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Liquid vapor equilibrium in nucleate and film boiling

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LIQUID VAPOR EQUILIBRIUM
IN NUCLEATE AND FILM BOILING
BY
WALTER HENRY ROTH AUG

A THESIS
PRESENTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE
OF
MASTER OF SCIENCE
AT
NEWARK COLLEGE OF ENGINEERING

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Newark, New Jersey
May, 1968

ABSTRACT

Liquid vapor equilibrium data were obtained for several solutions and azeotropes under both nucleate and film boiling. The data were invariant between the two boiling regimes indicating that both nucleate and film boiling are equilibrium vaporizations rather than either diffusional or bulk vaporizations. Boiling heat transfer versus temperature data were taken in nucleate and film boiling for the solutions and azeotropes and for several pure liquids. The critical heat flux for methyl alcohol-benzene solutions rose sharply at first and then more moderately with increasing alcohol concentration. The critical heat flux was practically constant regardless of concentration in ethyl alcohol-benzene solutions. Photographs of nucleate and film boiling were taken to illustrate the differences between the two boiling regimes. The photographs were consistent with previously published work.

APPROVAL OF THESIS
LIQUID VAPOR EQUILIBRIUM
IN NUCLEATE AND FILM BOILING

BY

WALTER HENRY ROTH AUG

FOR

DEPARTMENT OF CHEMICAL ENGINEERING AND CHEMISTRY
NEWARK COLLEGE OF ENGINEERING

BY

FACULTY COMMITTEE

APPROVED:

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MAY, 1968

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Regimes of Boiling

Vaporization of a liquid through boiling is one of the oldest phenomenon known to man. It is the purpose of this thesis to investigate nucleate and film boiling.

Early studies indicated that boiling was a more complex phenomenon than commonly believed. The first indication of the complex nature of boiling was the observation of the "repulsion" between a hot surface and a drop of water. This was the Leidenfrost phenomenon and was recorded in 1756 (1).

The first significant investigation of a liquid boiling was performed by Siro Nukiyama in 1934 (2). He submerged platinum wire into water at 100°C and heated the wire electrically to produce boiling. Upon heating the wire he noticed the rate of heat transfer from the wire to the water increased steadily until the ΔT (temperature difference) between the wire and the water was about 44°C. Then the ΔT suddenly and discontinuously jumped to 886°C; as the wire was heated further the heat transfer rate increased steadily. On the other hand by reducing the wire temperature he was able to lower the ΔT to 200°C, observing a steady decrease in heat transfer rate. At that temperature the ΔT dropped suddenly

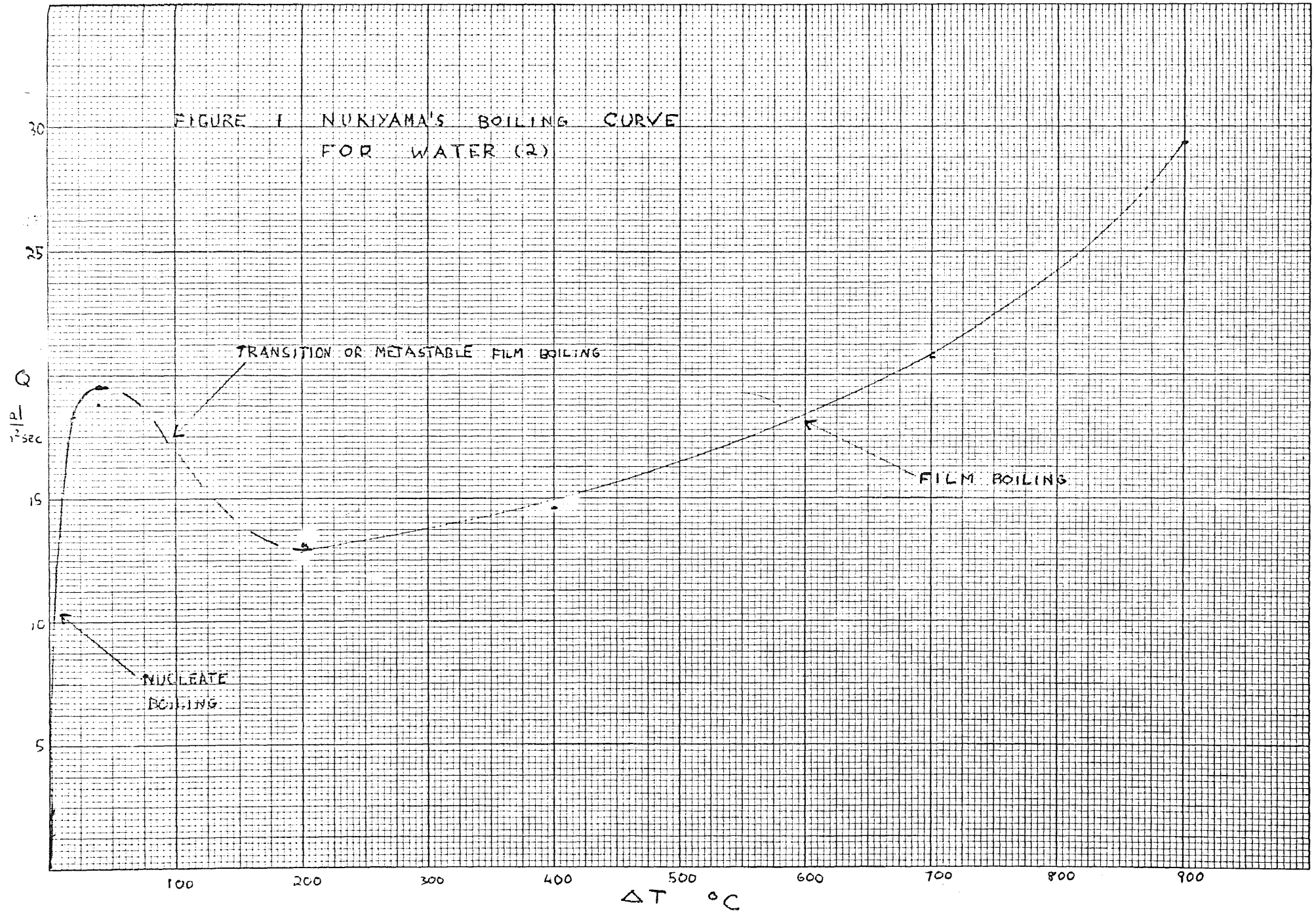
and discontinuously to less than 44°C . Nukiyama next tried wires of nickel and alloys with melting points lower than platinum. When a ΔT of about 44°C was exceeded the wires melted. This is the phenomenon of burnout. Nukiyama's boiling curve is shown in Figure 1. He believed that at least two distinct regimes of boiling occurred; one below $\Delta T = 44^{\circ}\text{C}$ and another above $\Delta T = 200^{\circ}\text{C}$. Between ΔT of 44°C and 200°C he postulated that another regime existed where for increasing ΔT heat transfer rate dropped, a contradiction of the rate law which states that flow is proportional to potential gradient.

Subsequent investigation proved Nukiyama correct (3)(4). At least three distinct regimes of boiling exist. In the region $\Delta T < 44^{\circ}\text{C}$ on figure 1 nucleate boiling exists. In the region $\Delta T > 200^{\circ}\text{C}$ film boiling exists. In the region $44^{\circ}\text{C} < \Delta T < 200^{\circ}\text{C}$ transition boiling occurs sometimes called metastable film boiling.

Nucleate Boiling

Nucleate boiling is characterized by bubble formation from active centers of nucleation on the heating surface. As soon as a bubble breaks loose another bubble begins to grow from the identical spot on the hot solid. Nearby spots produce no bubbles, but heat is transferred every-

FIGURE 1 NUKIYAMA'S BOILING CURVE
FOR WATER (2)



where on the heating surface. Where bubble growth does not occur the liquid superheats, Wismer (5) demonstrated that ether and pentane can be superheated by 110°C when the glass container is smooth and scrupulously clean. A superheated liquid is in a metastable state and will eventually vaporize. If the superheat is high it will explode. This is probably what happens when a liquid bumps. Microscopic investigations of heating surfaces reveal that the active center is a geometric imperfection in the heating surface where gas can be trapped (6). Bubbles grow from these gas traps. As the temperature of the heating surface increases the number of active centers increases until the critical ΔT is reached.

Several approaches have been tried to explain heat transfer in nucleate boiling. Rohsenow (7) assuming that the movement of a bubble at the instant of breaking away from the hot surface is of primary importance, developed the following semitheoretical equation

$$\text{Nu} = \text{Const.}(\text{Re})^{2/3}(\text{Pr})^{-0.7}$$

The constant varied from 0.006 to 0.015.

Forster and Zuber(8) assumed that the important mechanism is at the liquid-vapor interface when the bubble is still attached to the heating surface. Their semitheoretical equation is

$$\text{Nu} = 0.0015(\text{Re})^{.62}(\text{Pr})^{1/3}$$

Although the form of these equations is the same, the coefficients and powers differ. The equations are satisfactory for some systems but are unsatisfactory for others. Recent work in nucleate boiling heat transfer is summarized by Rohsenow (9) and Leppert and Pitts (10). Other theoretical explanations of the nucleate boiling process have been derived from rate process, thermodynamics and statistical mechanics. These are summarized by Westwater (11).

Transition or Metastable Film Boiling

Much less is known about the transition and film regimes than the nucleate regime. Since the principal motivation for doing research on the boiling phenomenon is to achieve high rates of heat transfer for low ΔT , and this occurs in the nucleate regime, most workers have consequently investigated this regime. High speed motion pictures of the transition regime have shown that vapor is formed by explosive bursts occurring at random locations on the heating surface. As the vapor film becomes thin, liquid moves in and a miniature blast occurs; the blast creates a slug of vapor and forces the liquid back; the vapor slug eventually ruptures and leaves the heating surface. The frequency of these vapor blasts is very high. Transition boiling for water occurs in the region of between $44^{\circ}\text{C} < \Delta T < 200^{\circ}\text{C}$

where the heat transfer rate decreases for increasing temperature difference. Many investigators believe that transition boiling is not a distinct regime but as its name implies a transition between nucleate and film boiling where the characteristics of both are exhibited. However Ishigui and Kuno (12) recently analyzed the oscilogram of the surface temperature of the heating element and concluded that transition boiling was a separate regime in which the heating surface is alternately wet and dry; the characteristic curve was smooth and continuous. However no satisfactory theoretical explanation for transition boiling has been established. Earlier work in transition boiling is summarized by Westwater (13).

Film Boiling

The film boiling region for water of $\Delta T > 200^\circ\text{C}$ is characterized by bubbles breaking loose from a stable vapor film which coats the heating surface. No active centers exist; no explosive bursts occur. Vapor is not generated at the heating surface, but only at the liquid vapor interface. Radiant heat transmission is now the dominant method of heat transfer at very high temperatures.

An important analogy between film boiling and

film condensation has been established. Bromley (14), presented a theoretical derivation of film boiling heat transfer based on the analogy to film condensation using Nusselt's (15) derivation as a model. Bromley's equation is

$$h' = 0.62 \sqrt{\frac{4 k_v^3 \rho_v (\rho_w - \rho_v) \lambda g}{D \mu_v \Delta T}}$$

This equation omits radiation given by the expression

$$h_R = \frac{\sigma' F_e (T_s^4 - T_i^4)}{\Delta T}$$

The combined film heat transfer coefficient becomes

$$h = h_R + h'$$

These equations give a satisfactory prediction of heat transfer in viscous film boiling.

Other Types of Boiling

Subcooled boiling occurs in the region of very low ΔT . It is characterized by currents of superheated liquid rising from the heating surface through the bulk of the liquid and vaporizing at the liquid's surface. High rates of heat transfer for low ΔT driving force are observed; consequently subcooled boiling has received considerable experimental attention.

Bulk boiling occurs when the liquid is heated to the boiling point by passing an electric current through the liquid; or when a chemical reaction or nuclear reaction in the liquid generates sufficient heat to bring the liquid to the boiling point; or if there is sufficient heat of mixing when two liquids mix.

In this case, there is no heating surface where bubble growth can occur; the bubbles grow in the bulk of the liquid. It is believed that bulk boiling is actually a part of the nucleate regime of boiling but much more information is needed before this conclusion can be substantiated. There is not very much work being done in bulk boiling and there is much room for research.

Significance of the Critical ΔT

The critical ΔT occurs when nucleate boiling changes to metastable film or transition boiling. Active centers of nucleation cease to exist and the heating surface becomes partially or entirely blanketed with vapor. It is known as the burnout point because certain heating elements are unable to make the transition to film boiling. Since the temperature in the film boiling regime corresponding to heat flux at the critical ΔT in the nucleate boiling regime is greater than the melting point of the heating element, the heating element melts or "burns out". The critical ΔT represents the peak heat flux for moderate ΔT . Gambill and Greene (16) reported peak heat flux of 54,800,000 BTU per hour per sq. ft. (17,400 watts per sq. cm.) under restricted conditions. Zuber and Tribus (17) have proposed the following equation for peak heat flux at the critical ΔT .

$$\frac{Q}{A} = \frac{\pi}{24} \lambda \rho_v \left[\frac{g \sigma (\rho_L - \rho_v)}{\rho_v^2} \right]^{1/4} \left[\frac{\rho_L}{\rho_L + \rho_v} \right]^{1/2}$$

which is satisfactory for a number of systems. This equation does not take into account forced flow, a condition which Gambill and Greene used.

