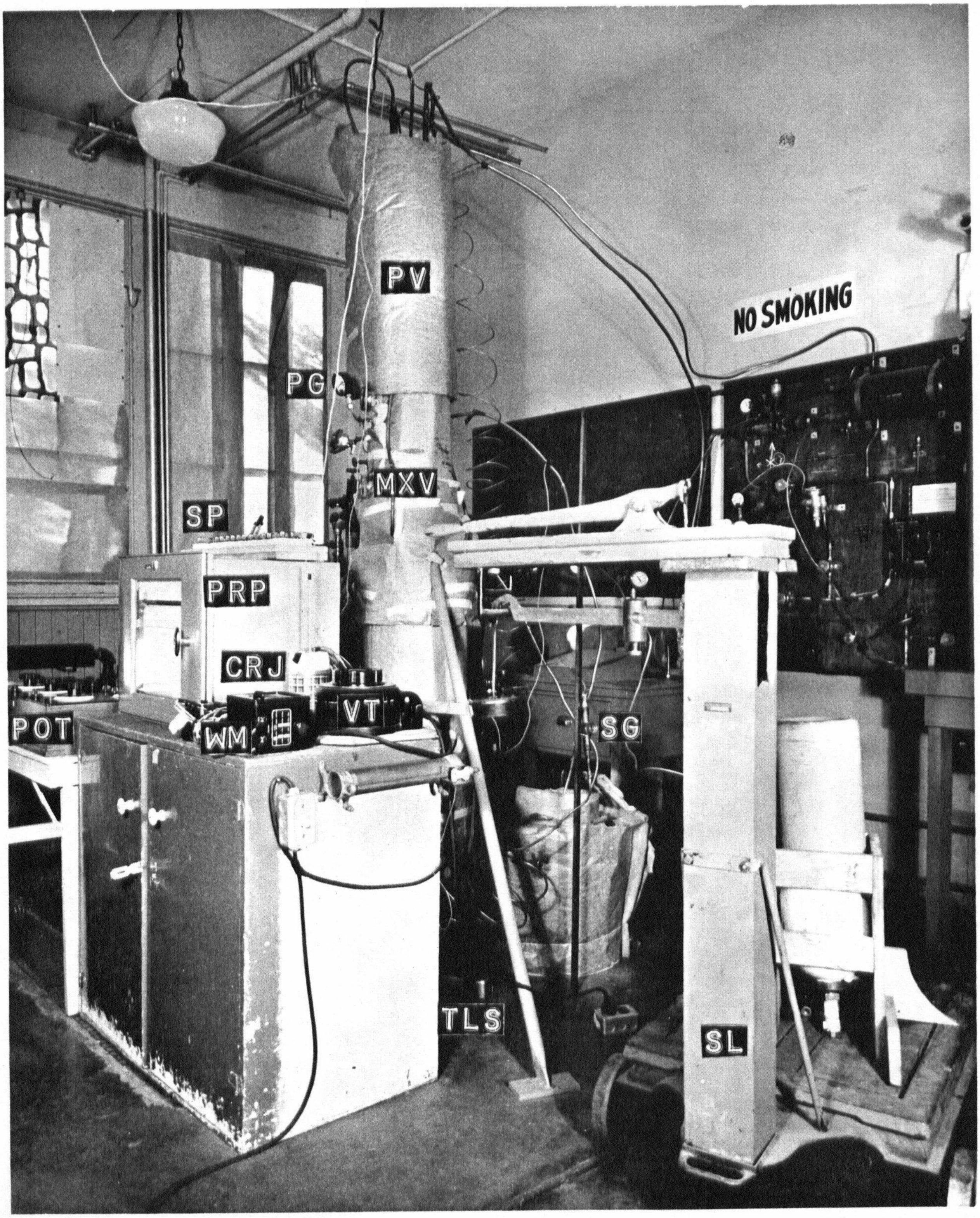


Fig. 2. Pool boiling apparatus

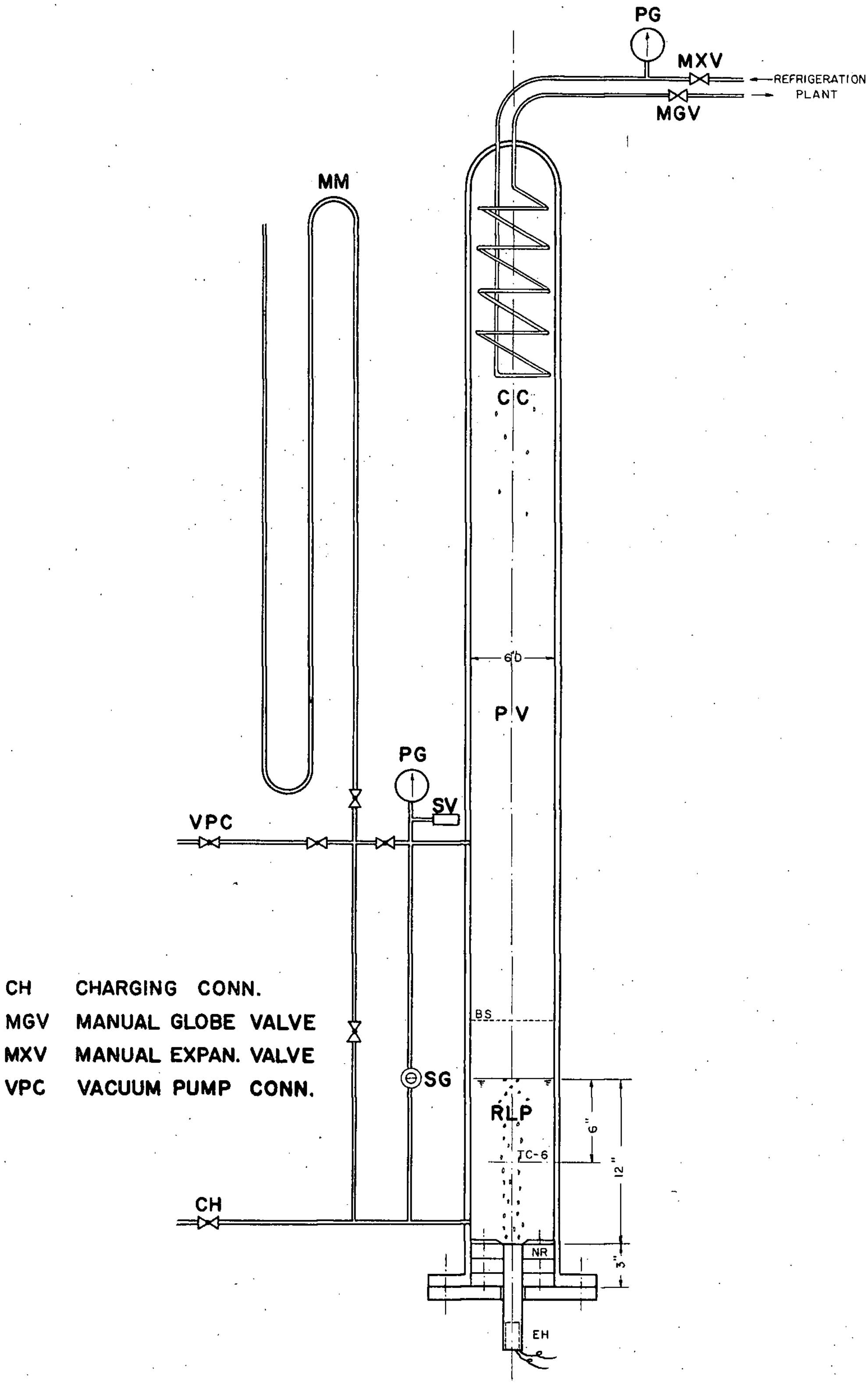


Fig. 3. Diagram of experimental apparatus

was to prevent the disturbance of the boiling mechanism by the falling droplets condensed over the cooling coil.

b. Heating Surface Assembly (Figs. 4 and 5) - The upper end of a vertical 2-inch pure copper rod was used as a heating surface. The heating surface was polished with 400-A emery paper before each set of test-runs. Surface roughness was measured by a calibrated profilometer and recorded (see Table II). Three 300-watt electric heating elements (HE) (0.75 inch diameter, 3.25 inches long) were embedded in the lower end of the copper rod to provide the heat input. The electric heat input was regulated by a 2-kilowatt Variac (Variable transformer, VT) and measured by a wattmeter (WM). A high limit thermostatic switch (TLS) was installed to prevent excessive heat flux. Four thermocouples TC's 1, 2, 4 and 5 were placed 0.253, 0.704, 1.560 and 3.035 inches respectively below the boiling surface (Fig. 4). These thermocouples were embedded in radial holes along the longitudinal axis of the copper rod at specific locations to measure the temperature gradients for calculating the heat flow along the copper rod. Heat leakages were minimized by mounting the copper rod in a 6 inch by 4 inches deep cushion of neoprene rubber (NP). Heat leakage was negligible according to a previous investigation by Furse [15].

c. Condensing Coil and Refrigeration Plant (Fig. 3) - The condensing coil (CC) (installed in the vapor filled space above the liquid level inside the pressure vessel) was connected to a 3 hp. refrigeration plant outside the apparatus. The refrigeration plant was used to provide a cooling effect in the condensing coil in order