If the critical ΔT is exceeded; 1. film boiling could occur with the heat transfer rate remaining practically constant; or 2. transition boiling could occur where the heat transfer rate would drop for increasing temperature difference; or 3. burnout could occur where the heat source would melt because of the sharp increase in temperature. When a wire is used, instability of the heating surface temperature makes it impossible for transition boiling to occur. Then only film boiling or burnout can occur. When a steam tube is used as the heating element, transition boiling usually occurs as the critical ΔT is exceeded.

In this thesis first the differences between nucleate and film boiling were demonstrated photographically. Second the behavior of azeotropes were investigated under nucleate and film boiling. Third liquid-vapor equilibrium data taken under film boiling were compared with data taken under nucleate boiling. Since practically all boiling is done in the nucleate regime and consequently all properties requiring boiling such as liquid-vapor equilibrium and azeotropic composition are taken under nucleate boiling conditions the comparison of these properties taken under both

regimes may give additional insight into the nature of the vaporization process. Fourth heat transfer data is taken under nucleate and film boiling for various pure liquids and solutions to determine when nucleate and film boiling is occurring.

Experimental Methods

Heat flux data and liquid vapor equilibrium data were obtained using a still with an internal electric heater(18). The experimental set up is shown in Figure 2. A 6 cm. strip of 10 mil platinum wire (Baker Platinum, Englehard Industries, Carteret, N. J.) was used both as the heating surface and as a resistance thermometer. The resistance of platinum is given by the equation (19)

$$r_t = r_0(1 + \alpha T)$$

where T is given in degrees centigrade, and α is the temperature resistance coefficient (0.003/°C) (20).

The resistance of platinum wire at 20°C per unit length* is 0.0259 ohms/cm. (21). Plots of temperature versus wire length are shown in Figure 3.

The temperature of the wire and the heat transferred from the heating surface to the boiling liquid were determined from measurements of the current in the circuit and the voltage drop across the platinum wire heating surface.

*10 mil diameter

FIGURE 2

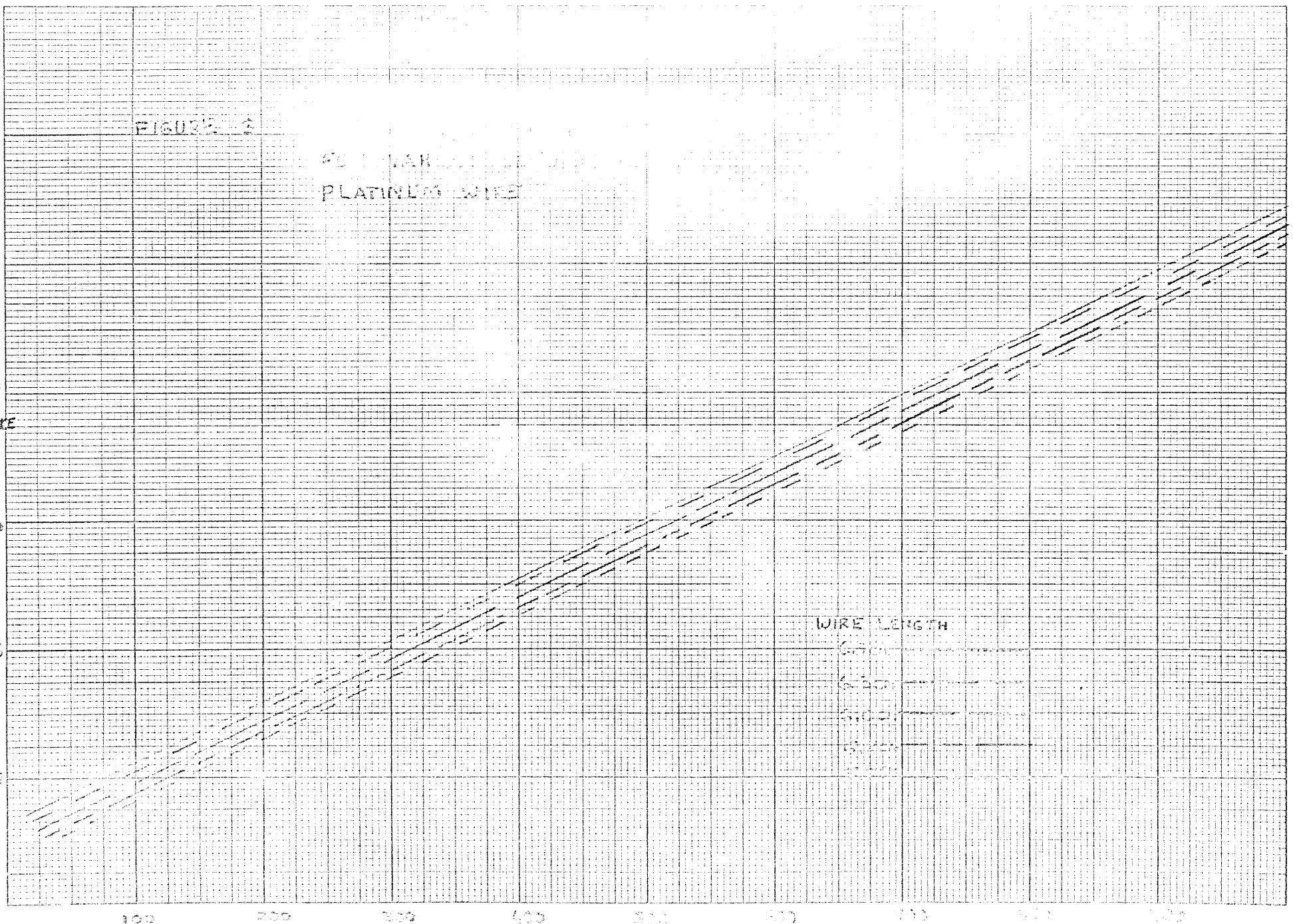
PLATINUM WIRE

RESISTANCE
OHMS

WIRE LENGTH

- 6.700
- 6.500
- 6.300
- 6.100
- 5.900

°C



100

200

300

400

500

600

700

800

900

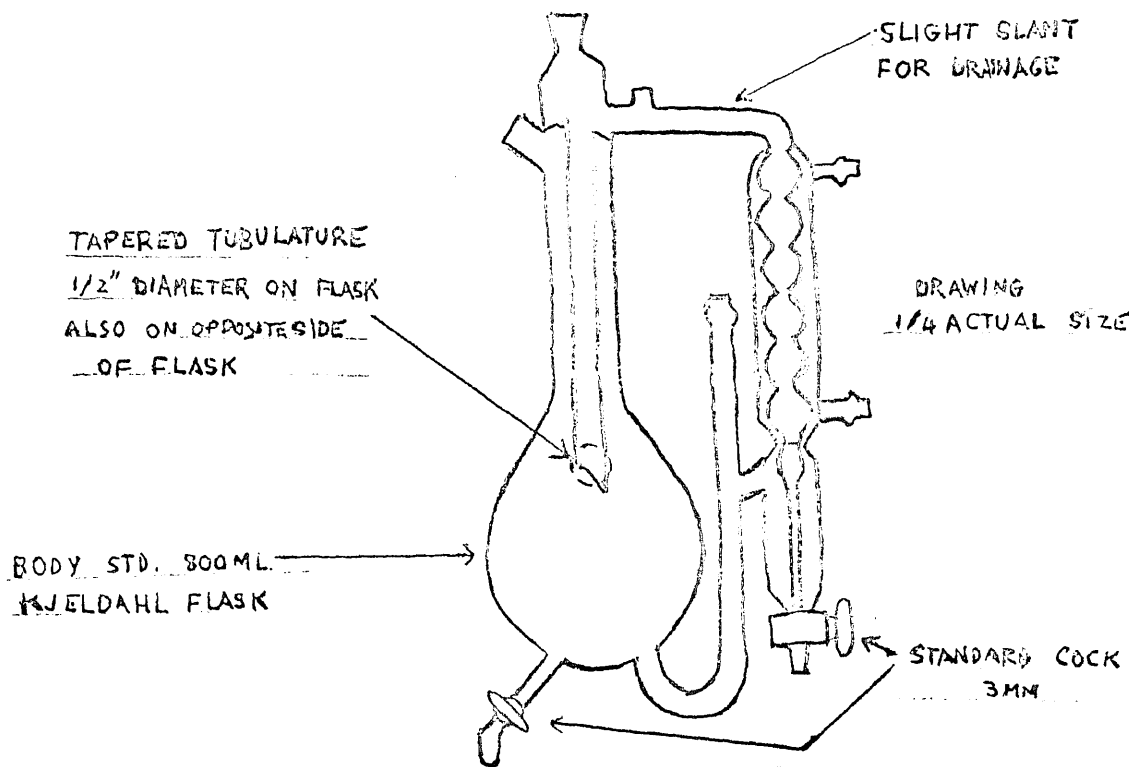


Figure 2a.

Liquid vapor equilibrium still
used in this study (18)

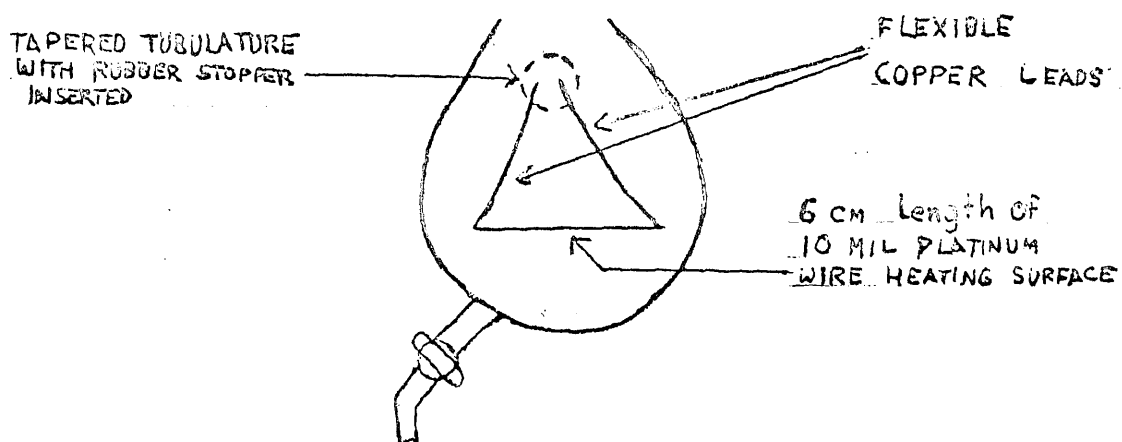


Figure 2b.

Arrangement of platinum heating
wire in flask of still

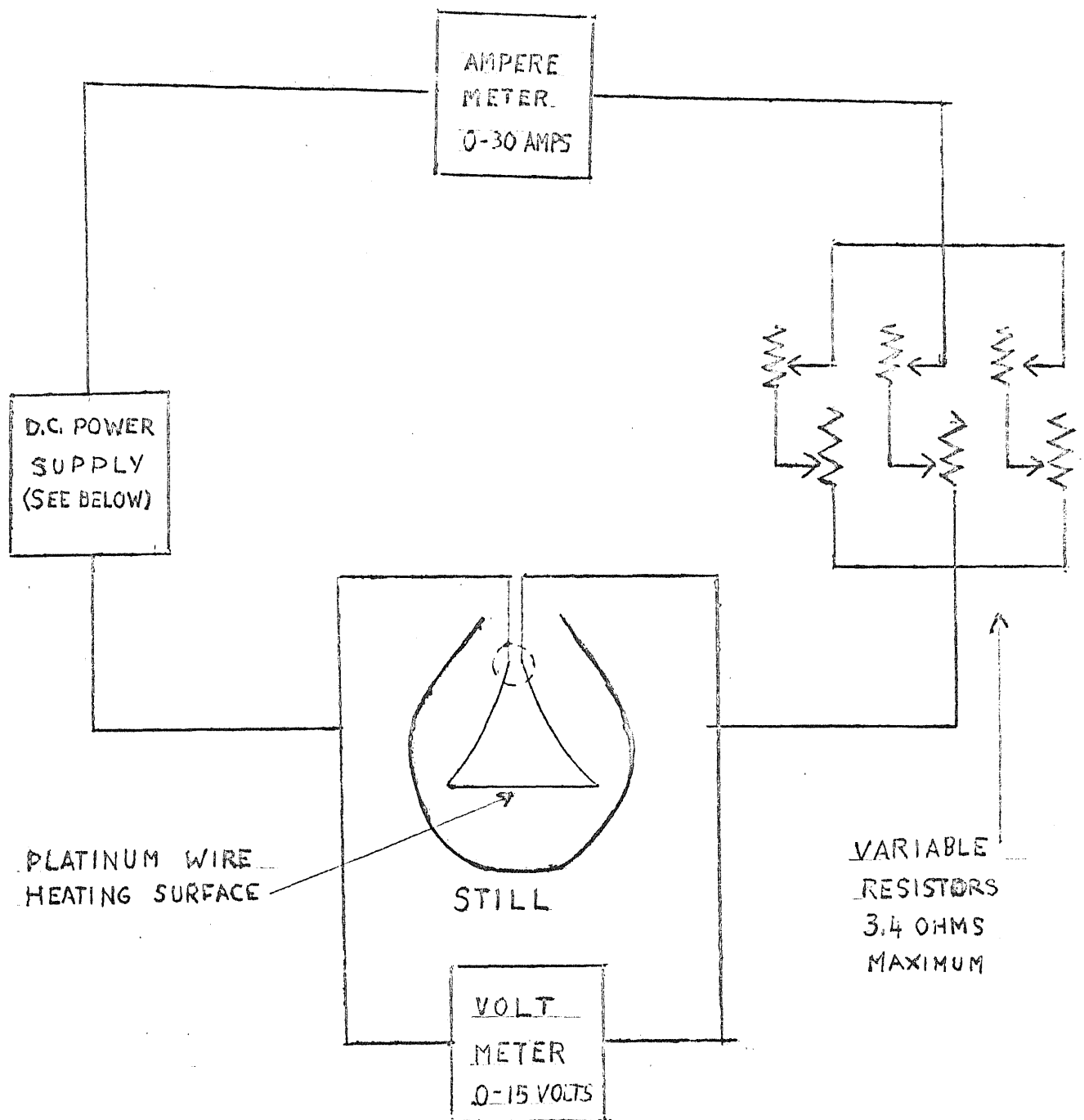


Figure 2c.

Diagram of electric circuit
used in study

D. C. Power Supply -- Model P.S. 50 * Electro Products
Laboratories, Chicago, Illinois.

(Actually the voltage is measured across the leads to the platinum wire. The leads are assumed to have negligible resistance. This assumption was experimentally verified.)

The resistance was determined from Ohm's law

$$r = v/i$$

and the temperature of the wire was determined from Figure 3. The power dissipated per unit area was obtained by dividing the geometric surface area of the platinum wire into the total power. The total power was calculated from the equation

$$P = i^2 r = iv$$

The results are reported in watts/cm² and are plotted against temperature as shown in Figures 4-21. Since liquid vapor equilibrium data were desired for both nucleate and film boiling regimes the temperature vs. power flux curves were used only to establish the temperature ranges of these regimes.

Reagent grade chemicals were used without further purification. The systems studied in this work are listed in Table I.

In a typical run the still was filled with liquid to a depth which submerged the wire. Since many of the chemicals studied are inflammable the interior of the still was provided with a nitrogen atmosphere. Then the power was turned on and boiling started at the heating surface of the platinum wire.

If the liquid temperature was well below the boiling point, then bubbles, generated at the heating surface, collapsed in the bulk of the liquid before reaching the liquid's

Table I Systems Studied

Azeotropes¹

methyl alcohol-benzene
ethyl alcohol-benzene
iso-propyl alcohol-benzene
n-propyl alcohol-benzene

Mixtures

methyl alcohol-benzene
ethyl alcohol-benzene

Pure Liquids

methyl alcohol
ethyl alcohol
iso-propyl alcohol
n-propyl alcohol
benzene
chloroform
carbon tetrachloride
methylene chloride
distilled water

¹ Adv. Chem. Ser., 6; 35;

surface. As the liquid temperature gradually increased a few bubbles were able to escape to the liquid's surface. These bubbles were smaller and less numerous than those encountered when the liquid temperature reached the boiling point. Then boiling became more vigorous and the bubbles, after leaving the heating surface, began to grow in the bulk of the liquid. As the temperature of the heating surface increased further (the bulk liquid temperature remained at the boiling point), heat flux increased and the number of active centers of nucleation increased until the heating surface was practically covered with bubbles. When the critical ΔT was reached, further increases in the current caused the temperature of the heating surface to increase suddenly and discontinuously approximately 500°C with only slight increases in the heat flux. This was the change from nucleate to film boiling. Then the heating surface became covered with a vapor film, bubbles were larger and agitation in the bulk liquid became less vigorous. Further increases in the current caused the temperature of the heating surface and the heat flux to increase.

Starting at a point in the film boiling region, decreasing the current caused the temperature and the heat flux to decrease continuously to a level well below the transition point between nucleate and film boiling. Then the temperature dropped suddenly and discontinuously several hundred degrees centigrade to a value below the critical ΔT in nucleate

Figure 4. HEAT TRANSFER VS TEMP. CURVE
FOR METHYL ALCOHOL.