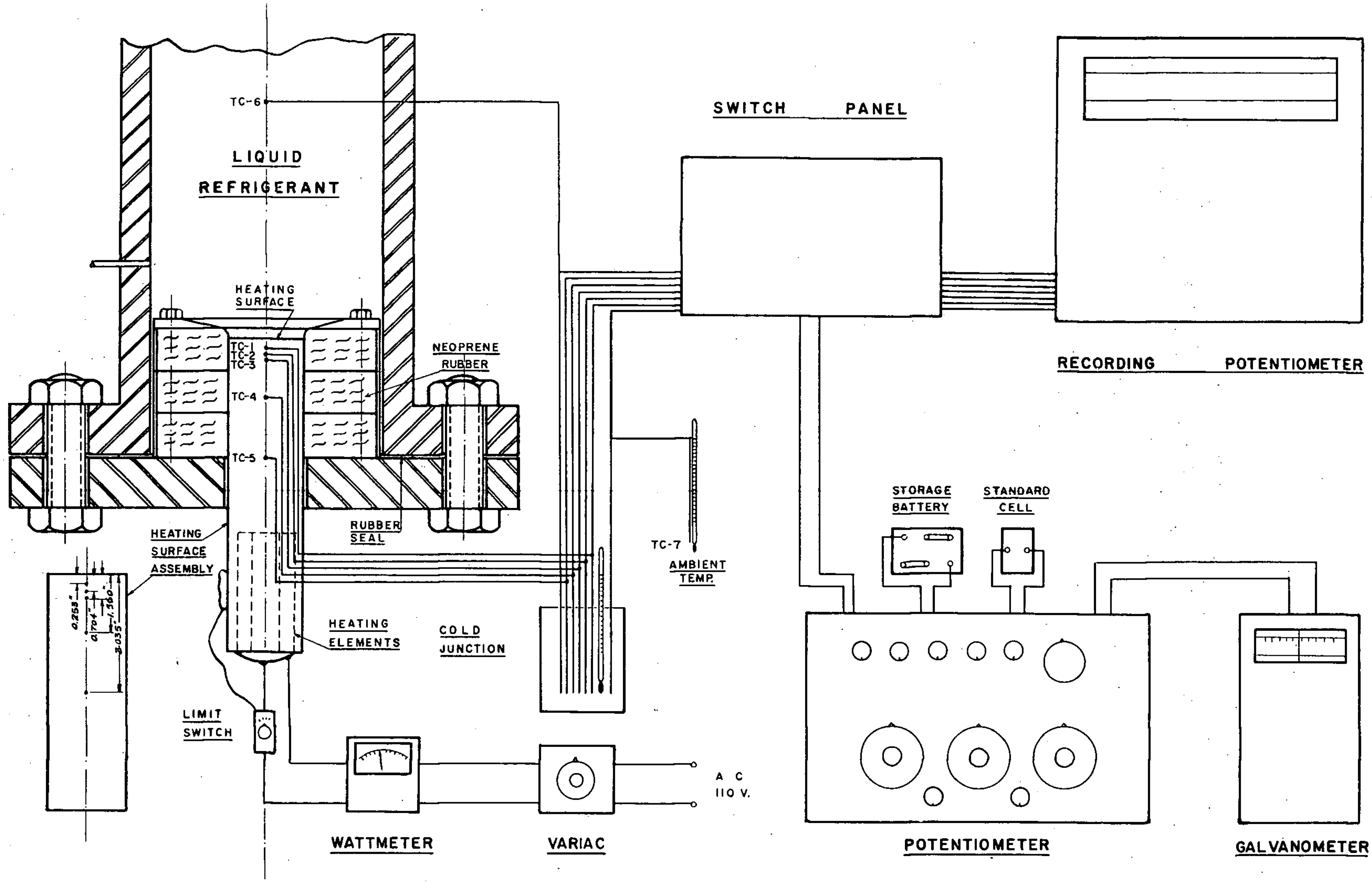


Fig. 4. Heating surface assembly and wiring diagram of instrumentation

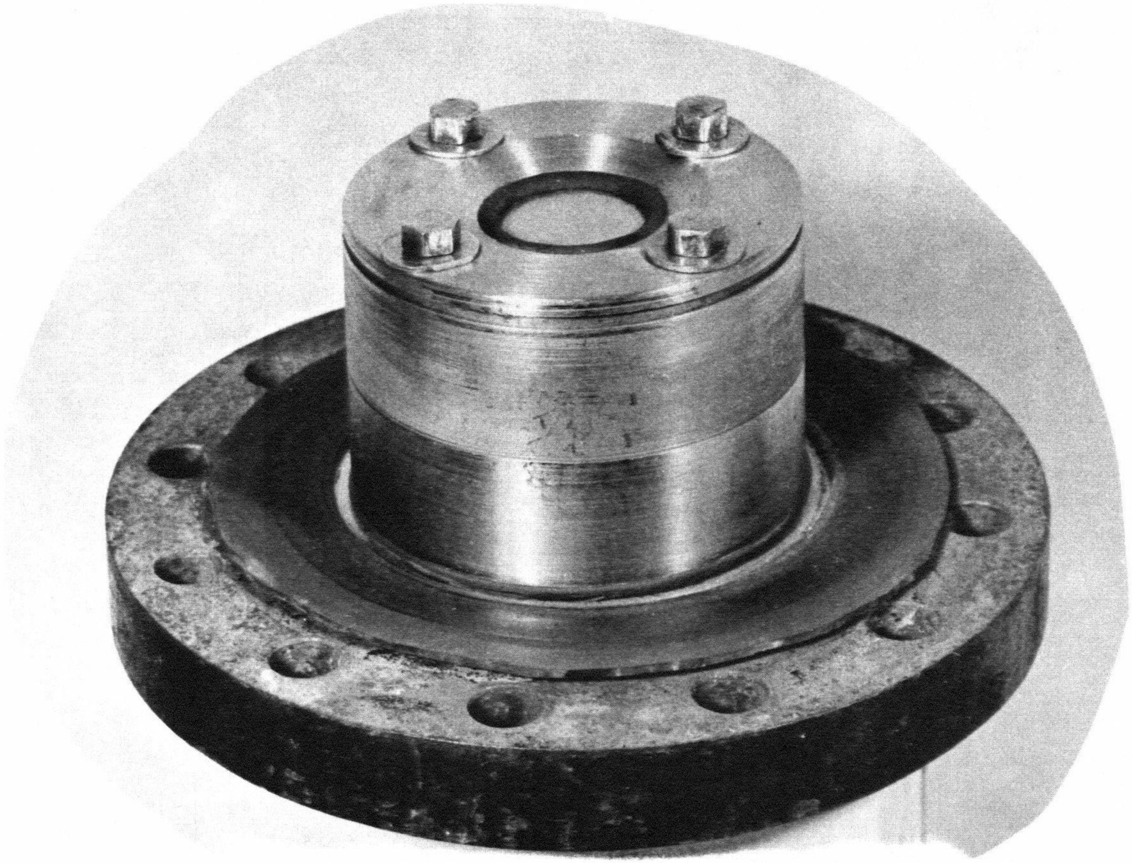


Fig. 5. Heating surface assembly

to control the boiling temperature inside the vessel during the course of the experiments.

d. <u>Pool of Liquid Refrigerant Dichlorodifluoromethane</u> (RLP) Fig. 3) - A pool of refrigerant approximately 12 inches deep was maintained inside the vessel at all times. The thermocouple TC-6 was placed at a position about 6 inches below the liquid surface. This provided a good indication of the bulk temperature of the boiling liquid.

e. <u>Temperature Measurement Circuit</u> (Figs. 4 and 6) - Temperatures of the boiling liquid and the temperature gradients along the longitudinal axis of the copper rod were obtained from thermocouples mounted at the points shown in Fig. 4. The thermocouple reference junction (CRJ) was kept in a mixture of water and crushed ice and a thermometer (TM-1) was inserted in the ice bath to verify that there was a constant cold junction temperature during each test-run. All thermocouple lead wires were electrically shielded and connected to a Philips Recording Potentiometer (PRP) through a switch panel (SP). The switch panel was wired in such a way that the temperature of any specific thermocouple could be measured by a precision potentiometer (POT) and galvanometer (GAL) unit during the course of a test. Thermocouple TC-7 was mounted in direct contact with a precision thermometer (TM-2) having 0.05 deg. F. divisions. The thermometer indicated the ambient temperature and at the same time

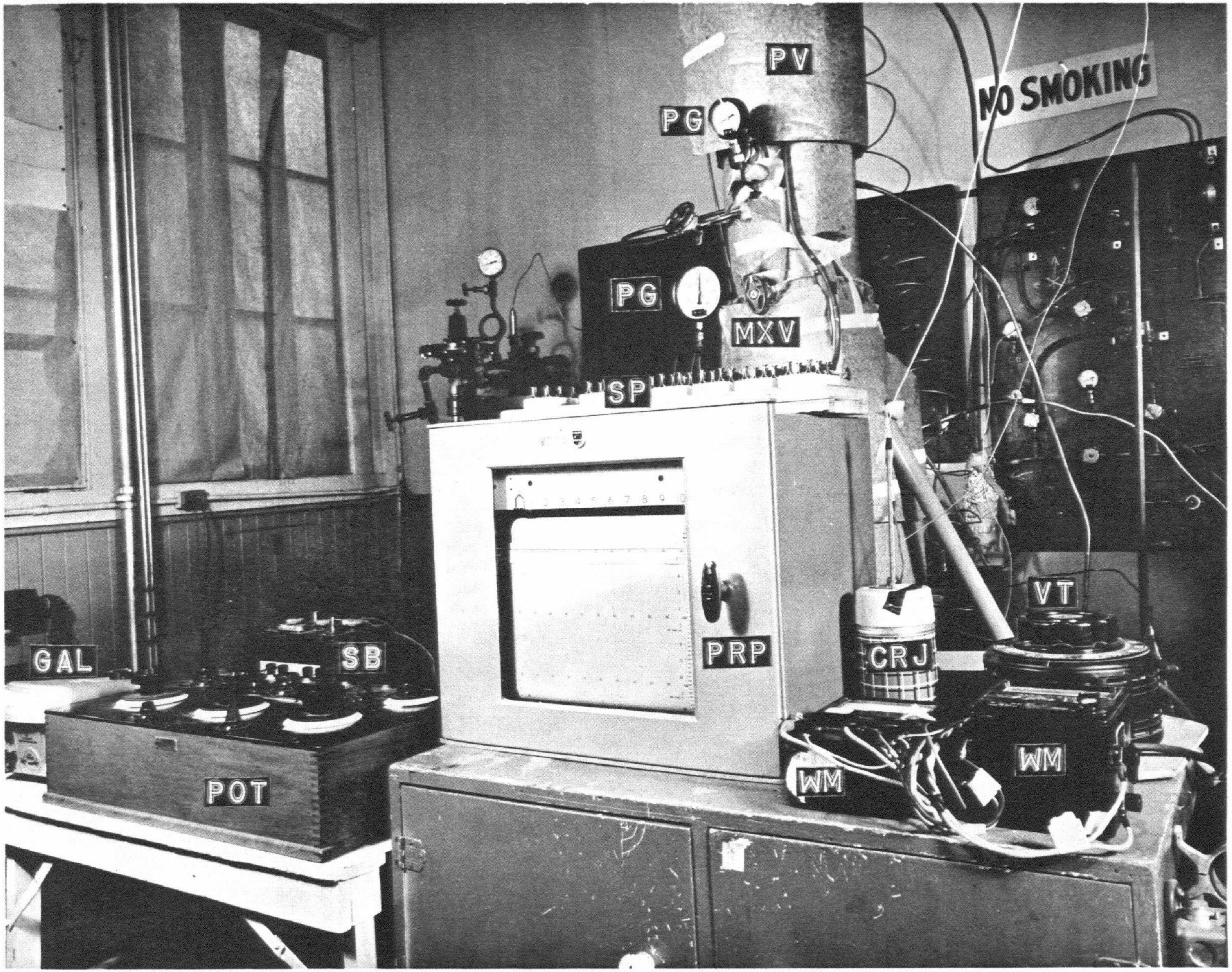


Fig. 6. Instrumentation layout

provided a check to the recorder reading from thermocouple TC-7. Periodic checks indicated the thermocouple readings were unaffected by the presence of electrical equipment in the test area.

f. Valves and Piping System (Fig. 3) - Valves and piping were arranged so that refrigerant could be charged to, or removed from the vessel. Air could be eliminated from the inside of the pressure vessel by a high vacuum pump (HVP, not illustrated) prior to charging with refrigerant. A pressure gauge (PG), mercury manometer (MM) and barometer (not illustrated) were used to ensure the accuracy of the boiling temperature measurements obtained from Thermocouple TC-6. A sight-glass (SG) was used to indicate the liquid refrigerant level and safety valves (SV) were provided to guarantee safe operation.

The steel testing vessel and the lower part of the heating surface assembly were completely insulated with 2-inch thick Microlite blanket insulation with vapor barrier to minimize the heat loss during the course of the experiment. The entire apparatus was electrically grounded.

IV. EXPERIMENTAL PROCEDURE

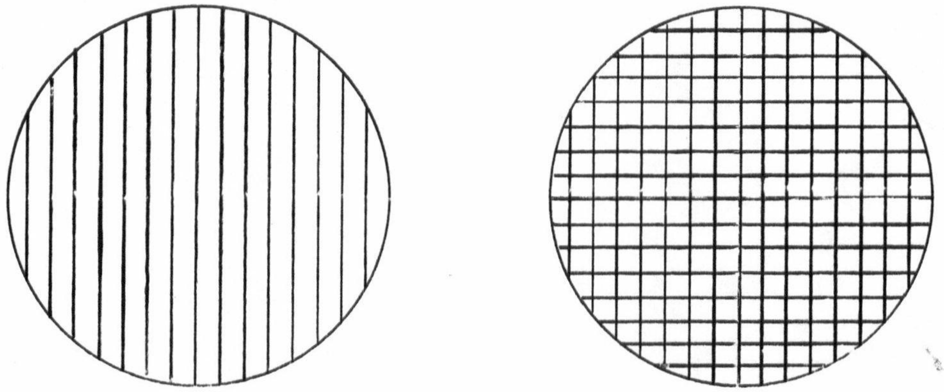
Before each series of test-runs, the heating surface was polished to the desired pattern (Fig. 7) using No. 400-A emery paper and cleaned with "Chlorothene" (CH_3CCl_3, inhibited 1,1,1-Trichloroethane). Profilometer measurements of surface roughness were taken before and after a series of test-runs. Roughness measurements are shown in Table II.

The inside of the pressure vessel was cleaned with "Chlorothene" before the apparatus was assembled. The apparatus was tested both at vacuum and under pressure for leakage.

Air was removed from the inside of the vessel by a high-vacuum pump and approximately sixteen pounds of refrigerant were charged into the vessel which resulted in a pool of liquid about 12 inches deep. The sight-glass indicated the proper liquid level.

Heat was supplied by three 300-watt cartridge heaters at the lower end of the heating rod. Heat flux densities were controlled by use of a Variac and the power input was indicated by a wattmeter which provided a check on the calculated heat flux values.

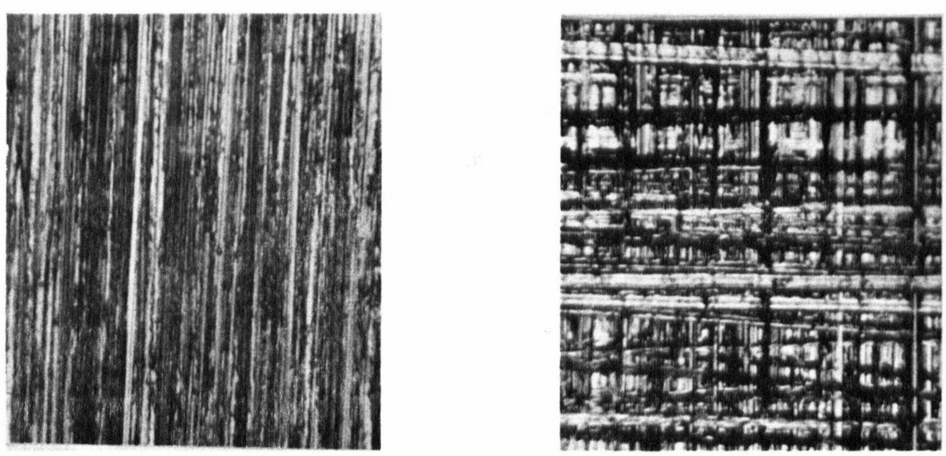
As evaporation of the liquid was taking place inside the vessel, the cooling effect of the condensing coil connected to the refrigeration plant caused vapor to condense on the outer surface of the coil and drip down to the liquid. The cooling effect of the condensing coil was controlled by the position of the manually adjusted expansion valve at the coil inlet and the globe valve at the coil outlet to obtain the desired constant boiling temperature of the liquid inside the vessel.



(a) (b)

Fig. 7. Finish patterns of copper heating surface

(a) parallel-line pattern (b) cross-line pattern



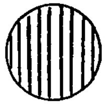
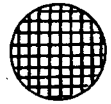
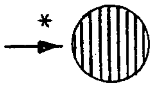
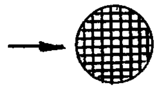
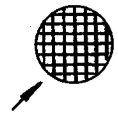
(a) (b)

Fig. 8. Photomicrographs of 400-A polished copper heating surfaces

(a) parallel-line pattern (b) cross-line pattern

(magnification power: 160)

Table II. Measurements of Surface Roughness (microinches r.m.s.)

Test-run Numbers \ Finish Pattern / Direction of measurement / Before or after a series of test-runs							Surface was finished by emery paper No.
		* 					
15.001 to 20.041	before	11.0 - 12.0	9.5 - 10.0	8.0 - 9.0	-	-	400-A
	after	9.5 - 10.5	9.0 - 10.0	8.5 - 9.5	-	-	
21.042 to 26.099	before	11.0 - 13.0	10.0 - 11.0	7.5 - 8.5	-	-	
	after	9.5 - 10.5	12.0 - 14.0	8.0 - 9.0			
27.100 to 31.138	before	-	-	-	11.0 - 12.0	12.0 - 14.0	
	after	-	-	-	10.0 - 11.0	11.0 - 12.0	
32.139 to 35.162	before	-	-	-	11.0 - 13.0	13.0 - 15.0	
	after	-	-	-	10.0 - 12.0	13.0 - 14.0	
36.163 to 39.189	before	-	-	-	12.0 - 13.0	13.0 - 14.0	
	after	-	-	-	10.0 - 12.0	13.0 - 14.0	
40.190 to 26.242	before	18.0 - 19.0	19.0 - 20.0	15.0 - 17.0	-	-	220-A

* Arrowhead (—➤) shows the direction of measurements

Temperatures were measured by thermocouples at various locations and recorded by the Philips recorder on a continuous chart at a speed of 300 mm per hour.

Steady-state boiling at any desired temperature and heat flux density was attained in about 30 minutes by adjusting the Variac and the valves at the inlet and outlet of the condensing coil. This condition was clearly defined when steady readings from the thermocouples were indicated on the chart of the Philips recorder. When steady-state boiling was attained, all instrument readings such as wattmeter, barometer, manometer, pressure gauge, ice bath thermometer, and room temperature thermometer were read and recorded.

After the completion of each series of test-runs, the refrigerant was removed from the vessel and the apparatus was disassembled. The above-mentioned steps were repeated after the heating surface was re-polished to a new desired finish pattern.

V. CALCULATIONS

The surface temperature of the heating surface was determined by extrapolation from temperatures measured at two or more points below the heating surface along the longitudinal axis of the vertical 2-inch diameter 12-inch long copper rod. No correction was made for the fin effect of the embedded thermocouple wires [9, 17] since the small effect was believed to be less than the accuracy of the instrument readings.

The thermal conductivity of the copper heating rod was assumed to be that of pure copper. By using the calculated cross-sectional area of the rod and the distance between any two of the four thermocouples, the heat flux could be calculated with good precision and apparently good accuracy. In calculating the heat flux density, the variation of the thermal conductivity of copper with temperature was allowed for.

The recorded thermocouple millivolt readings were converted to temperature by standard conversion tables. The recorded data (T_1, T_2, T_4, T_5, T_6 and W) and the calculated data (surface temperature "T_w", surface-to-liquid temperature difference "ΔT", unit heat flux "Q/A", and heat flux density by wattmeter "Q_w") are listed in Appendix II. The first column heading "TR-N" of Appendix II denotes the test-run numbers. Other headings are explained in "List of Symbols". Sample calculations are shown in Appendix I.

Measurements taken of the boiling temperature by thermocouple TC-6 were checked against temperature values obtained by means of the mercury manometer (MM) and barometer. The differences were less than half a degree (see Appendix I). Thus the thermocouple values were believed to be entirely reliable and were used without any correction.

VI. DISCUSSION OF PROCEDURE

To insure the consistency of homogeneous physical properties of the dichlorodifluoromethane (CCl_2F_2), Genetron-12 of Allied Chemical Canada Ltd. was used in all test-runs throughout the course of experimentation.

To study the effects of the surface texture on heat transfer coefficient, tests were conducted separately by finishing the heating surface in two different patterns (Fig. 7) while the geometric arrangement of the apparatus and testing conditions remained unchanged. Photomicrographs of the surface are shown in Fig. 8.

A 12-inch depth of liquid refrigerant over the heating surface seemed to be deep enough to avoid any effect of the liquid level on the heat transfer coefficient at nucleate boiling. Yamagata and co-workers [19] have conducted boiling heat transfer experiments at several depths of liquid level and showed that the heat transfer coefficients remain fairly constant over the range of liquid level from 40 to 60 mm.

To prevent possible hysteresis effects as described by Corty and Foust [13], the test sequence of each run was from higher to lower heat flux densities. A few test-runs from lower to higher heat flux densities were also conducted.

To mimimize variations of the heat transfer coefficient due to ageing of the heating surface, series of test-runs were completed in the minimum possible time after each polishing of the heating surface.

Copper- constantan thermocouple wires (Gauge 26 B & S) were used to measure the temperature at various locations and proper precautions were taken to avoid inaccurate readings. The thermocouples responded sensitively to any change in either heat input or test vessel pressure.

All instruments and equipment were carefully inspected, aligned, and calibrated before and during each series of test-runs.

The experimental results were accurate enough for analytic purposes. A high precision galvanometer and potentiometer were used to check the accuracy of temperature measurement by the Philips recorder of each thermocouple.

All experimental data in Appendix II were recorded by the Philips recorder except the second set of data in Test-run Nos. 45 and 46 which were measured by using a Cambridge vernier potentiometer and a Scalamp galvanometer as a check. A comparison of pairs of values in Test-run Nos. 45 and 46 show that apparently the Philips recorder gave quite reliable and accurate readings.

A sensitive microphone was used to try to detect the instant of inception of boiling without success.

VII. ANALYSIS OF TEST RESULTS

The results of this investigation are summarized in Fig. 9 in which the heat transfer coefficient "h" is plotted as a function of the unit heat flux "Q/A" and in Figs. 10, 11, 12, and 13 in which the heat transfer coefficient is plotted as a function of the temperature difference "ΔT".

In Fig. 9, the results of the investigation are compared with those given in recent papers by Stephan [3] and Furse [15].

In the nucleate boiling region, the relationship between heat transfer coefficient and temperature difference can usually be approximated by the empirical relation [1, 12].

$$h = \text{const.}\ (Tw - Ts)^{m} \qquad (8)$$

with m from 1 to 3; the constant depends on the thermodynamic properties of the vapor and of the liquid and also on the solid-liquid combination.

Comparison to Stephan's and Furse's results for boiling Freon-12, shown in Fig. 9 revealed that all data obtained in the present investigation gave curves which were considerably steeper than those of these investigators. It was found, after correlating the experimental data by Equation (8), that Stephan's and Furse's results show a value of "m" of 2.6 and 6.54 respectively and the present case yields a very much larger value of 24 for "m".

Recent experimental results, as mentioned in Zuber's papers [1, 5], show that both the value of the constant and of the exponent in Equation (8) depend on the characteristics of the surface. The value of the exponent "m" at a constant pressure and for the