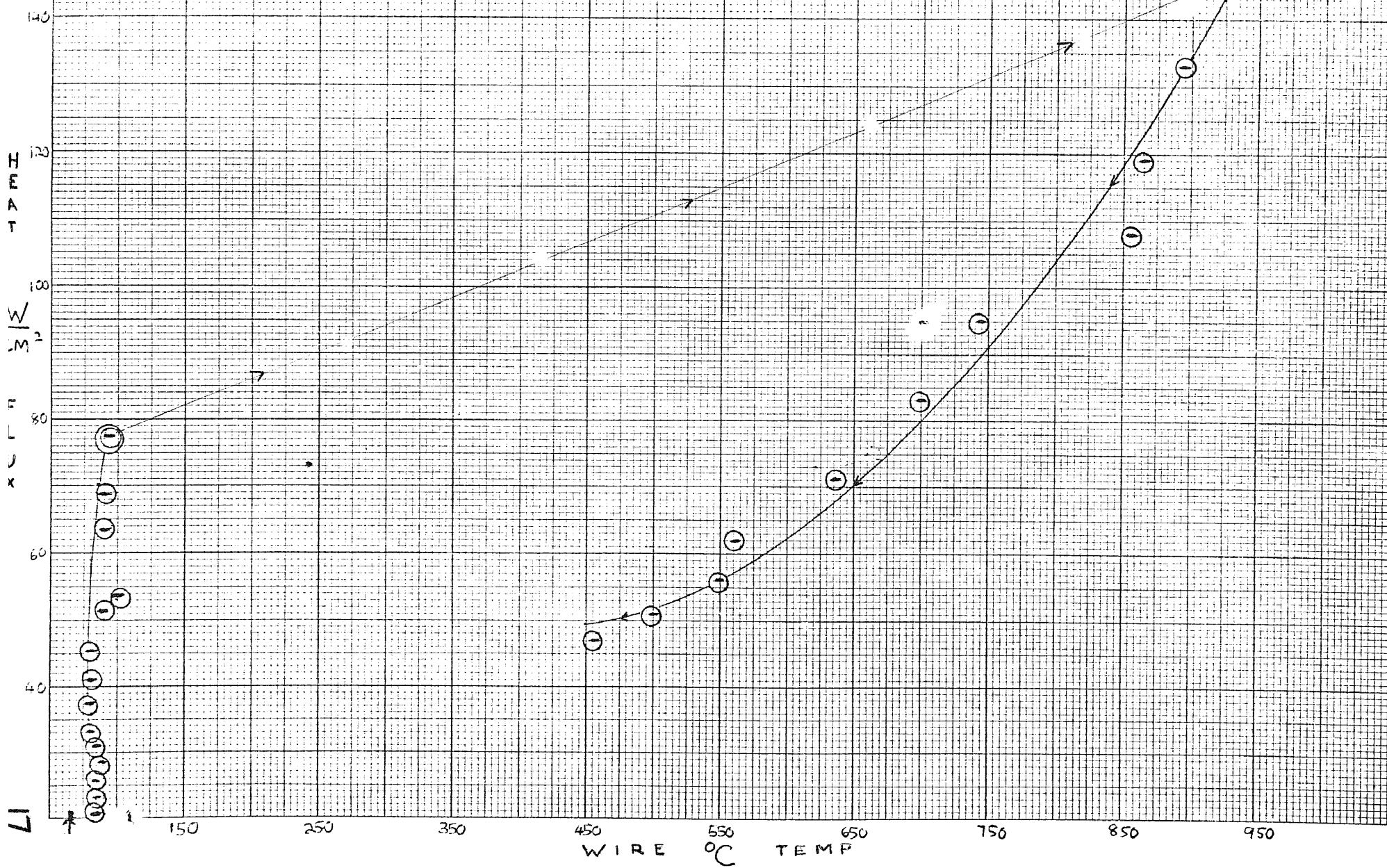


FIGURE 5. HEAT TRANSFER VS. TEMPERATURE CURVE
FOR ETHYL ALCOHOL

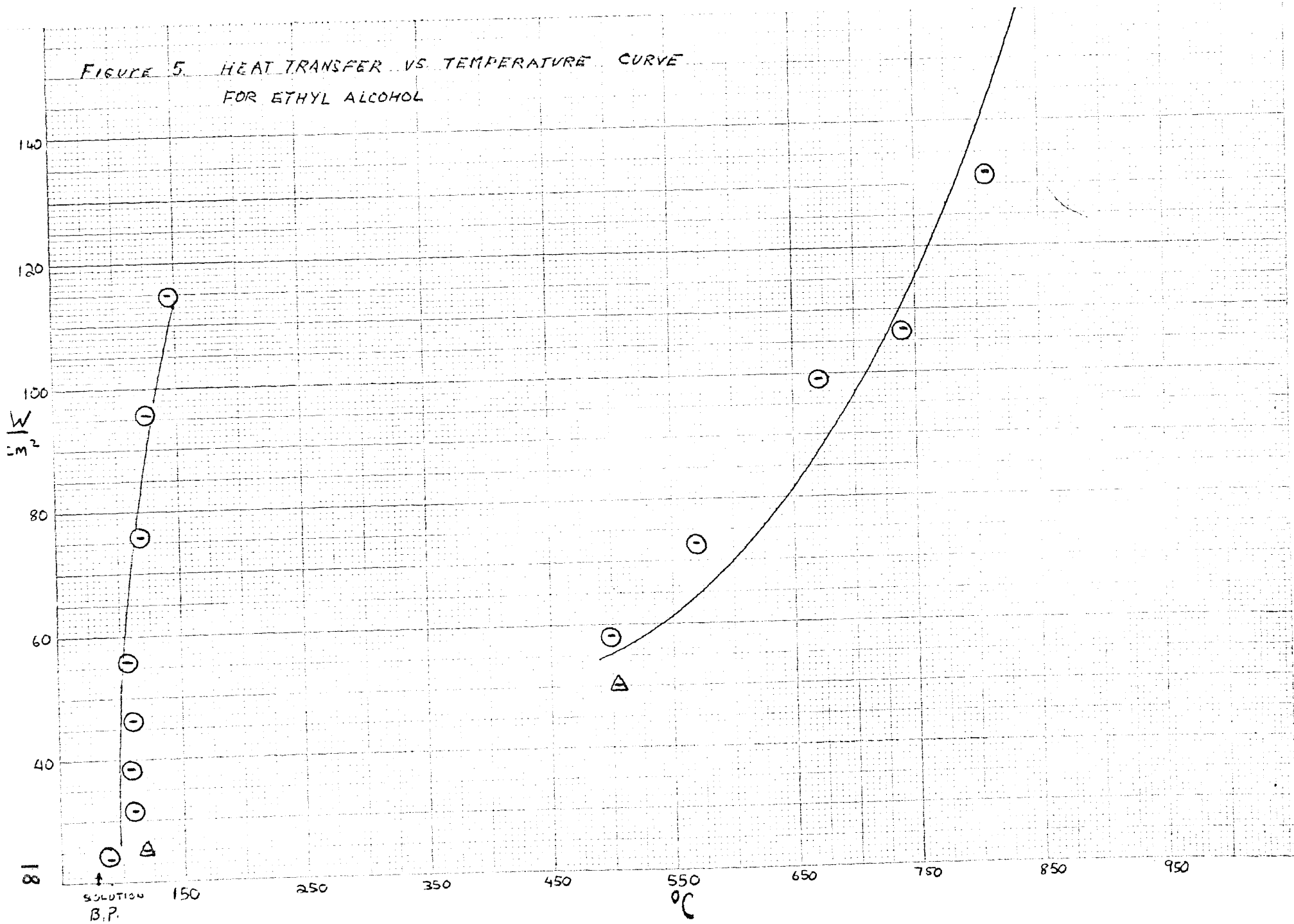


Figure 6 HEAT TRANSFER VS. TEMPERATURE CURVE FOR N-PROPYL ALCOHOL

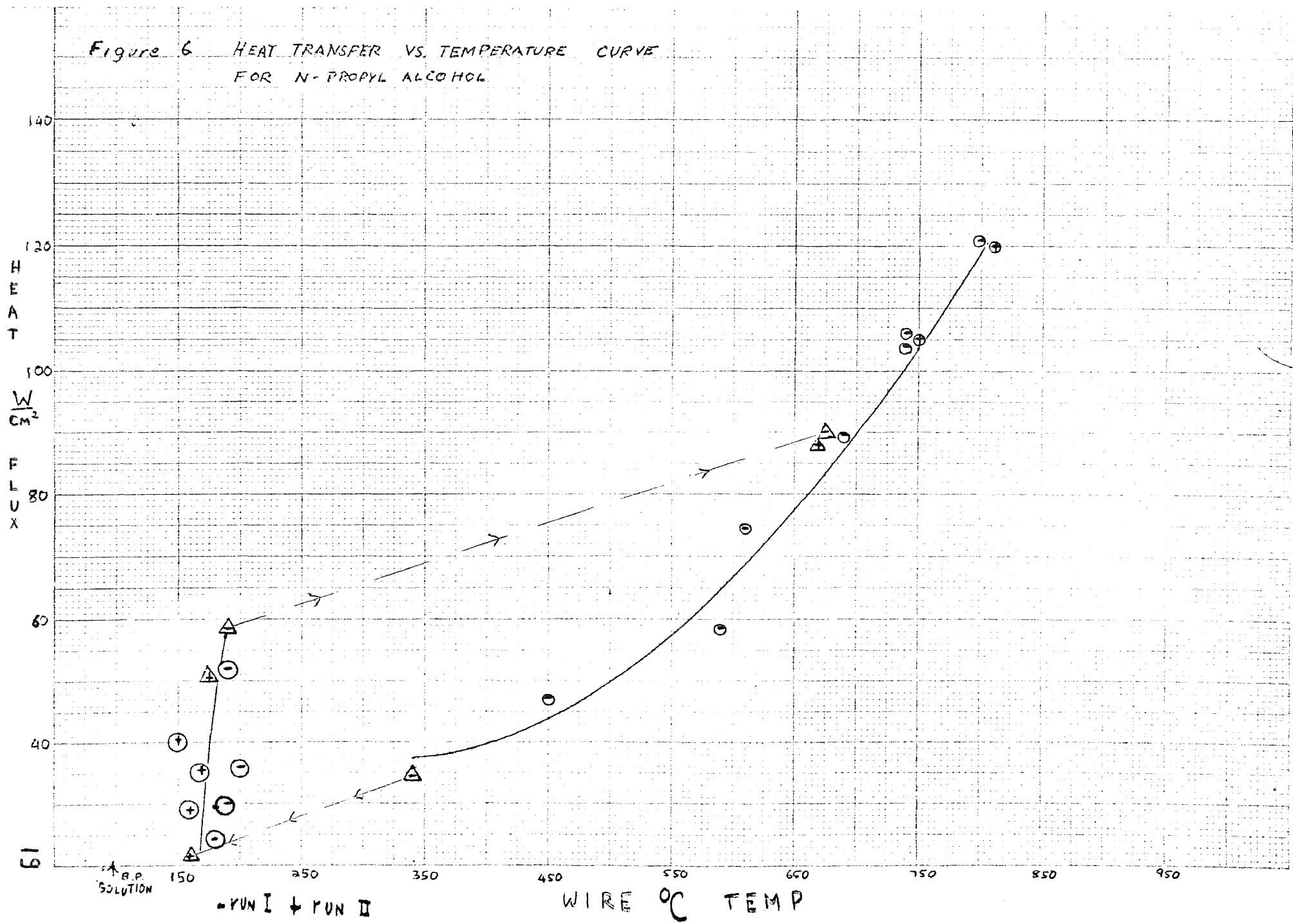


FIGURE 7 HEAT TRANSFER VS. TEMP. CURVE
FOR ISO-PROPYL ALCOHOL

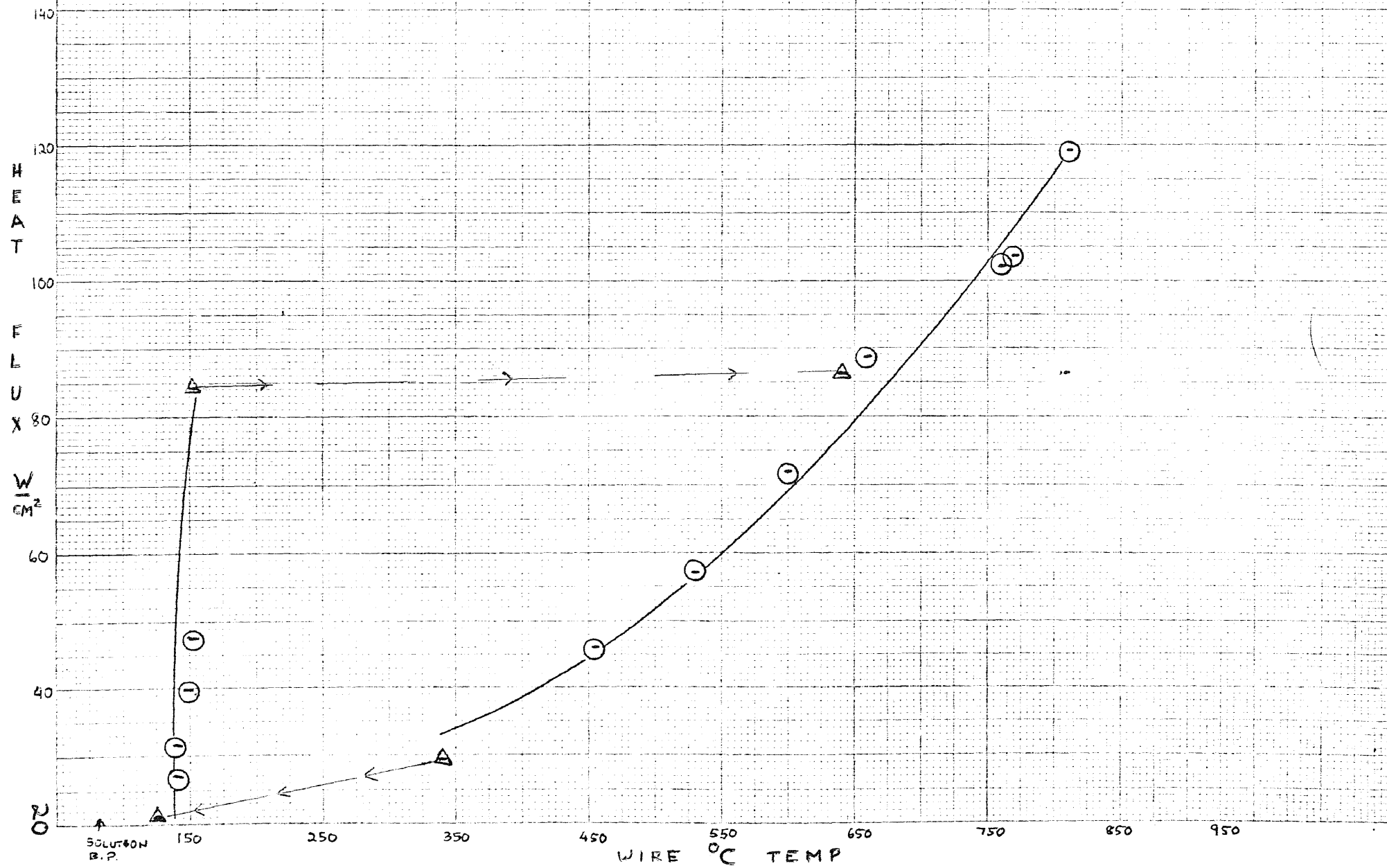


FIGURE 8 HEAT TRANSFER vs. TEMP CURVE FOR BENZENE

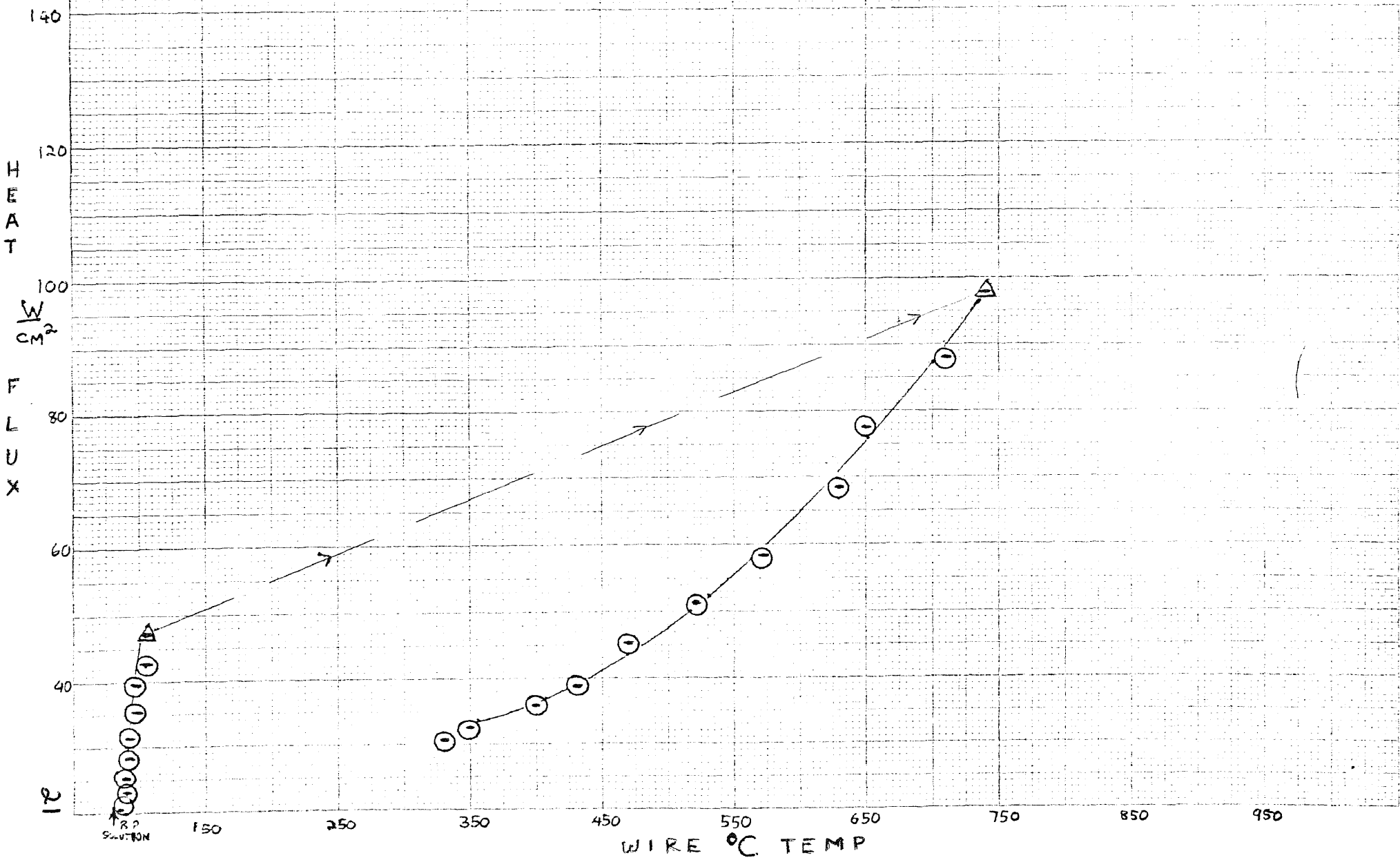