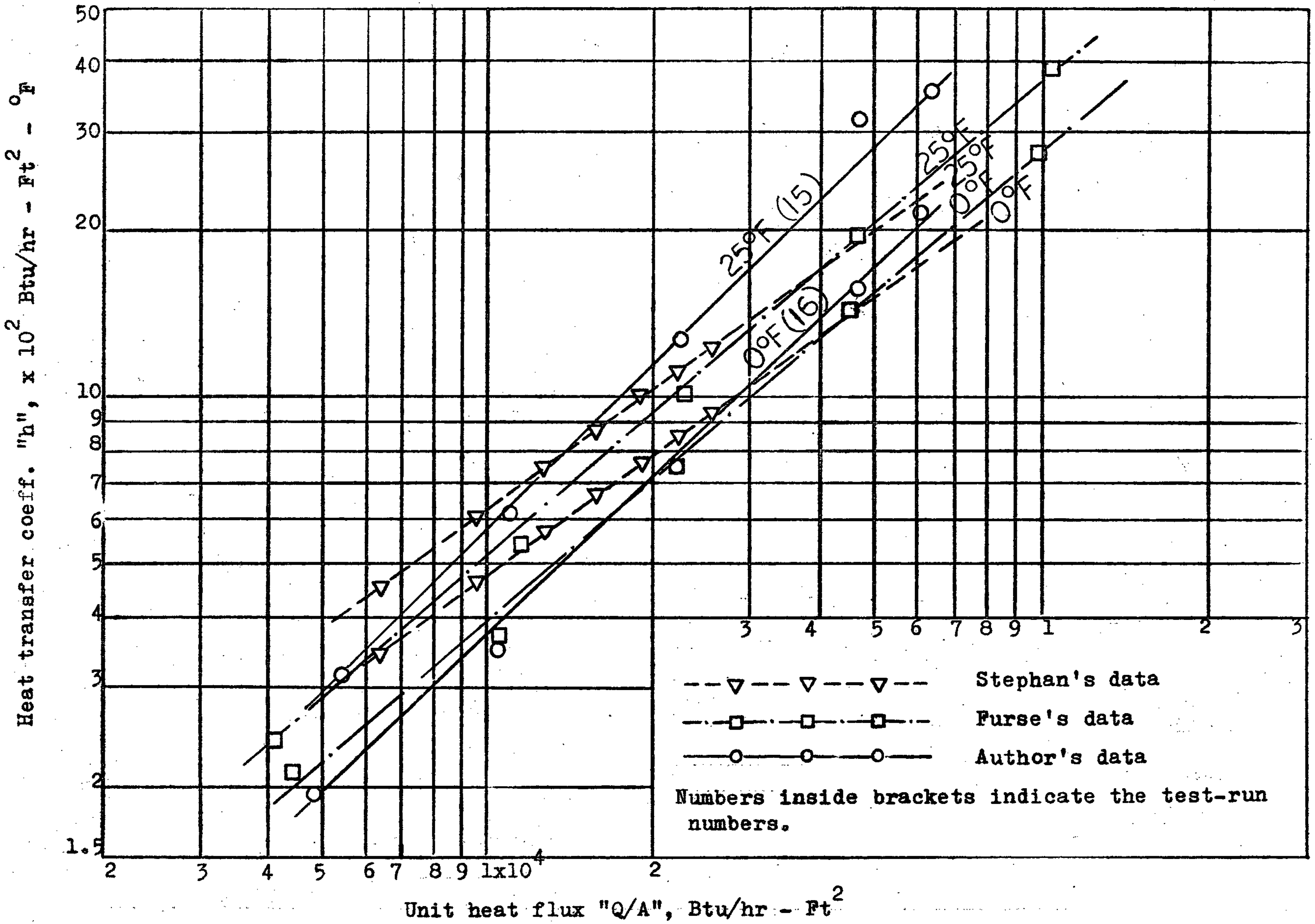


Fig. 9. Comparison between Stephan's, Furse's, and author's experimental results

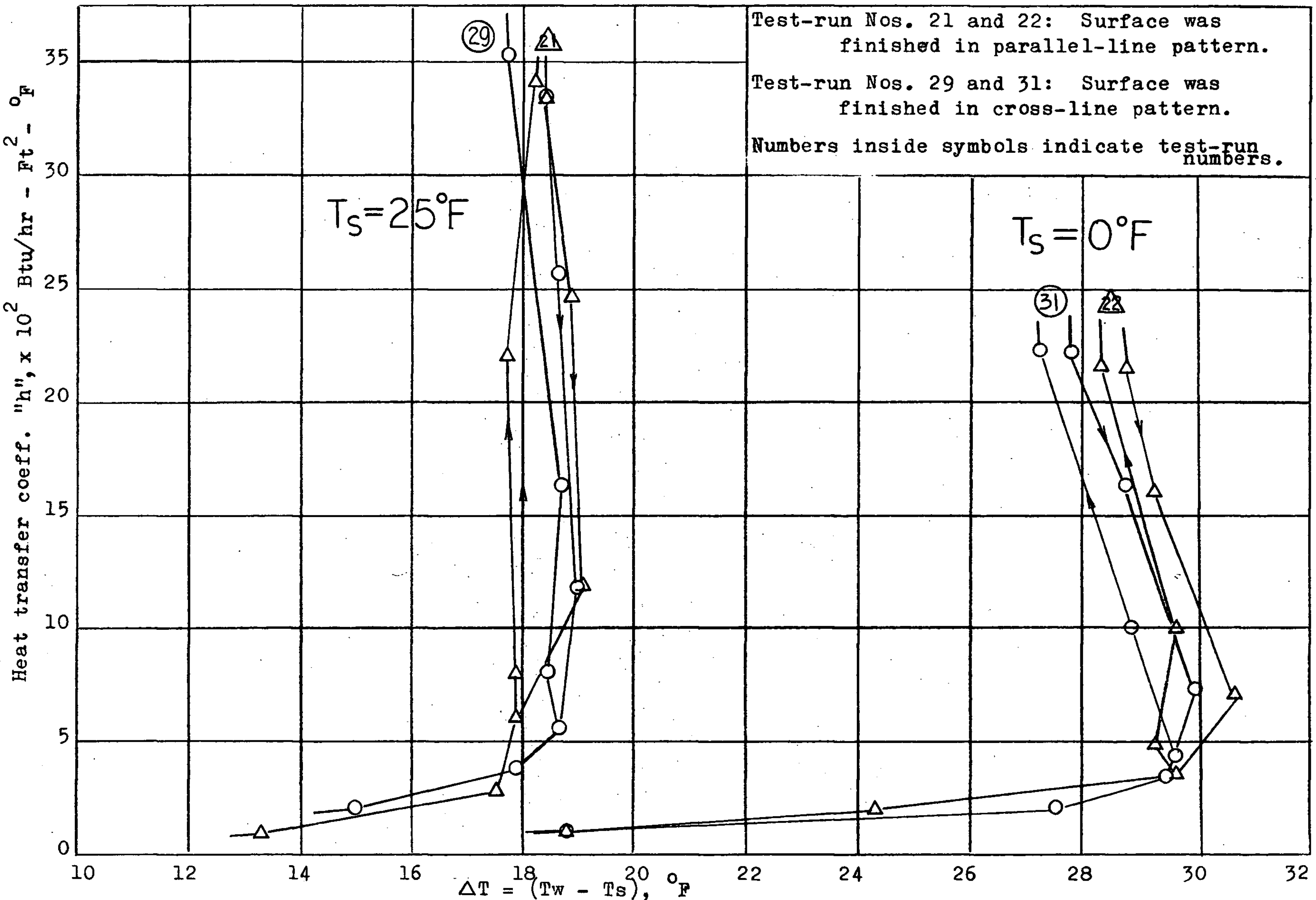


Fig. 10. Boiling curve of high-low-high heat flux densities

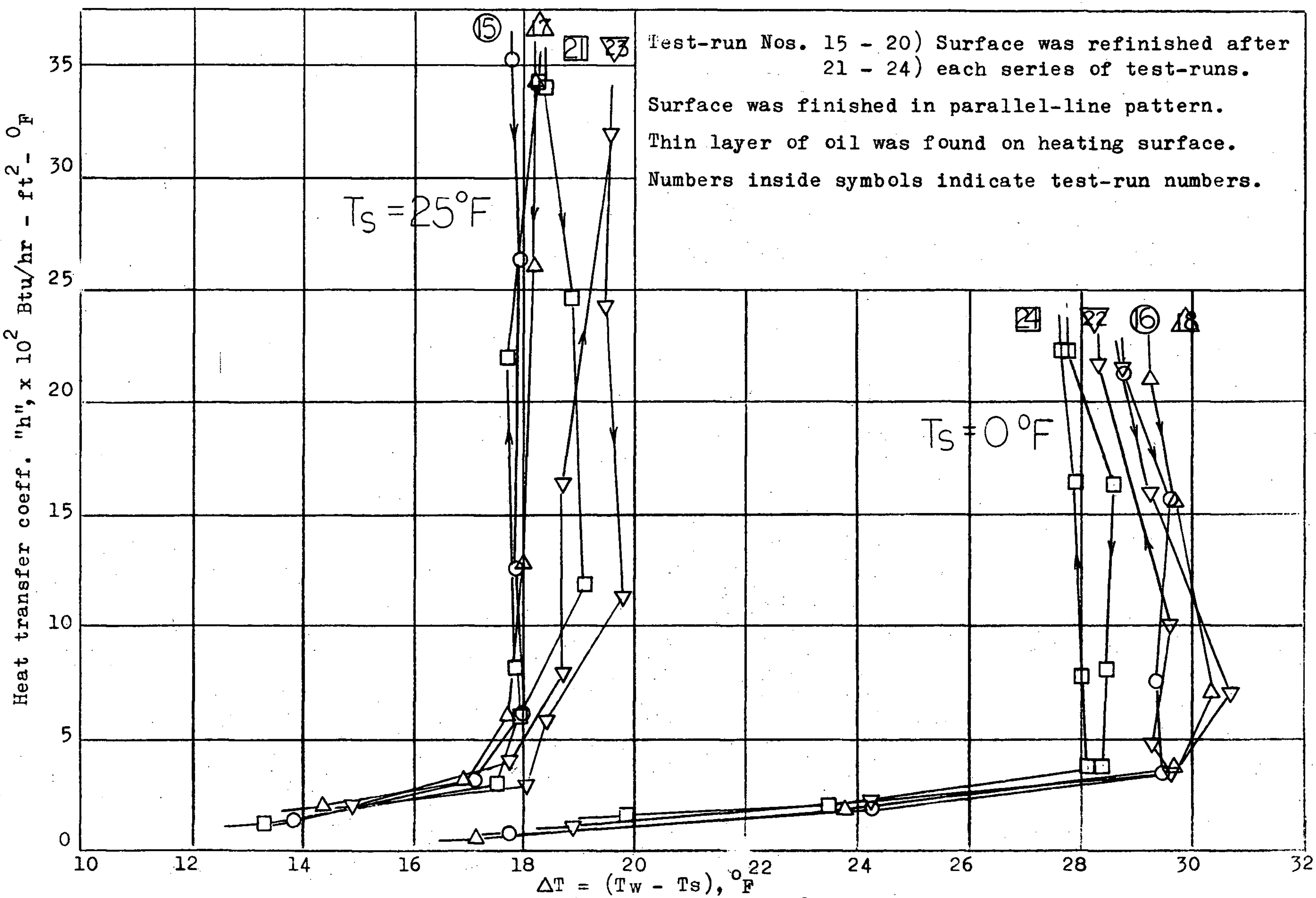


Fig. 11 Boiling curve of Genetron-12 at 25 °F & 0 °F saturation temperatures (parallel-line finish pattern)

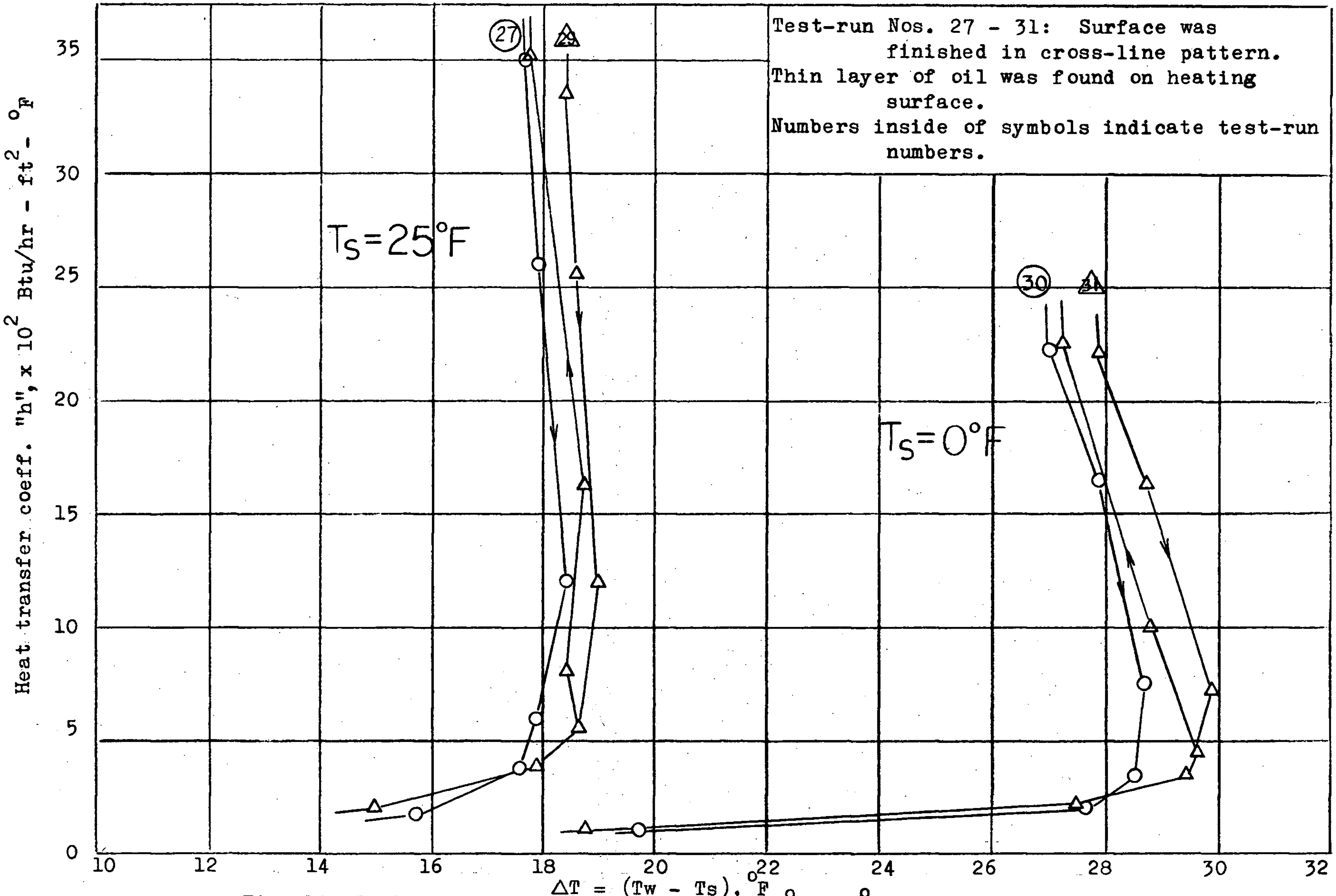


Fig. 12 Boiling curve of Genetron-12 at 25 °F & 0 °F saturation temperatures (cross-line finish pattern)

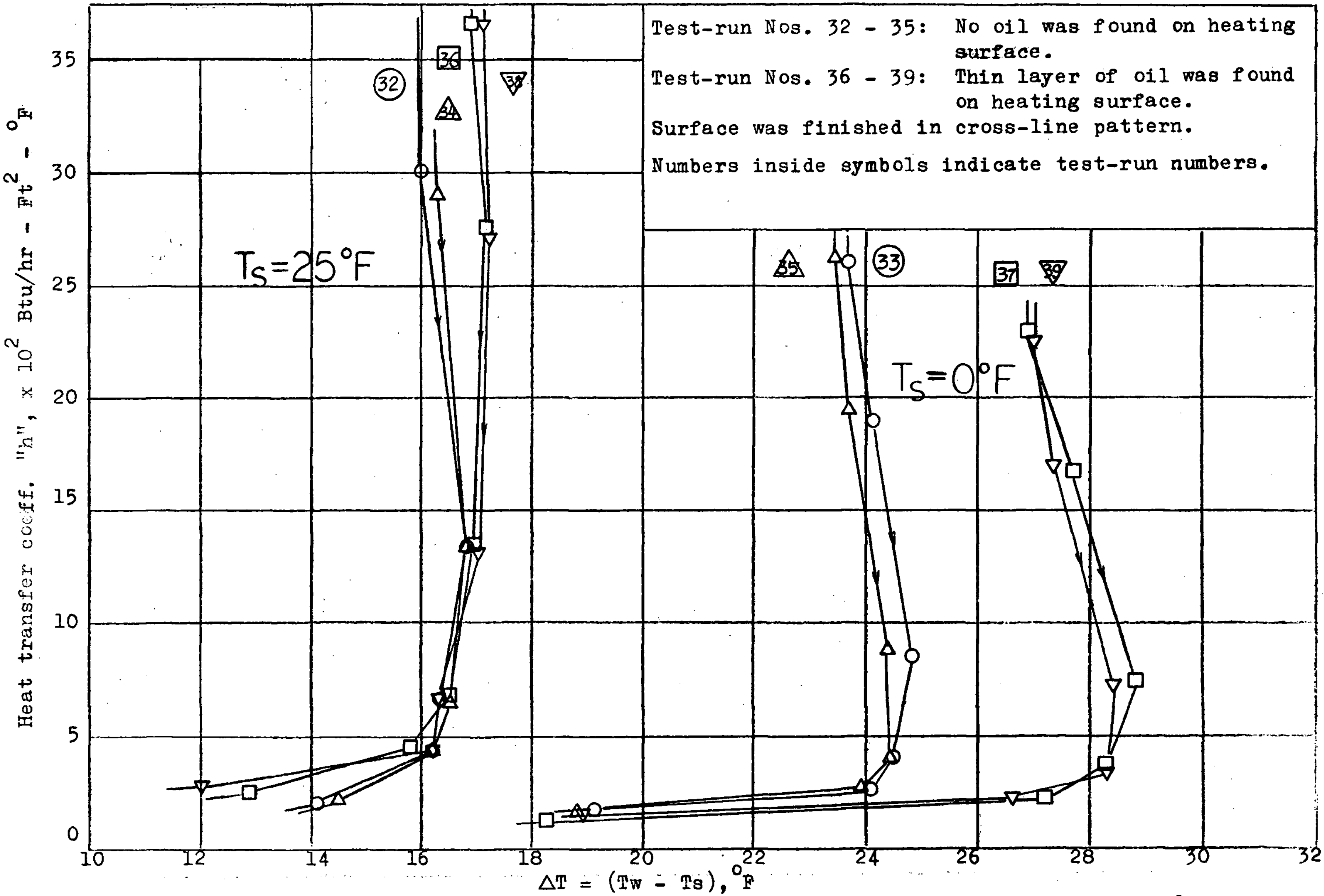


Fig. 13. Effects of heat transfer coefficient by thin layer of oil on heating surface

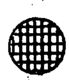
same solid-liquid combination can be varied from 3 to 24 by changing the surface roughness.

Examination of Figs. 10 to 13, shows that all boiling curves (h vs. ΔT) plotted from the present experimental data revealed an "S" shape which deviates in a pronounced manner from the general form (Fig. 1) assumed for a boiling curve, especially at lower saturation temperature. None of Stephan's or Furse's boiling curves was found in "S" shape.

A comparison of the experimental parameters of Stephan [3], Furse [15] and the author is shown in Table III. Disregarding the surface finish pattern, all conditions or values of the parameters are nearly the same except for the considerable difference in surface roughness.

Table III. Comparison of Experimental Parameters

Testing Under Sat. Temp. $0^{o}F$ & $25^{o}F$

Investigator	Heating Surface	Refrigerant	Finish Pattern	Surface Roughness (microinches r.m.s.)
Stephan	130 mm. dia., horizontal copper surface	Freon-12	Unknown	40
Furse	2 in. dia., horizontal copper surface	Freon-12		8-15 (radial) 18-27 (circumferential)
Author	2 in. dia., horizontal copper surface	Freon-12	 	9 - 13

From Fig. 9, it is noted that the finer surface finish yields the steeper boiling curve. When this steeper curve was converted and replotted as a function of "h" and temperature difference, an "S" shaped boiling curve was obtained. Therefore, it may be concluded that an "S" shaped boiling curve is attributable to certain specific nucleating characteristics which occur on surface with such a finer degree of finish.

Zuber [1] confirmed that similar results of an "S" shaped boiling curve were obtained previously by Corty and Foust [13] , and Long [18] . Zuber [1], Rohsenow [6], Westwater [2], and others all agreed that a generalized correlation cannot be expected unless the correlation takes into account the nucleating characteristics of the heating surface and of the bubble population.

Since all the present correlations for nucleate boiling were evaluated from a normal-shape (Fig. 1) boiling curve, the present data cannot be correlated by any of the existing empirical equations suggested by previous investigators [6, 14, 16, etc.] .

Unfortunately, at present, there is no correlation which can predict a boiling curve in "S" shape. Further investigation in the nucleating characteristics of the heating surface and solid-liquid combination may give an empirical equation of the type

$$h = C_1 (\Delta T)^m + C_2 (\Delta T)^n \text{ -------------- } (9)$$

which might predict the true shape of a boiling curve in the nucleate boiling region.

Corty et al [13] obtained an "S" shape boiling curve when heat was supplied from lower to higher heat flux. They attributed the effect to hysteresis. In the present investigation, a few test-runs were conducted both from higher to lower and lower to higher heat flux densities, and hysteresis effects in boiling were not observed. The shape of the boiling curve for both increasing and decreasing heat flux remains the same as shown in Figs. 10, 11 and 12.

The heat transfer coefficients obtained were virtually independent of surface finish pattern within the range of experiments performed. (Figs. 11 and 12). A comparison of Figs. 10 and 11 shows that the cross-line finish pattern had a slightly better heat transfer coefficient than that of the parallel-line. This is probably due to the fact that the cross-line pattern had more nucleation cavities than the parallel-line pattern.

Identical boiling curves were only approximately obtained for separate tests of the same surface after each refinishing. This is attributed to the fact that different thicknesses of light oil contaminated with dirt were found on the heating surface after each series of test-runs.

A clean surface or a surface with a thin layer of oil gave slightly better rates of heat transfer (see Fig. 13) than a heavily contaminated surface. The presence of oil in the apparatus was probably due to either impurities in the refrigerant or the residual lubricant in the apparatus and its piping system from Furse's previous experiment in "Pool-Boiling of Mixtures of Oil and Refrigerant" [15].

The slope of the boiling curve at the nucleate boiling region was found to decrease gradually in each consecutive series of test-runs (Figs. 11 and 12). This phenomenon indicated that the reduced rate of boiling heat transfer was due to the ageing effect of the surface and the fouling effect of the solids deposited on the surface during the time of use.

VIII. CONCLUSIONS

For boiling of Freon-12 on a copper surface as described, classical correlations are inadequate [8].

No great influence of pattern of finish upon heat transfer coefficient has been observed provided that the overall roughness is the same.

Slight influence of surface contamination upon heat transfer coefficient was noted during the course of the investigation.

The experimental results of the present and few other investigations [13, 18] have concluded that the negative-slope or "S" shape is another possible form of a boiling curve which may be due to the unpredictable nucleating characteristics of a heating surface and of bubble population. Therefore, further investigations, both theoretical and experimental, in boiling heat transfer are required to be conducted in order to obtain a complete knowledge of bubble mechanics.

IX. SUGGESTIONS FOR MODIFICATION OF APPARATUS

A sight window on the main body of the vessel near the heating surface is deemed indispensable in observing the boiling phenomena and the flow pattern of the boiling liquid in the immediate vicinity of the horizontal surface during experimentation. It would also be used to take photographic pictures for studying the bubble separation mechanism and for searching a representative model of boiling heat transfer.

The unsteady power-line voltage caused a fluctuation of heat flux generated by the three cartridge heaters which in turn made it difficult to maintain a steady-state condition in the apparatus. It is recommended that a constant voltage regulator be installed between the power source and the variable transformer.

A fine-control variable transformer is needed to control the exact value of the heat input.

A fine-control expansion valve should be installed at the inlet of the condensing coil. It took a much longer time to attain a desired saturation temperature inside the vessel by adjusting the present valve.

In order to obtain the pattern of the temperature distribution of the boiling liquid, more thermocouples should be installed at different liquid levels above the heating surface.

X. APPENDICES

Appendix I. SAMPLE CALCULATIONS

d = diameter of heating surface = 1.9695 in. = 0.164 ft.

A = area of heating surface = 0.02115 sq. ft.

x_1 = distance to thermocouple 1 from surface = 0.253 in.

x_5 = distance to thermocouple 5 from surface = 3.035 in.

Data for Test-run No. 15.001:-

Barometer reading = 29.82 in. Hg.

Barometer calibration error = -0.08 in. Hg.

Heat input to apparatus by wattmeter = 403 watts.

Room temperature = 77.3 °F.

Thermocouple No.	1	2	4	5	6	7
Millivolts	.360	-	1.066	1.845	-.149	.996
Temperature (°F)	48.65	-	80.4	114.0	25.0	77.3

Calculation for Test-run No. 15.001:-

$$T_w = T_1 - \frac{x_1}{x_5 - x_1}(T_5 - T_1) = 42.72\ ^{\circ}F.$$

$$\Delta T = T_w - T_6 = 17.72\ ^{\circ}F.$$

$$k = 225 - 0.04\,(T_4) = 221.8\ \text{Btu/hr-ft-}^{\circ}F.$$

$$Q/A = \frac{k(T_5 - T_1)}{(x_5 - x_1)} = 62472\ \text{Btu/hr-ft}^2$$

$$Q = (Q/A)\times(A) = 1321\ \text{Btu/hr.}$$

$$h = (Q/A)/\Delta T = 3526\ \text{Btu/hr-ft}^2 - {}^{\circ}F.$$

$$Q_w = 3.41 \times 403 = 1374\ \text{Btu/hr.}$$

P/Q = percentage difference between Q and Q_w.

$$= \frac{Q - Q_w}{Q_w} = 3.85\%.$$

Liquid temperature determined from vessel pressure:

(Pressure in vessel above liquid) = (Manometer reading) $\pm$ (Manometer temp. correction) + (Mercury barometer reading) $\pm$ (Barometer correction)

P_v = (50.15 - 0.208 + 29.82 - 0.08) = 79.67 in. Hg. abs.

Temperature at liquid surface = 24.70 $^{\circ}$F. (corresponding to the above vessel temperature)

Difference between pressures at liquid surface and at thermocouple TC-6 = 6 in. Genetron-12 at 25° F.