FIGURE 9 HEAT TRANSFER VS. TEMPERATURE CURVE
FOR 4.5 wt% METHYL ALCOHOL 95.5 wt% BENZENE

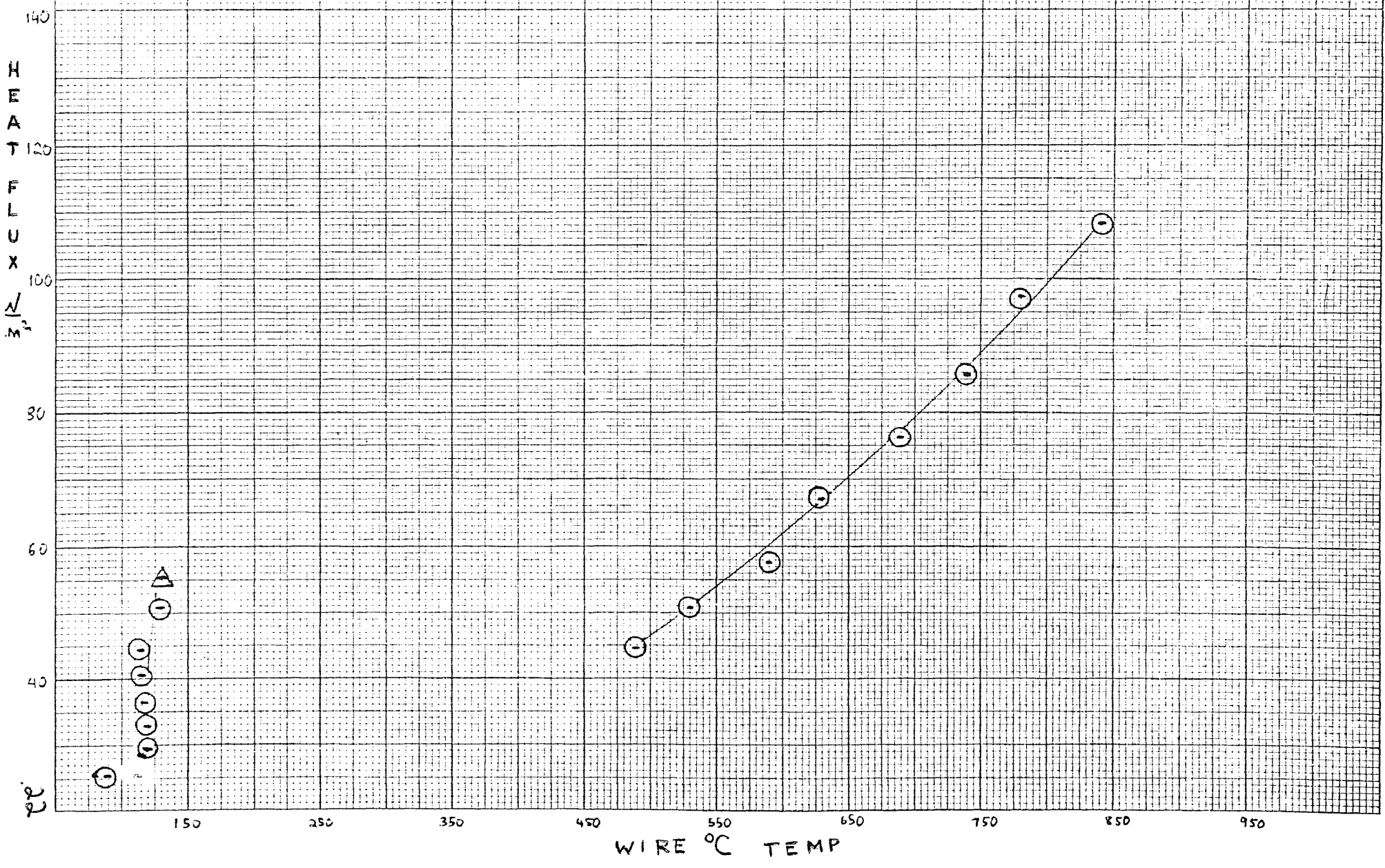


FIGURE 10 HEAT TRANSFER VS. TEMPERATURE CURVE
FOR 15 wt% METHYL ALCOHOL 85 wt% BENZENE

H
E
A
T
F
L
U
X
 $\frac{W}{CM^2}$

23

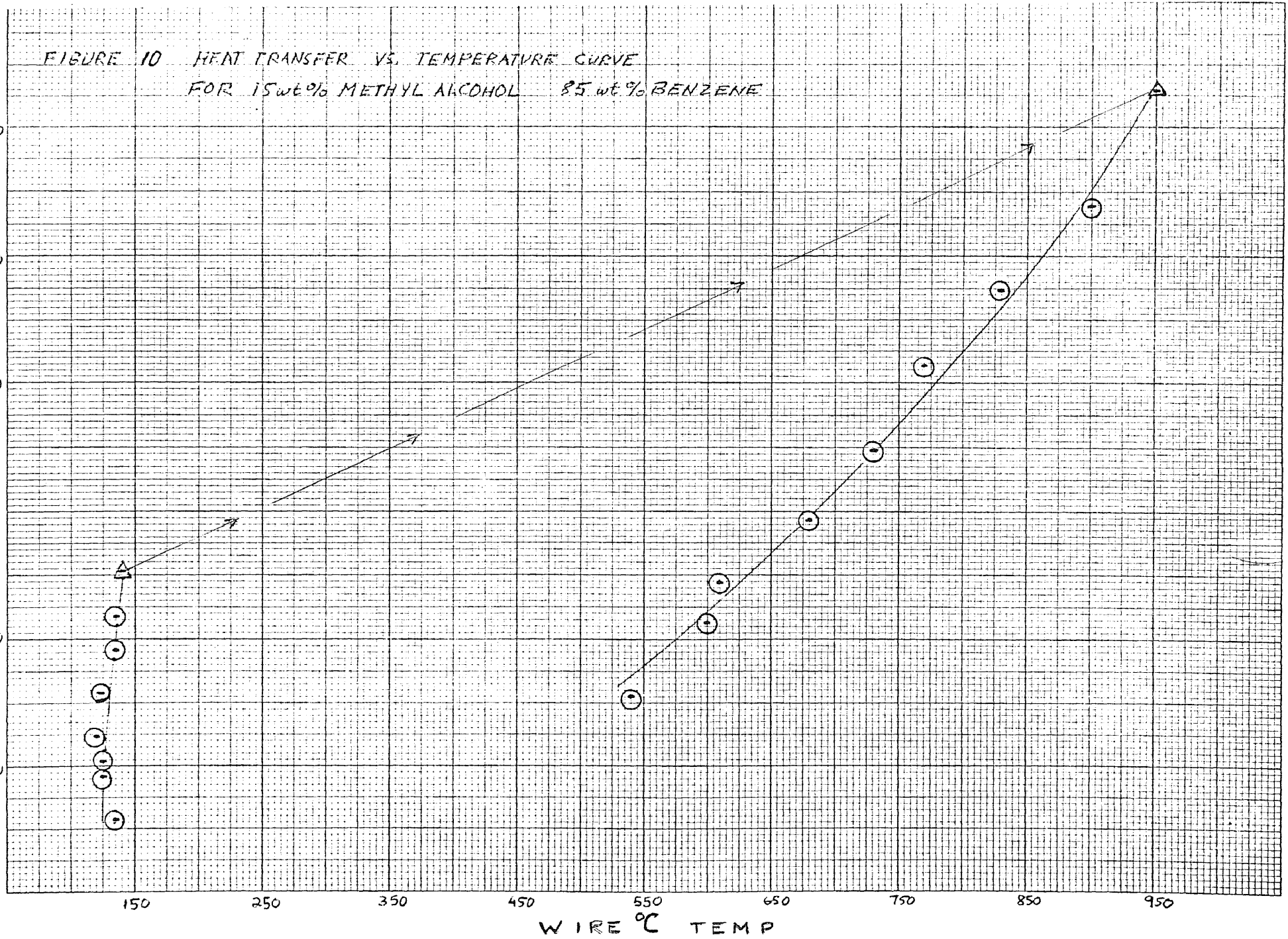
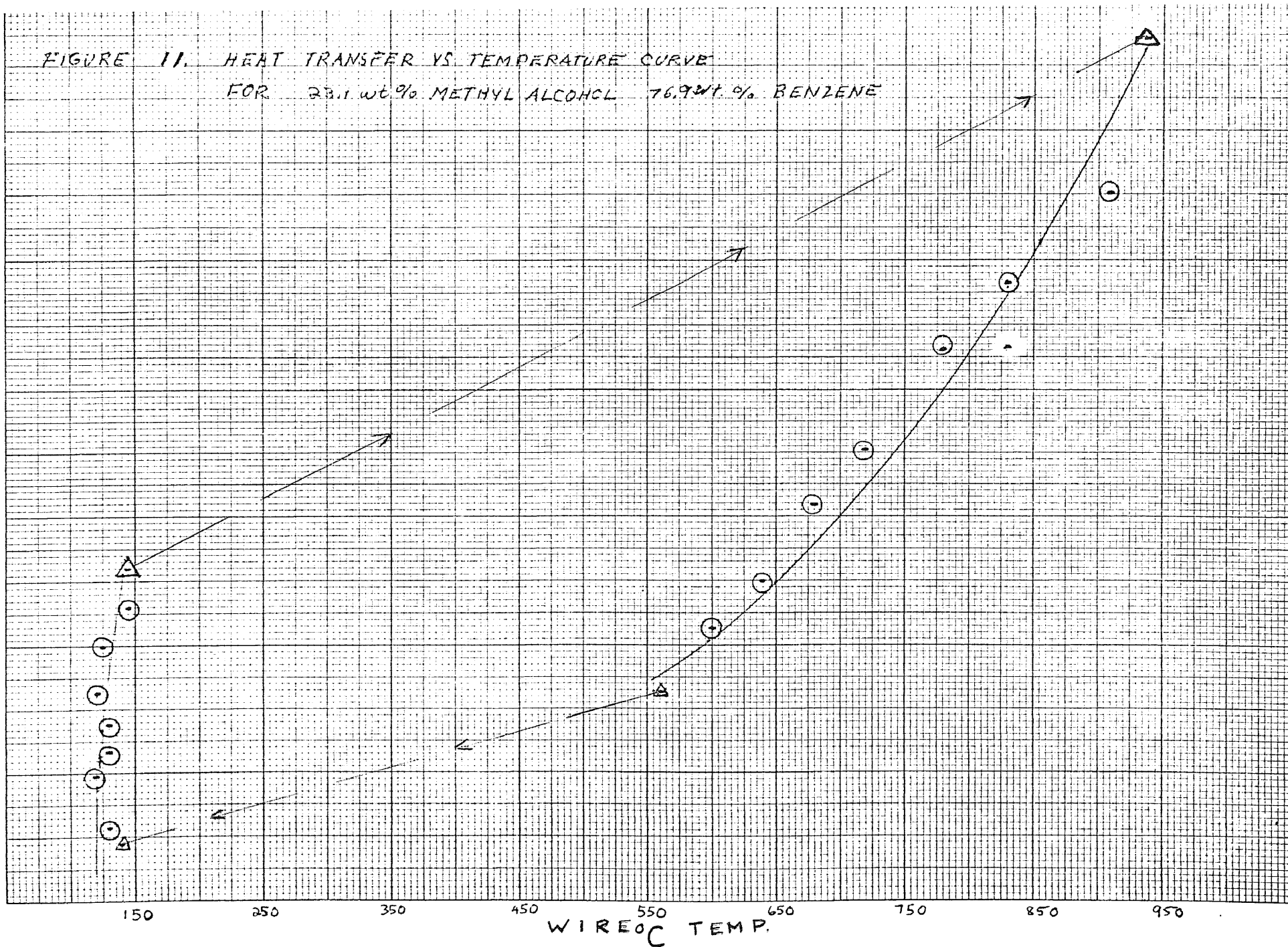


FIGURE 11. HEAT TRANSFER VS. TEMPERATURE CURVE
FOR 23.1 wt% METHYL ALCOHOL 76.9 wt% BENZENE

HEAT
FLUX
 $\frac{W}{m^2}$



WIRE °C TEMP.