= 0.3 psi.

Temperature difference corresponding to above = 0.4°F.

Temperature at thermocouple 6 = 24.7 + 0.4 = 25.1 $^{\circ}$F.

Note: Thermocouple TC-3 was damaged and not connected.

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12)

T-R NR	T1	T2*	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
15.001	48.65	0.	80.40	114.00	25.00	403.00	42.72	17.72	62472.	1321.	3526.	1374.	3.85
15.002	47.70	0.	71.40	96.80	25.35	303.00	43.24	17.89	47014.	994.	2628.	1033.	3.76
15.003	45.00	0.	56.00	68.55	25.00	146.00	42.86	17.86	22612.	478.	1265.	498.	3.94
15.004	44.40	0.	49.50	55.90	25.40	77.00	43.36	17.96	11055.	234.	615.	263.	10.95
15.005	43.00	0.	45.20	48.60	25.40	40.40	42.49	17.09	5387.	114.	315.	138.	17.29
15.006	39.50	0.	40.10	41.50	25.50	20.50	39.32	13.82	1926.	41.	139.	70.	41.73
16.007	34.40	0.	64.90	98.10	-0.15	398.00	28.62	28.77	61065.	1292.	2123.	1357.	4.84
16.008	33.90	0.	56.70	82.10	-0.05	303.00	29.52	29.57	46274.	979.	1565.	1033.	5.28
16.009	31.80	0.	42.60	54.75	0.35	149.00	29.72	29.37	22089.	467.	752.	508.	3.05
16.010	30.90	0.	35.80	41.60	0.50	74.50	29.93	29.43	10311.	218.	350.	254.	14.16
16.011	24.80	0.	26.80	29.75	0.10	39.50	24.35	24.25	4778.	101.	197.	135.	24.98
16.012	18.10	0.	18.20	19.50	0.25	20.20	17.97	17.72	1353.	29.	76.	69.	58.45
17.013	49.25	0.	80.50	114.45	25.15	400.00	43.33	18.18	62328.	1318.	3428.	1364.	3.36
17.014	47.75	0.	71.50	96.95	25.15	306.00	43.28	18.13	47109.	996.	2598.	1043.	4.51
17.015	45.45	0.	56.60	69.15	25.35	151.00	43.30	17.95	22754.	481.	1263.	515.	6.54
17.016	43.70	0.	48.70	54.70	25.00	74.50	42.70	17.70	10576.	224.	597.	254.	11.95
17.017	42.40	0.	44.70	47.90	24.95	40.40	41.90	16.95	5292.	112.	312.	138.	18.76
17.018	40.05	0.	41.20	42.95	25.45	24.70	39.79	14.34	2792.	59.	195.	84.	29.89
18.019	35.60	0.	66.40	100.00	0.50	403.00	29.75	29.25	61720.	1305.	2110.	1374.	5.01
18.020	34.55	0.	57.50	82.80	0.50	301.00	30.17	29.67	46316.	980.	1561.	1026.	4.56
18.021	32.80	0.	43.70	55.35	0.40	150.00	30.75	30.35	21700.	459.	715.	511.	10.27
18.022	30.65	0.	35.80	41.80	0.	77.00	29.64	29.64	10745.	227.	363.	263.	13.45
18.023	24.45	0.	26.35	29.00	0.30	40.20	24.04	23.74	4392.	93.	185.	137.	32.24
18.024	17.70	0.	18.25	18.80	0.50	20.30	17.60	17.10	1063.	22.	52.	69.	67.51
19.025	37.85	0.	38.60	39.90	25.55	19.80	37.66	12.11	1975.	42.	163.	68.	33.15
19.026	40.10	0.	42.30	45.40	25.50	38.70	39.62	14.12	5101.	108.	361.	132.	18.24
19.027	42.10	0.	47.10	53.20	25.65	75.50	41.09	15.44	10675.	226.	691.	257.	12.31
19.028	44.50	0.	55.00	67.50	25.60	149.00	42.41	16.81	22088.	467.	1314.	508.	8.06
19.029	47.05	0.	70.30	96.85	25.20	303.00	42.53	17.33	47694.	1009.	2752.	1033.	2.37
19.030	48.95	0.	79.60	114.05	25.25	398.00	43.04	17.79	62242.	1316.	3499.	1357.	3.00
20.031	17.15	0.	17.35	18.45	0.10	19.70	17.03	16.93	1257.	27.	74.	67.	60.43
20.032	21.60	0.	23.50	26.40	0.15	40.50	21.16	21.01	4636.	98.	221.	138.	29.01
20.033	22.85	0.	27.35	33.60	0.	74.50	21.87	21.87	10375.	219.	474.	254.	13.63
20.034	25.70	0.	36.60	48.90	0.	149.00	23.59	23.59	22354.	473.	947.	508.	5.95
20.035	29.25	0.	52.30	77.70	-0.20	296.00	24.85	25.05	46551.	985.	1858.	1009.	2.45
20.036	31.75	0.	63.40	97.80	-0.20	402.00	25.75	25.95	63335.	1340.	2440.	1371.	2.28
20.037	30.00	0.	53.30	79.30	-0.35	300.00	25.52	25.87	47359.	1002.	1830.	1023.	2.09
20.038	28.05	0.	39.00	51.45	0.	151.00	25.93	25.93	22537.	477.	869.	515.	7.43
20.039	26.35	0.	31.30	37.65	0.	76.00	25.32	25.32	10898.	230.	430.	259.	11.06
20.040	23.30	0.	25.00	27.60	0.	40.50	22.91	22.91	4152.	88.	181.	138.	36.42
20.041	18.70	0.	19.30	20.30	-0.10	20.50	18.55	18.65	1546.	33.	83.	70.	53.21

* Zero values in column "T2" indicate readings were unobtainable.

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
21.042	48.75	60.30	79.40	113.65	24.50	402.00	42.86	18.36	62053.	1312.	3380.	1371.	4.26
21.043	47.75	56.20	70.70	96.25	24.50	303.00	43.35	18.85	46445.	982.	2464.	1033.	4.93
21.044	45.40	49.30	56.20	69.00	24.20	152.00	43.26	19.06	22659.	479.	1189.	518.	7.54
21.045	43.40	45.20	48.40	54.60	24.50	75.00	42.38	17.88	10769.	228.	602.	256.	10.95
21.046	42.40	43.10	44.70	47.80	24.40	40.00	41.91	17.51	5195.	110.	297.	136.	19.44
21.047	38.00	38.05	38.85	39.75	24.60	20.00	37.84	13.24	1685.	36.	127.	68.	47.73
21.048	43.70	46.15	50.50	58.70	24.50	100.00	42.34	17.84	14417.	305.	808.	341.	10.58
21.049	46.60	53.90	65.60	87.15	25.25	250.00	42.92	17.67	38868.	822.	2200.	852.	3.57
21.050	49.25	60.60	79.90	114.25	25.15	404.00	43.35	18.20	62143.	1314.	3415.	1378.	4.60
21.051	49.40	0.	80.00	114.70	24.45	405.00	43.47	19.02	62429.	1320.	3282.	1381.	4.39
22.052	34.60	46.40	64.80	99.15	0.	400.00	28.74	28.74	61881.	1309.	2153.	1364.	4.05
22.053	34.00	42.90	56.80	82.50	0.35	301.00	29.60	29.25	46562.	985.	1592.	1026.	4.06
22.054	33.00	36.75	43.40	55.45	0.30	150.00	30.96	30.66	21605.	457.	705.	511.	10.67
22.055	30.75	0.	35.75	41.35	0.20	75.00	29.79	29.59	10215.	216.	345.	256.	15.53
22.056	25.00	0.	27.00	29.90	0.30	39.70	24.56	24.26	4729.	100.	195.	135.	26.11
22.057	19.20	0.	20.00	21.30	0.20	24.60	19.01	18.81	2029.	43.	108.	84.	48.83
22.058	30.85	0.	37.75	45.65	0.30	101.00	29.51	29.21	14257.	302.	488.	344.	12.45
22.059	32.70	38.10	47.00	63.70	0.30	200.00	29.89	29.59	29813.	631.	1008.	682.	7.54
22.060	34.60	45.80	64.45	98.35	0.50	398.00	28.81	28.31	61118.	1293.	2159.	1357.	4.75
23.061	50.35	61.90	72.20	115.50	24.85	400.00	44.43	19.58	62373.	1319.	3185.	1364.	3.28
23.062	48.90	57.60	71.90	98.10	25.00	303.00	44.43	19.43	47106.	996.	2424.	1033.	3.58
23.063	46.65	50.50	56.80	69.75	24.80	149.00	44.55	19.75	22177.	469.	1123.	508.	7.69
23.064	44.60	46.00	49.50	55.55	25.20	74.50	43.61	18.41	10526.	223.	572.	254.	12.37
23.065	43.75	0.	45.80	49.20	25.20	40.50	43.26	18.06	5243.	111.	290.	138.	19.71
23.066	40.50	0.	41.45	43.50	25.35	25.00	40.23	14.88	2888.	61.	194.	85.	28.35
23.067	44.00	0.	46.75	51.00	25.65	49.50	43.36	17.71	6732.	142.	380.	169.	15.64
23.068	45.20	47.40	51.90	60.30	25.15	100.00	43.83	18.68	14509.	307.	777.	341.	10.01
23.069	46.80	0.	61.80	78.70	25.25	204.00	43.90	18.65	30598.	647.	1640.	696.	6.97
23.070	50.65	0.	81.25	115.30	25.25	403.00	44.78	19.53	61794.	1307.	3164.	1374.	4.90
24.071	34.10	45.90	64.20	98.60	0.50	400.00	28.24	27.74	61840.	1308.	2229.	1364.	4.11
24.072	33.35	41.70	56.00	81.85	0.40	302.00	28.95	28.55	46568.	985.	1631.	1030.	4.36
24.073	30.90	35.20	42.00	54.45	0.30	151.00	28.76	28.46	22669.	479.	796.	515.	6.89
24.074	29.65	30.90	34.85	40.70	0.30	75.50	28.65	28.35	10650.	225.	376.	257.	12.51
24.075	24.20	24.60	26.00	29.00	0.30	40.50	23.76	23.46	4634.	98.	197.	138.	29.04
24.076	20.30	0.	21.10	23.00	0.20	29.00	20.05	19.85	2609.	55.	131.	99.	44.21
24.077	28.90	30.00	33.60	39.80	-0.20	76.50	27.91	28.11	10508.	222.	374.	261.	14.81
24.078	29.90	0.	40.00	52.35	-0.10	149.00	27.86	27.96	21618.	457.	773.	508.	10.01
24.079	32.00	40.25	54.00	79.60	-0.20	300.00	27.68	27.88	45721.	967.	1640.	1023.	5.47
24.080	33.25	44.75	63.40	98.10	-0.25	403.00	27.36	27.61	62184.	1315.	2252.	1374.	4.30
25.081	40.40	40.60	41.50	43.40	25.15	25.00	40.13	14.98	2888.	61.	193.	85.	28.35
25.082	42.15	43.10	45.10	49.00	25.15	50.00	41.53	16.38	6590.	139.	402.	170.	18.25
25.083	46.15	50.10	56.80	69.30	25.10	150.50	44.05	18.95	22225.	470.	1173.	513.	8.41
25.084	51.05	62.50	81.40	116.00	25.25	403.00	45.15	19.90	62079.	1313.	3119.	1374.	4.46
25.085	49.30	58.15	72.40	98.80	25.35	305.00	44.81	19.46	47389.	1002.	2436.	1040.	3.63
25.086	46.45	50.50	57.25	70.10	25.35	150.00	44.30	18.95	22703.	480.	1198.	511.	6.13
25.087	44.55	46.15	49.25	55.30	25.15	74.00	43.57	18.42	10334.	219.	561.	252.	13.38
25.088	42.85	43.40	45.00	48.10	25.20	40.00	42.37	17.17	5051.	107.	294.	136.	21.68
25.089	40.90	40.95	42.00	43.70	25.15	24.70	40.65	15.50	2695.	57.	174.	84.	32.32
26.090	18.55	-0.	19.50	21.15	0.30	25.30	18.31	18.01	2513.	53.	139.	86.	38.40
26.091	23.30	23.75	26.00	29.85	0.35	50.00	22.71	22.36	6323.	134.	283.	170.	21.57
26.092	26.00	28.00	33.15	41.10	0.30	101.00	24.63	24.33	14558.	308.	598.	344.	10.60
26.093	29.00	34.80	44.00	61.15	0.35	202.00	26.08	25.73	30936.	654.	1202.	689.	5.01
26.094	33.40	44.85	63.45	97.70	0.05	396.00	27.56	27.51	61656.	1304.	2241.	1350.	3.43

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
26.095	32.25	41.05	55.00	81.15	0.05	303.00	27.81	27.76	46961.	993.	1692.	1033.	3.87
26.096	30.50	35.15	41.50	53.70	0.60	150.00	28.39	27.79	22334.	472.	804.	511.	7.65
26.097	28.75	30.30	34.10	39.90	0.35	76.00	27.74	27.39	10748.	227.	392.	259.	12.29
26.098	27.25	28.00	29.95	33.90	0.45	50.50	26.65	26.20	6415.	136.	245.	172.	21.21
26.099	19.05	-0.	20.40	21.80	0.40	25.30	18.80	18.40	2657.	56.	144.	86.	34.85

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
27.100	48.80	60.10	79.10	113.30	25.30	400.00	42.94	17.64	61674.	1304.	3496.	1364.	4.37
27.101	47.60	56.30	70.40	96.25	25.30	300.00	43.18	17.88	46592.	985.	2605.	1023.	3.67
27.102	45.80	49.70	56.45	69.00	25.30	149.00	43.69	18.39	22274.	471.	1211.	508.	7.28
27.103	44.10	45.80	49.25	55.25	25.25	75.00	43.09	17.84	10719.	227.	601.	256.	11.36
27.104	43.45	44.60	46.55	50.30	25.30	51.00	42.83	17.53	6588.	139.	376.	174.	19.88
27.105	41.25	41.55	42.40	44.05	25.30	24.50	41.00	15.70	2695.	57.	172.	84.	31.77
28.106	33.50	44.60	63.40	97.60	0.35	402.00	27.68	27.33	61465.	1300.	2249.	1371.	5.17
28.107	33.30	41.70	56.00	81.80	0.45	303.00	28.90	28.45	46568.	985.	1637.	1033.	4.68
28.108	31.30	35.25	41.90	53.90	0.45	151.00	29.25	28.80	21755.	460.	755.	515.	10.64
28.109	29.90	31.55	35.15	40.70	0.40	76.00	28.92	28.52	10409.	220.	365.	259.	15.05
28.110	28.25	29.00	30.85	34.95	0.45	49.50	27.64	27.19	6462.	137.	238.	169.	19.03
28.111	20.30	20.45	21.15	22.50	0.45	25.20	20.10	19.65	2126.	45.	108.	86.	47.68
29.112	49.55	60.70	79.90	114.10	25.30	403.00	43.69	18.39	61713.	1305.	3356.	1374.	5.02
29.113	48.40	57.00	71.80	98.10	25.30	307.00	43.89	18.59	47585.	1006.	2560.	1047.	3.86
29.114	46.35	50.40	57.30	69.65	25.30	151.00	44.23	18.93	22367.	473.	1181.	515.	8.13
29.115	44.95	46.60	49.90	55.90	25.35	75.00	43.96	18.61	10525.	223.	566.	256.	12.96
29.116	43.85	44.60	46.90	51.00	25.35	50.80	43.20	17.85	6876.	145.	385.	173.	16.04
29.117	40.65	41.10	42.00	43.90	25.40	25.20	40.35	14.95	3128.	66.	209.	86.	23.00
29.118	45.15	47.65	52.25	60.50	25.35	102.00	43.76	18.41	14749.	312.	801.	348.	10.32
29.119	46.95	52.80	62.15	78.60	25.40	200.00	44.08	18.68	30356.	642.	1625.	682.	5.86
29.120	49.10	60.65	79.10	114.60	25.40	405.00	43.15	17.75	62630.	1325.	3528.	1381.	4.09
30.121	33.20	44.25	63.40	97.60	0.35	404.00	27.35	27.00	61753.	1306.	2287.	1378.	5.19
30.122	32.70	41.10	55.20	80.60	0.50	298.00	28.35	27.85	45999.	973.	1652.	1016.	4.26
30.123	31.00	35.00	41.50	53.20	0.35	149.00	28.98	28.63	21371.	452.	746.	508.	11.04
30.124	29.85	-0.	34.65	40.05	0.40	74.50	28.92	28.52	9831.	208.	345.	254.	18.15
30.125	28.60	29.45	31.40	34.60	0.40	50.00	28.06	27.66	5786.	122.	209.	170.	28.22
30.126	20.30	20.50	21.20	22.40	0.40	25.00	20.11	19.71	2029.	43.	103.	85.	49.66
31.130	34.05	45.25	64.15	98.40	0.35	400.00	28.21	27.86	61697.	1305.	2215.	1364.	4.33
31.131	33.50	41.80	56.20	82.40	0.35	305.00	29.06	28.71	46951.	993.	1635.	1040.	4.52
31.132	32.45	36.50	43.00	55.00	0.45	151.00	30.40	29.95	21702.	459.	725.	515.	10.86
31.133	30.75	-0.	35.80	41.20	0.40	75.50	29.80	29.40	10070.	213.	343.	257.	17.27
31.134	28.40	29.20	31.35	34.55	0.35	49.50	27.84	27.49	5931.	125.	216.	169.	25.68
31.135	19.30	19.40	20.10	21.40	0.35	24.70	19.11	18.76	2029.	43.	108.	84.	49.04
31.136	31.25	32.80	37.25	44.75	0.40	100.00	30.02	29.62	13006.	275.	439.	341.	19.33
31.137	31.90	37.00	46.10	62.40	0.35	201.00	29.13	28.78	29337.	620.	1019.	685.	9.47
31.138	33.50	44.50	63.40	97.80	0.45	403.00	27.66	27.21	61657.	1304.	2266.	1374.	5.11

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
32.139	47.15	58.90	78.35	113.00	25.30	410.00	41.17	15.87	62974.	1332.	3968.	1398.	4.74
32.140	45.80	54.51	69.45	95.85	25.30	308.00	41.26	15.96	47941.	1014.	3005.	1050.	3.46
32.141	44.15	48.00	55.00	67.45	25.30	151.00	42.03	16.73	22376.	473.	1337.	515.	8.09
32.142	42.60	44.50	47.65	53.85	25.30	75.50	41.58	16.28	10818.	229.	665.	257.	11.13
32.143	42.15	43.30	45.35	49.25	25.35	50.20	41.51	16.16	6830.	144.	423.	171.	15.61
32.144	39.65	39.90	40.90	42.70	25.35	25.50	39.37	14.02	2936.	62.	209.	87.	28.58
33.145	29.85	40.65	59.80	94.15	0.35	403.00	24.01	23.66	61697.	1305.	2607.	1374.	5.05
33.146	28.85	36.60	50.80	76.55	0.45	297.00	24.52	24.07	45843.	970.	1905.	1013.	4.26
33.147	27.10	30.70	36.90	49.00	0.35	152.00	25.11	24.76	21100.	446.	852.	518.	13.90
33.148	25.70	27.20	30.30	35.65	0.35	75.50	24.80	24.45	9598.	203.	393.	257.	21.15
33.149	25.00	25.50	27.50	31.40	0.35	49.20	24.42	24.07	6177.	131.	257.	168.	22.14
33.150	19.75	-0.	21.00	23.30	0.35	29.60	19.43	19.08	3430.	73.	180.	101.	28.13
34.151	46.95	58.30	77.65	111.65	25.35	403.00	41.08	15.73	61882.	1309.	3935.	1374.	4.76
34.152	46.00	54.50	69.00	94.90	25.35	303.00	41.56	16.21	46843.	991.	2890.	1033.	4.11
34.153	44.25	48.35	55.30	67.90	25.35	151.00	42.10	16.75	22711.	480.	1356.	515.	6.71
34.154	42.80	44.70	47.85	53.65	25.35	75.00	41.81	16.46	10433.	221.	634.	256.	13.72
34.155	42.00	43.15	45.20	49.15	25.20	50.30	41.35	16.15	6879.	145.	426.	172.	15.18
34.156	40.00	40.40	41.60	43.30	25.25	26.00	39.70	14.45	3177.	67.	220.	89.	24.22
35.157	29.60	40.20	59.45	93.65	0.35	403.00	23.78	23.43	61461.	1300.	2623.	1374.	5.41
35.158	28.40	36.35	50.65	76.50	0.35	300.00	24.03	23.68	46229.	978.	1952.	1023.	4.42
35.159	26.70	30.35	36.80	48.85	0.35	149.00	24.69	24.34	21341.	451.	877.	508.	11.16
35.160	25.65	27.30	30.35	35.70	0.35	74.50	24.74	24.39	9694.	205.	398.	254.	19.29
35.161	24.85	25.25	27.60	31.40	0.35	49.50	24.26	23.91	6321.	134.	264.	169.	20.80
35.162	19.50	19.80	20.70	22.75	0.40	29.50	19.20	18.80	3140.	66.	167.	101.	33.97

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
36.163	48.00	59.10	78.50	112.60	25.30	403.00	42.13	16.83	61777.	1307.	3670.	1374.	4.92
36.164	46.85	55.40	70.00	96.05	25.30	306.00	42.38	17.08	47122.	997.	2758.	1043.	4.49
36.165	44.35	48.25	55.40	67.95	25.30	150.00	42.21	16.91	22663.	479.	1340.	511.	6.29
36.166	42.70	44.40	47.80	53.90	25.30	75.50	41.68	16.38	10770.	228.	657.	257.	11.53
36.167	41.65	42.75	45.00	48.95	25.30	49.60	40.99	15.69	7023.	149.	448.	169.	12.18
36.168	38.40	39.05	40.00	41.80	25.30	24.20	38.09	12.79	3274.	69.	256.	83.	16.09
37.169	33.10	44.05	63.40	97.70	0.35	405.00	27.23	26.88	61945.	1310.	2304.	1381.	5.14
37.170	32.50	40.65	55.20	80.65	0.45	302.00	28.13	27.68	46239.	978.	1671.	1030.	5.04
37.171	31.10	34.45	41.30	53.30	0.30	149.80	29.08	28.78	21372.	452.	742.	511.	11.51
37.172	29.60	-0.	34.60	40.45	0.35	75.50	28.61	28.26	10458.	221.	370.	257.	14.09
37.173	28.05	28.90	30.85	34.40	0.30	51.20	27.47	27.17	6125.	130.	225.	175.	25.81
37.174	18.70	18.95	19.60	21.15	0.30	24.00	18.48	18.18	2368.	50.	130.	82.	38.81
38.175	48.25	59.70	78.90	113.30	25.30	405.00	42.34	17.04	62202.	1316.	3650.	1381.	4.74
38.176	47.05	55.40	70.00	95.75	25.40	303.00	42.63	17.23	46643.	986.	2707.	1033.	4.52
38.177	44.35	48.35	55.40	67.90	25.20	151.00	42.21	17.01	22614.	478.	1329.	515.	7.11
38.178	42.60	44.65	48.00	53.90	25.30	74.50	41.57	16.27	10866.	230.	668.	254.	9.54
38.179	42.10	43.25	45.30	49.25	25.30	49.50	41.45	16.15	6878.	145.	426.	169.	13.81
38.180	37.60	-0.	39.10	41.00	25.30	25.00	37.29	11.99	3274.	69.	273.	85.	18.76
39.181	33.20	44.15	63.00	96.65	0.45	404.00	27.44	26.99	60846.	1287.	2255.	1378.	6.59
39.182	32.00	39.90	54.35	80.10	0.35	303.00	27.63	27.28	46198.	977.	1693.	1033.	5.43
39.183	30.70	33.40	40.10	52.10	0.35	149.00	28.76	28.41	20606.	436.	725.	508.	14.22
39.184	29.50	31.35	33.70	39.35	0.35	74.50	28.61	28.26	9496.	201.	336.	254.	20.95
39.185	27.50	28.60	30.30	33.70	0.40	50.50	26.94	26.54	5981.	126.	225.	172.	26.55
39.186	19.60	20.15	20.90	22.60	0.40	25.00	19.33	18.93	2899.	61.	153.	85.	28.09
39.188	37.30	50.80	74.40	116.40	0.45	500.00	30.12	29.67	75699.	1601.	2552.	1705.	6.10
39.189	35.25	47.50	69.70	108.40	0.35	450.00	28.61	28.26	70064.	1482.	2479.	1534.	3.43