FIGURE 13 HEAT TRANSFER VS TEMPERATURE CURVE
FOR 39.1 wt% METHYL ALCOHOL 60.9 wt% BENZENE

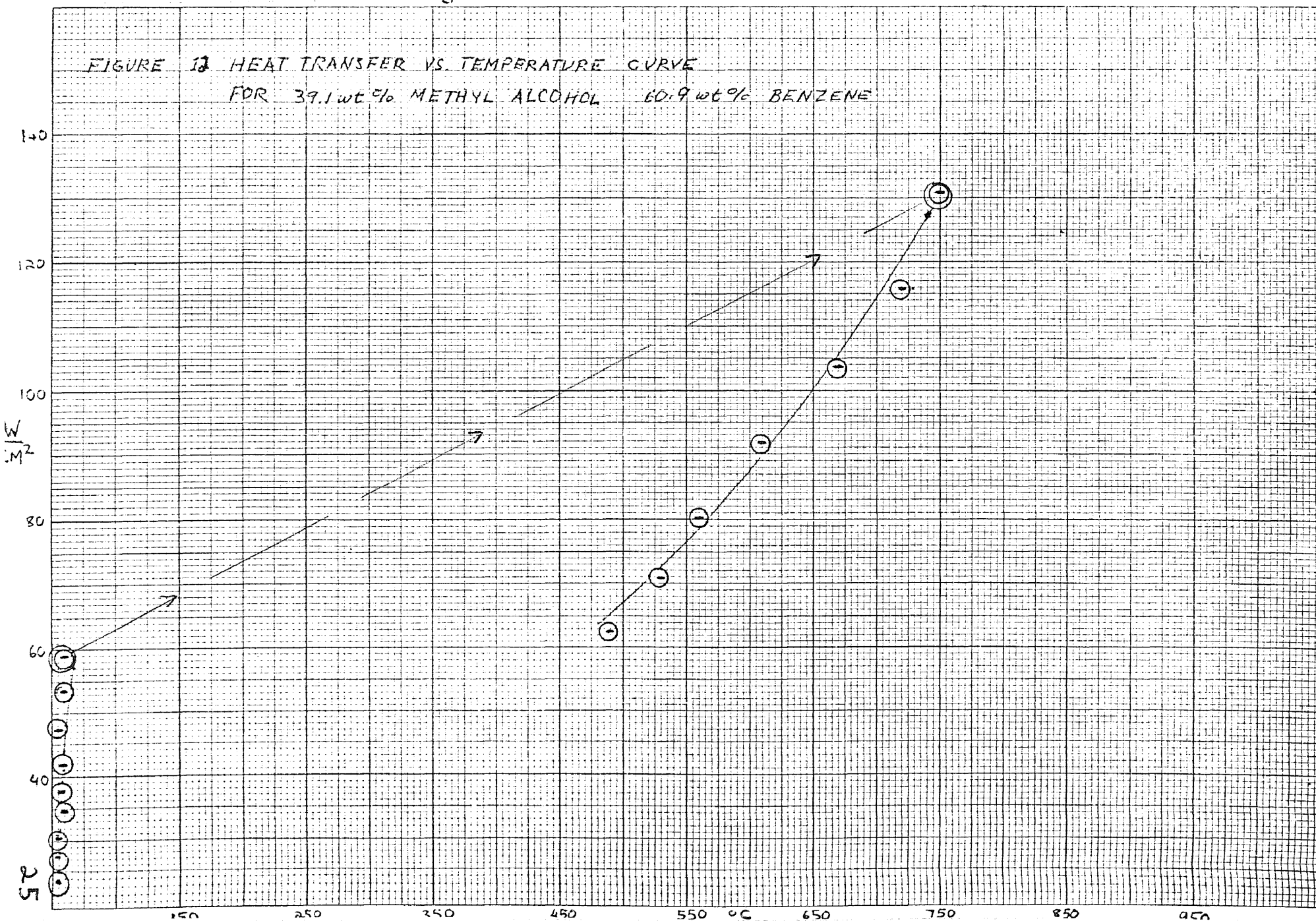


FIGURE 13 HEAT TRANSFER VS. TEMPERATURE CURVE
FOR 62.2 WT% METHYL ALCOHOL 37.8 WT% BENZENE

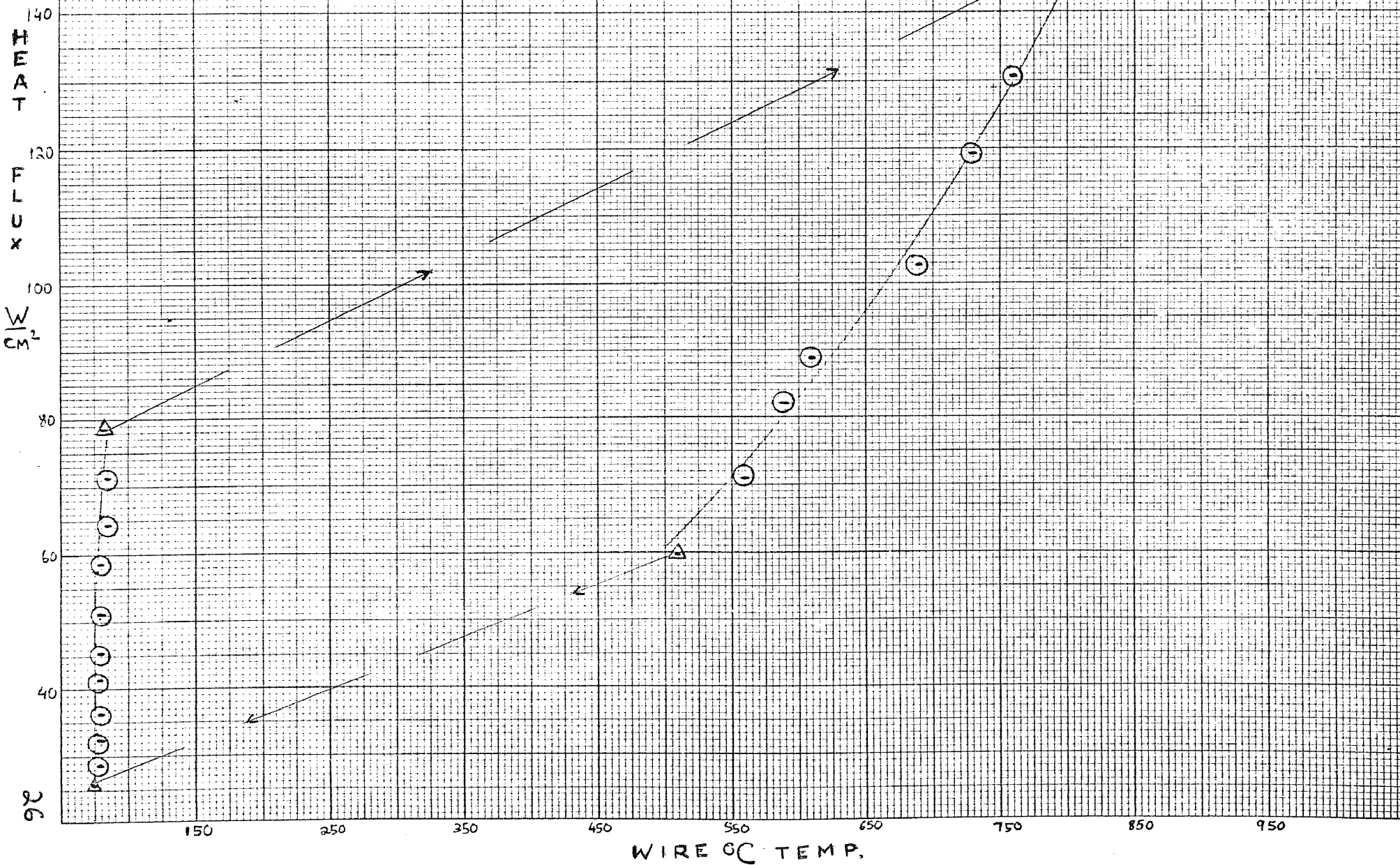


FIGURE 14 HEAT TRANSFER VS TEMPERATURE CURVE
FOR 73 WL % METHYL ALCOHOL 27 WL % BENZENE

HEAT
FLUX
 $\frac{W}{CM^2}$

27

WIRE TEMP. °C

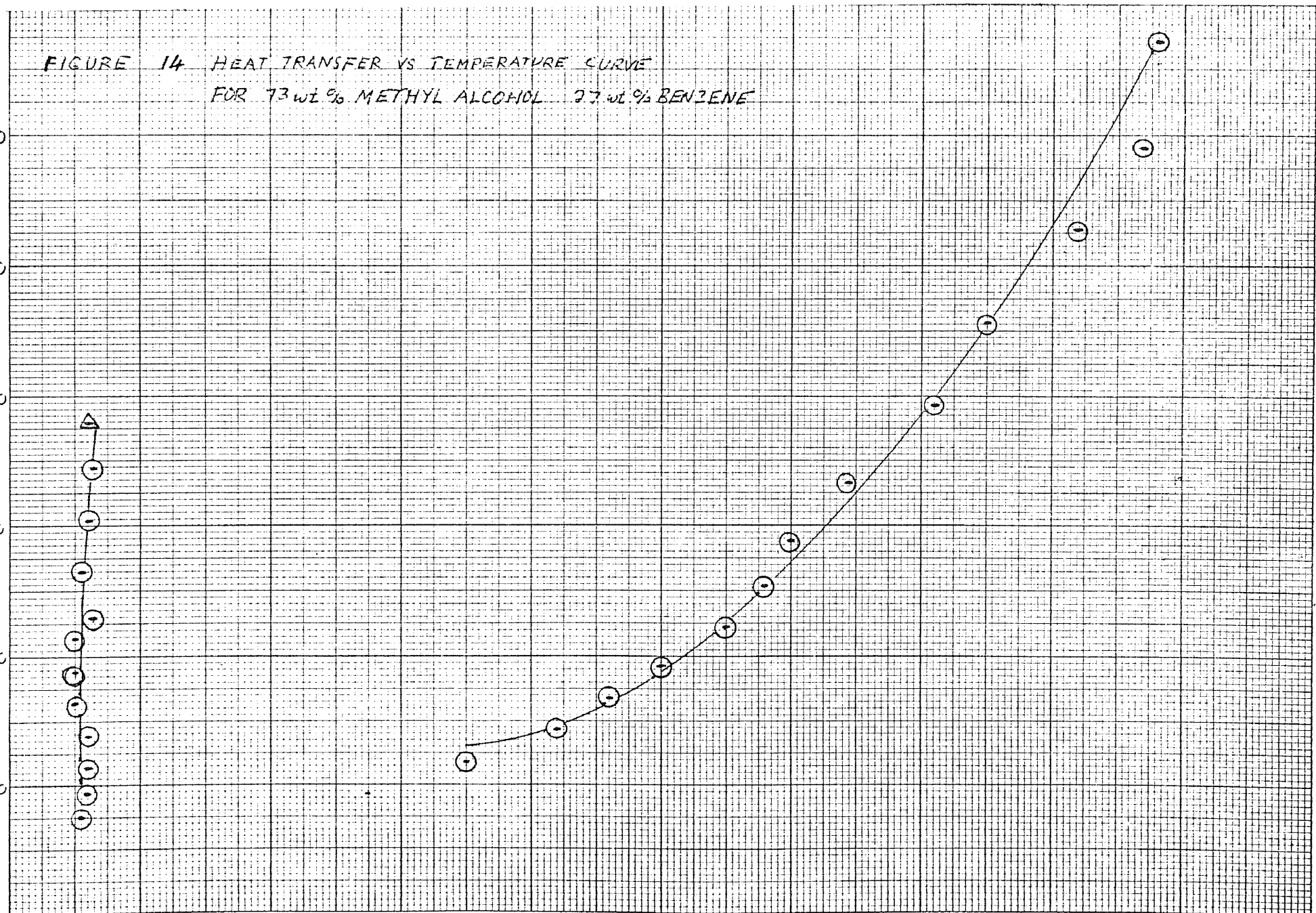


FIGURE 15 HEAT TRANSFER VS. TEMPERATURE
CURVE FOR
9 wt % Ethyl Alcohol 91 wt % Benzene

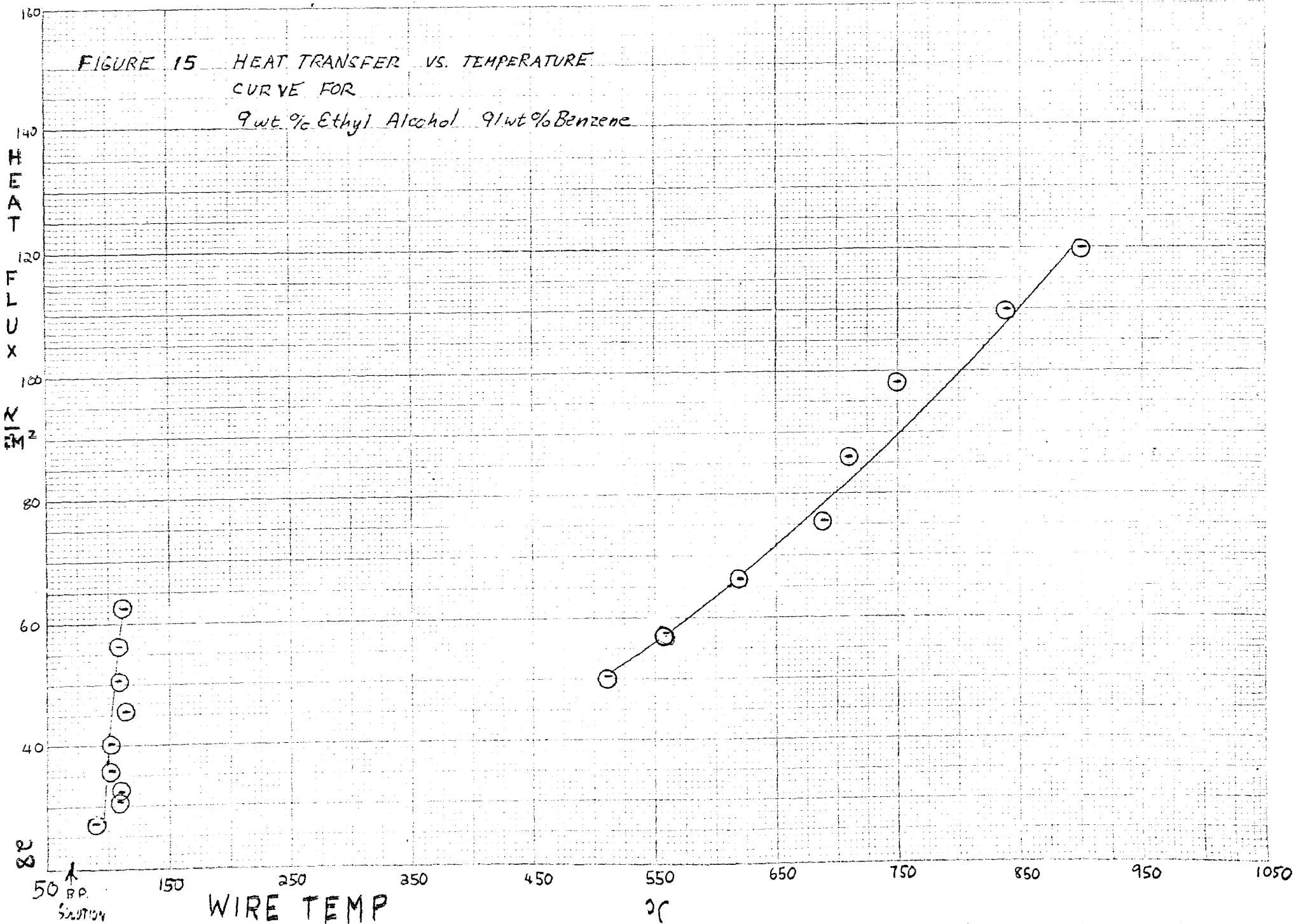


FIGURE 15 HEAT TRANSFER VS. TEMPERATURE.