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
40.190	33.00	44.50	62.75	97.25	0.45	405.00	27.17	26.72	61616.	1303.	2306.	1381.	5.64
40.191	32.05	40.65	54.55	80.35	0.45	303.00	27.66	27.21	46388.	981.	1705.	1033.	5.04
40.192	30.25	34.25	40.90	53.35	0.45	151.00	28.15	27.70	22240.	470.	803.	515.	8.65
40.193	29.00	30.40	33.70	39.50	0.35	76.00	28.05	27.70	10122.	214.	365.	259.	17.39
40.194	28.00	28.75	30.85	34.60	0.40	50.80	27.40	27.00	6366.	135.	236.	173.	22.28
40.195	22.75	-0.	23.65	25.15	0.45	25.20	22.53	22.08	2318.	49.	105.	86.	42.95
41.196	49.60	61.75	80.40	115.30	25.30	403.00	43.63	18.33	62807.	1328.	3426.	1374.	3.34
41.197	48.60	57.80	71.70	98.10	25.20	302.00	44.11	18.91	47395.	1002.	2507.	1030.	2.66
41.198	47.00	51.20	57.90	70.60	25.40	149.00	44.86	19.46	22652.	479.	1164.	508.	5.71
41.199	45.65	47.50	50.90	57.05	25.30	76.00	44.61	19.31	10956.	232.	567.	259.	10.59
41.200	45.15	46.20	48.40	52.40	25.35	51.00	44.49	19.14	6971.	147.	364.	174.	15.23
41.201	41.85	42.15	43.35	45.10	25.25	24.80	41.55	16.30	3128.	66.	192.	85.	21.78
41.202	44.75	45.70	47.90	51.75	25.25	50.80	44.11	18.86	6731.	142.	357.	173.	17.82
41.203	47.00	52.55	61.60	78.70	25.30	200.00	44.12	18.82	30407.	643.	1616.	682.	5.70
41.204	49.20	60.90	79.45	114.00	25.30	400.00	43.32	18.02	61957.	1310.	3439.	1364.	3.93
42.205	49.55	61.60	81.45	117.25	25.30	408.00	43.40	18.10	64707.	1369.	3574.	1391.	1.63
42.206	48.60	57.45	72.20	98.40	25.20	305.00	44.08	18.88	47677.	1008.	2526.	1040.	3.05
42.207	46.50	50.70	57.65	70.25	25.20	147.00	44.34	19.14	22797.	482.	1191.	501.	3.81
42.208	45.50	47.25	50.60	56.75	25.35	75.50	44.48	19.13	10812.	229.	565.	257.	11.18
42.209	44.75	45.80	48.00	51.80	25.30	50.50	44.11	18.81	6779.	143.	360.	172.	16.74
43.211	26.60	27.20	29.40	33.00	0.40	50.50	26.02	25.62	6174.	131.	241.	172.	24.17
43.212	27.05	28.40	31.55	37.40	0.35	74.50	26.11	25.76	9981.	211.	387.	254.	16.90
43.213	28.15	31.90	38.30	50.45	0.35	149.00	26.13	25.78	21480.	454.	833.	508.	10.59
43.214	29.70	38.80	53.00	78.40	0.45	300.00	25.28	24.83	46786.	990.	1884.	1023.	3.27
43.215	32.00	42.60	61.40	95.20	0.45	396.00	26.26	25.81	60624.	1282.	2349.	1350.	5.05
43.216	32.40	44.65	66.10	104.80	0.35	453.00	25.83	25.48	69390.	1468.	2724.	1545.	4.99
43.217	32.00	43.05	62.20	96.65	0.35	403.00	26.13	25.78	62006.	1311.	2405.	1374.	4.57
43.218	31.50	39.35	53.35	79.20	0.45	301.00	27.17	26.72	45822.	969.	1715.	1026.	5.58
44.219	29.30	34.60	43.60	60.65	0.30	198.00	26.45	26.15	30168.	638.	1154.	675.	5.50
44.220	28.40	31.15	35.50	43.40	0.45	102.50	27.04	26.59	14456.	306.	544.	350.	12.53
44.221	27.10	28.00	29.80	33.70	0.35	50.00	26.50	26.15	6367.	135.	243.	170.	21.02
44.222	21.25	21.40	22.20	24.10	0.40	29.50	20.99	20.59	2753.	58.	134.	101.	42.12
44.223	27.15	28.00	29.85	33.80	0.35	51.20	26.55	26.20	6415.	136.	245.	175.	22.29
44.224	28.40	30.85	35.25	43.20	0.40	102.50	27.06	26.66	14263.	302.	535.	350.	13.69
44.225	29.15	34.70	43.85	60.30	0.35	198.00	26.32	25.97	29975.	634.	1154.	675.	6.10
45.226	29.80	42.40	61.50	96.60	-0.30	400.00	23.73	24.03	64076.	1355.	2666.	1364.	0.64
45.226	30.30	42.20	61.50	96.50	0.10	400.00	24.29	24.19	63501.	1343.	2625.	1364.	1.54
45.227	29.20	-0.	53.00	79.00	0.10	302.00	24.68	24.58	47842.	1012.	1947.	1030.	1.74
45.227	28.85	-0.	53.00	78.30	0.40	302.00	24.36	23.96	47506.	1005.	1983.	1030.	2.43
45.228	27.65	-0.	38.20	50.85	0.35	153.00	25.54	25.19	22347.	473.	887.	522.	9.41
45.228	27.40	-0.	38.20	50.80	0.20	153.00	25.28	25.08	22540.	477.	899.	522.	8.63
45.229	26.40	-0.	31.00	36.20	0.15	73.00	25.51	25.36	9452.	200.	373.	249.	19.69
45.229	25.90	-0.	31.00	36.40	-0.10	73.00	24.95	25.05	10127.	214.	404.	249.	13.96
45.230	25.45	26.30	28.10	31.40	0.65	49.30	24.91	24.26	5742.	121.	237.	168.	27.77
45.230	24.80	-0.	28.10	31.40	0.35	49.30	24.20	23.85	6369.	135.	267.	168.	19.87
45.231	20.15	20.35	21.30	23.15	0.40	30.00	19.88	19.48	2898.	61.	147.	102.	40.08
45.231	19.85	-0.	21.30	23.10	0.10	30.00	19.55	19.45	3140.	66.	161.	102.	35.08
45.232	29.65	42.90	61.70	96.35	-0.30	403.00	23.59	23.89	63978.	1353.	2678.	1374.	1.54
45.232	30.30	-0.	61.70	95.70	0.30	403.00	24.36	24.06	62731.	1327.	2607.	1374.	3.45
45.233	28.80	39.10	53.40	79.60	-0.40	303.00	24.19	24.59	48800.	1032.	1985.	1033.	0.11
45.233	29.40	-0.	53.40	78.70	0.45	303.00	24.92	24.47	47359.	1002.	1935.	1033.	3.06
45.234	27.60	-0.	39.30	51.60	-0.10	150.00	25.42	25.52	23113.	489.	906.	511.	4.43
45.234	27.90	-0.	39.30	51.40	0.45	150.00	25.77	25.32	22632.	479.	894.	511.	6.42

Appendix II. TEST DATA OF REFRIGERANT DICHLORODIFLUOROMETHANE (GENETRON-12) - (Continued)

T-R NR	T1	T2	T4	T5	T6	W	TW	DEL T	Q/A	Q	H	QW	P/Q
46.235	29.00	41.60	60.50	95.25	-6.40	402.00	22.98	29.38	63560.	1344.	2163.	1371.	1.94
46.235	29.40	-0.	60.50	94.85	-5.80	402.00	23.46	29.26	62793.	1328.	2146.	1371.	3.12
46.236	28.15	37.40	51.50	77.40	-6.20	298.00	23.68	29.88	47327.	1001.	1584.	1016.	1.50
46.236	28.50	-0.	51.50	77.10	-6.00	298.00	24.09	30.09	46702.	988.	1552.	1016.	2.80
46.237	26.40	-0.	38.10	50.25	-6.40	149.00	24.23	30.63	22974.	486.	750.	508.	4.37
46.237	26.65	-0.	38.10	50.00	-6.15	149.00	24.53	30.68	22492.	476.	733.	508.	6.37
46.238	24.95	26.50	29.50	34.35	-5.60	72.00	24.10	29.70	9069.	192.	305.	246.	21.88
46.238	24.50	-0.	29.50	34.70	-6.10	72.00	23.57	29.67	9840.	208.	332.	246.	15.23
46.239	21.25	22.10	23.85	27.30	-6.00	49.50	20.70	26.70	5843.	124.	219.	169.	26.79
46.239	20.85	-0.	23.85	27.15	-6.15	49.50	20.28	26.43	6084.	129.	230.	169.	23.77
46.240	28.35	41.50	61.00	96.20	-6.80	407.00	22.19	28.99	65089.	1377.	2245.	1388.	0.81
46.240	28.85	-0.	61.00	95.40	-6.05	407.00	22.81	28.86	63842.	1350.	2212.	1388.	2.71
46.241	26.60	-0.	42.60	59.60	-6.60	200.00	23.60	30.20	31762.	672.	1052.	682.	1.50
46.241	27.00	-0.	42.60	59.00	-6.00	200.00	24.09	30.09	30799.	651.	1023.	682.	4.49
46.242	28.25	41.40	60.40	94.65	-6.50	398.00	22.22	28.72	63705.	1347.	2218.	1357.	0.72
46.242	29.00	-0.	60.40	93.70	-5.50	398.00	23.13	28.63	62074.	1313.	2169.	1357.	3.27

Appendix III. LIST OF EQUIPMENT AND INSTRUMENTATION

a. High Vacuum Pump (HVP) - CENCO HYVAC^{O}7, Serial No. 2487, Cat. No. 91506, Driven by 1/3 G.E. Motor, Central Scientific Co., Chicago, U.S.A.

b. Profilometer - Surfindicator, Model BL-110, 115 V, 0.25 A, 50/60 cycles, Brush Instruments Co., Cleveland, Ohio, U.S.A.

c. Standard Mercurial Barometer - Cat. No. 453, Precision Thermometer & Instrument Co., Philadelphia, Pa., U.S.A.

d. Scale (SL) - 0 - 100 lb.

e. Thermometers (TM-1, TM-2) - 0 - 100 ^{o}F (1^{o}F division).
66 - 96 ^{o}F (0.05 ^{o}F division)

f. Galvanometer (GAL) - Scalamp Galvanometer, PYE, 115 V, 60 cycles, 24 ohms, The Ealing Corp, Cambridge, Mass., U.S.A.

g. Potentiometer (POT) - Vernier Potentiometer, Cambridge Instrument Co., Ltd., England. (minimum reading 0.0000001 volt).

h. Standard Cell (SC) - Weston Standard Cell, Model 4, No. 11644, Weston Electrical Instrument Corp., Neward, U.S.A.

i. Variable Transformer (VT) (Variac) - 115 V, 20 A, 50/60 cycles, General Radio Co., Cambridge, Mass, U.S.A.

j. Wattmeters (WM) - 0 - 150 watt, Sensitive Research Instrument Corp., New Rochelle, N.Y., U.S.A.
- 0 - 1000 watt.

k. Thermostatic Limit Switch (TLS) - 60 - 250 °F, 35 A, 125 V.A.C., General Electric.

l. Cold Reference Junction (CRJ).

m. Philips Recording Potentiometer (PRP) - Automatic compensator with 12-channel recording for mV and temperature measurements, PR 3216 A/00, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Holland. To record continuously the mV reading of each thermocouple on a 10-inch chart. The chart was marked off in 100 intervals which could give a fairly accurate reading to 0.0025 mV on the 1 - mV range.

n. Storage Battery (SB) - 6 V.

o. Switch Panel (SP) - Double throw double pole switches.

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