CURVE FOR
22.9 wt % Ethyl Alcohol 77.1 wt % Benzene

H
E
A
T

F
L
U
X

 $\frac{W}{CM^2}$

62

50 ↑
B.P.
SOLUTION

WIRE TEMP

°C

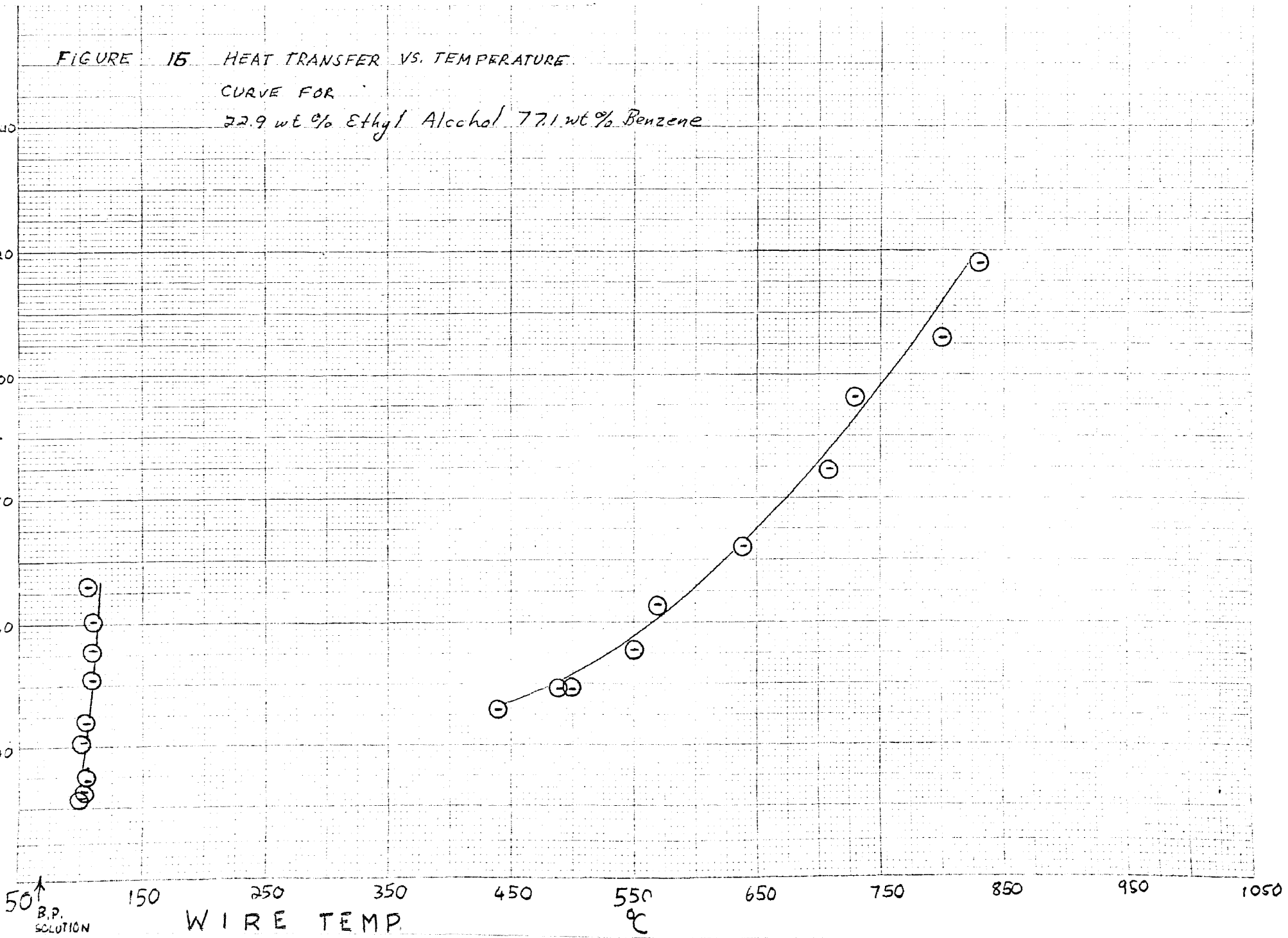


FIGURE 17 HEAT TRANSFER VS TEMPERATURE
CURVE FOR
32.4 wt % Ethyl Alcohol 67.6 wt % Benzene

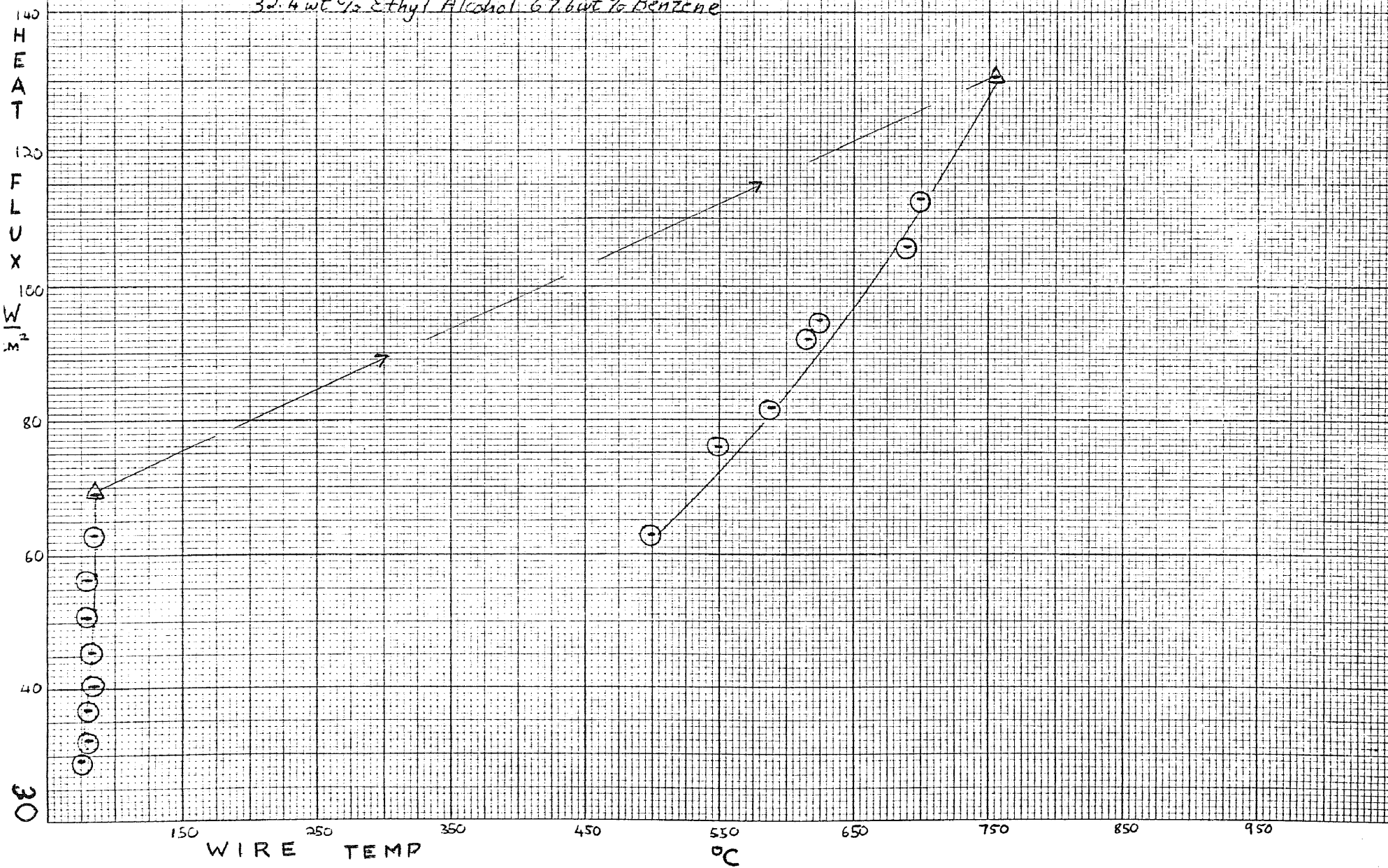


FIGURE 18 HEAT TRANSFER VS TEMPERATURE
CURVE FOR
56.8 wt % Ethyl Alcohol 43.2 wt % Benzene

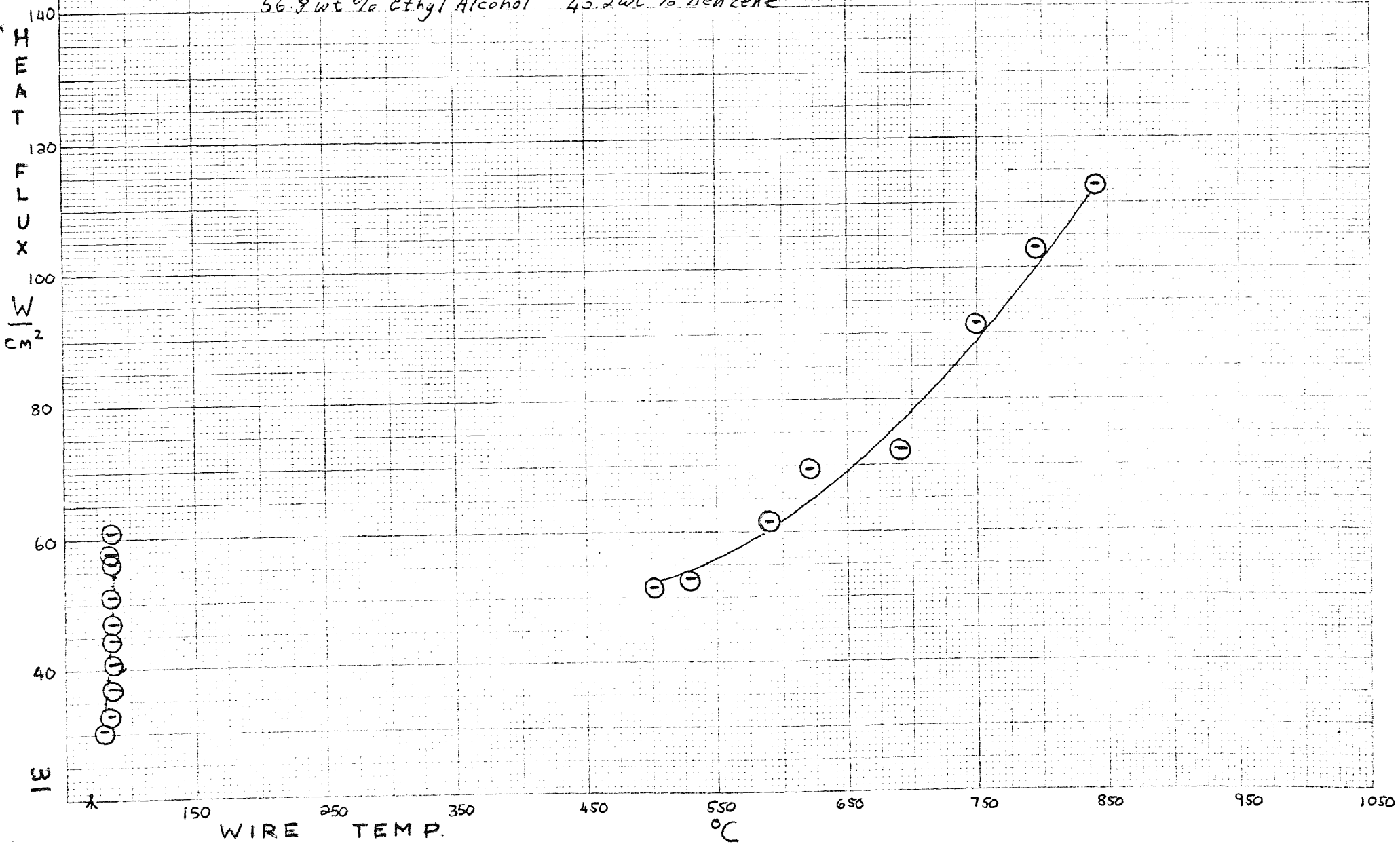


FIGURE 19 HEAT TRANSFER VS TEMPERATURE
CURVE FOR 78% ETHYL ALCOHOL 22 wt % BENZENE

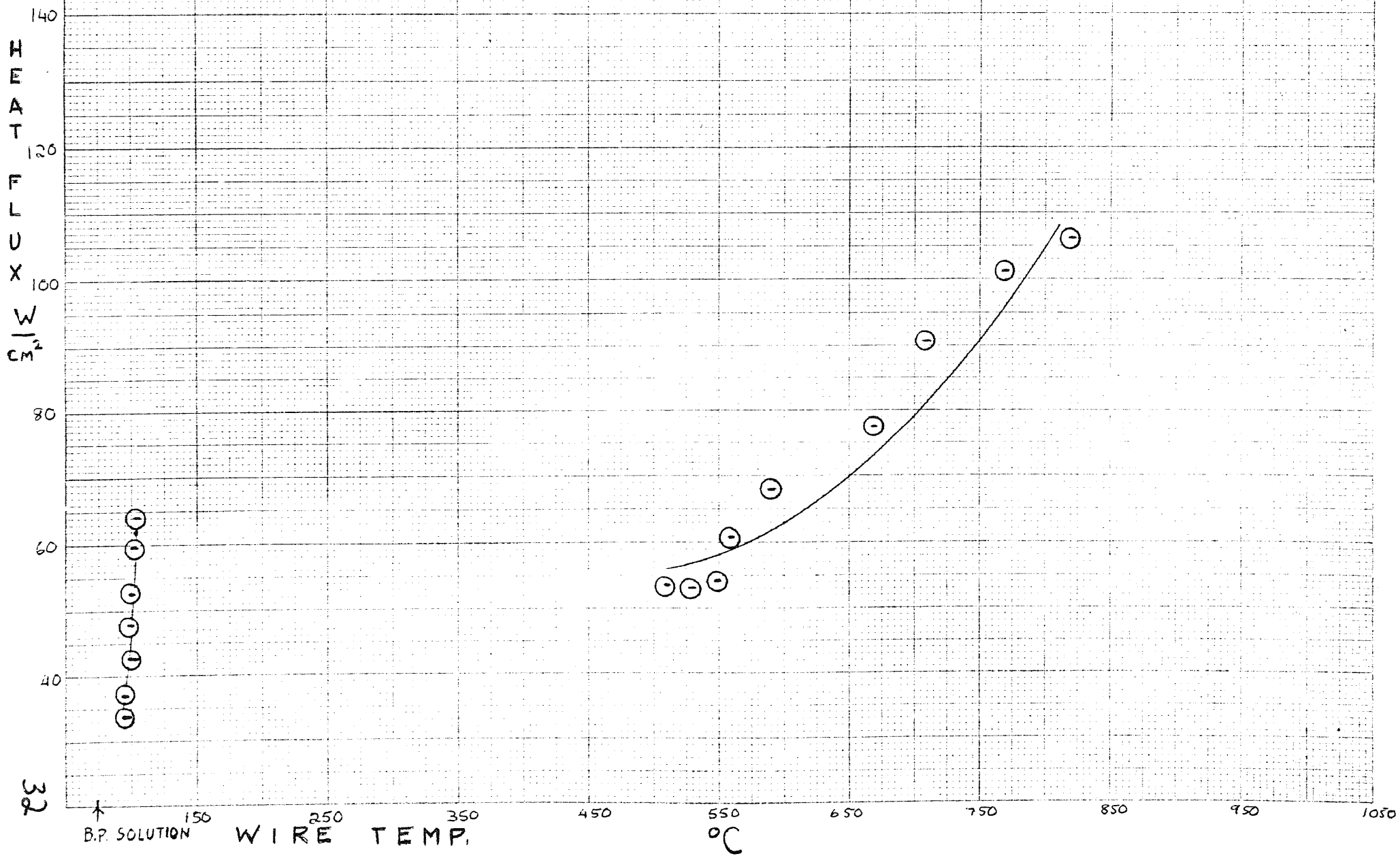


FIGURE 20 HEAT TRANSFER VS TEMPERATURE

CURVE FOR 33.7wt% ISOPROPYL ALCOHOL 66.3wt% BENZENE

HEAT
FLUX
 $\frac{W}{cm^2}$

150
120
90
60
33

WIRE TEMP. °C

°C

B.P. SOLUTION

50 150 250 350 450 550 650 750 850 950 1050

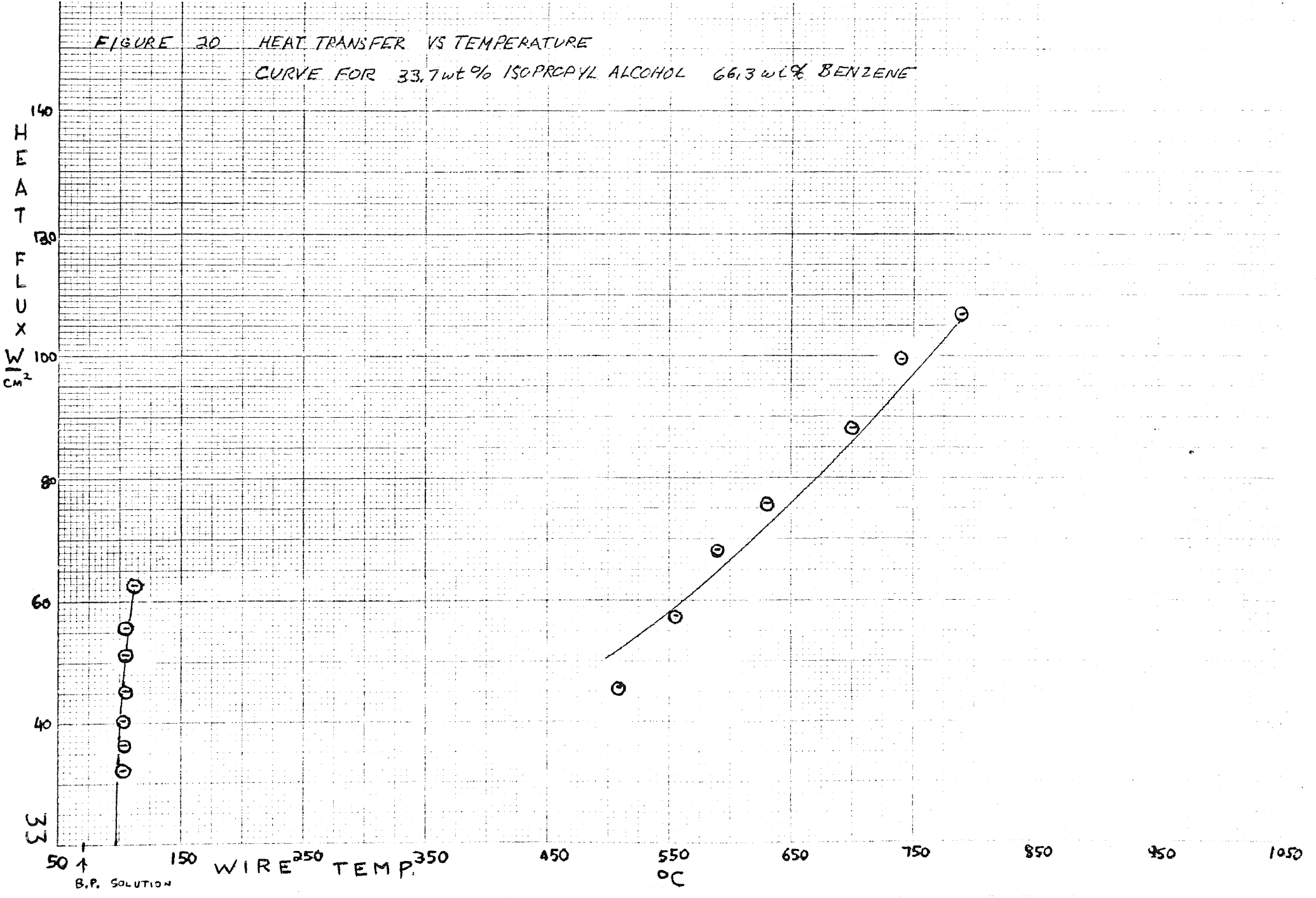
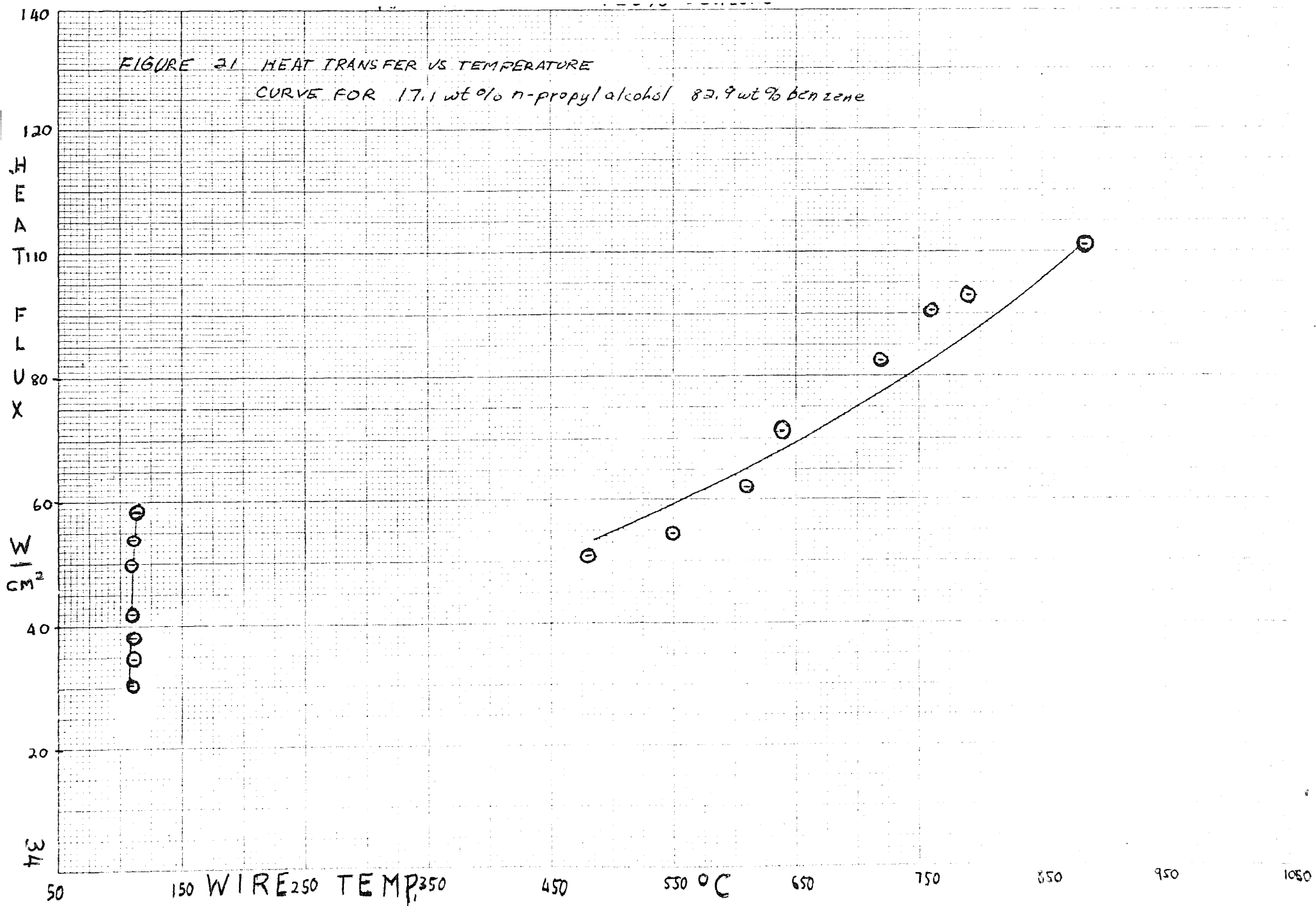


FIGURE 21 HEAT TRANSFER VS TEMPERATURE
CURVE FOR 17.1 wt% n-propyl alcohol 82.9 wt% benzene



boiling while the heat flux only decreased slightly. This corresponds to the change from film to nucleate boiling. The heat flux curves obtained in this study are shown in Figures 4-21. In general, these results were consistent with those of Nukiyama (2).

Several difficulties were associated with the heat flux measurements. First, in principle, the change from nucleate to film boiling should occur when the critical temperature difference and corresponding heat flux are exceeded; however, in practice, the change can occur below the critical values. Second, it was observed that film boiling could be localized to a part of the wire heating surface. This was especially true in the change from film to nucleate boiling. This condition could be stabilized for several minutes and yield unreliable temperature and heat flux data. Third, the platinum wire melted on numerous runs; even though the melting point of platinum is well above the maximum temperature recorded. Localized film boiling could cause this "burnout" during the change from nucleate to film boiling. During the change from nucleate to film boiling it was observed that the region of film boiling started at one end of the wire and moved across until the wire was entirely encircled with vapor film. Thus, during the period of several seconds nucleate boiling is occurring on part of the wire and film boiling is occurring on the other part. Thus the resistance, temperature, and heat flux is not constant along the length

of the wire. As a result the temperature of one part of the heating surface could increase beyond the melting point of the platinum because the heat cannot be dissipated rapidly enough through the wire surface area. Then the platinum wire "burns out" (4).

Liquid vapor equilibrium data was taken by the method outlined by Othmer (18). The first samples of condensate and distillate were taken in the nucleate regime with the heating wire 2-3 cm. below the liquid surface. The current was then increased and the change from nucleate to film boiling occurred. The current was then decreased to lower the temperature and second samples of condensate and distillate were taken in the film boiling regime. The lower temperature was used to minimize pyrolysis of the liquids. No samples were taken during the two regime behavior described above. After the liquid surface level was lowered until the heating wire was just barely covered with liquid (depth less than 0.25 cm.), samples of distillate and condensate were taken under the same conditions of temperature and heat flux. Then the wire temperature was further reduced and samples of distillate and condensate were taken in the nucleate regime. In all cases the liquid was allowed to boil for about 15 minutes before samples were withdrawn. Finally a complete power flux vs. temperature study was performed for the nucleate and film boiling regimes for each liquid.

Results and Discussion

Photographs, taken at 1/2000 second, of ethyl alcohol boiling from a 10 mil platinum wire heating surface are presented in Figures 22-26. They illustrate the differences between nucleate boiling (Figures 22-23) and film boiling (Figures 24-25) and are consistent with those presented by Westwater (11) (13) and McAdams (22). Of special significance were the photographs of the wire boiling partly in the nucleate regime and partly in the film regime (See Figure 26). It is this condition that was responsible for frequent burnout of the platinum wire as described on page 35.

Heat transfer vs. temperature curves (Figures 4-21) were qualitatively similar to those of Nukiyama (2), Weiss (23) and Westwater and Santangelo (24). These curves indicate that, for mixtures of benzene with methyl alcohol, the critical heat flux increases with increasing methyl alcohol concentration. It is seen in Figure 27 that this increase is sharp up to 15 mole % methyl alcohol, then moderate beyond 15 mole %. However, this increase in heat flux is not noticeable in ethyl alcohol--benzene and is approximately constant with alcohol concentration. No explanation for this behavior is readily apparent. However, Bonilla and Perry (28) found that similar curves could be obtained by plotting critical ΔT versus concentration.



Figure 22a Nucleate Boiling 14 watts/cm² 125°C

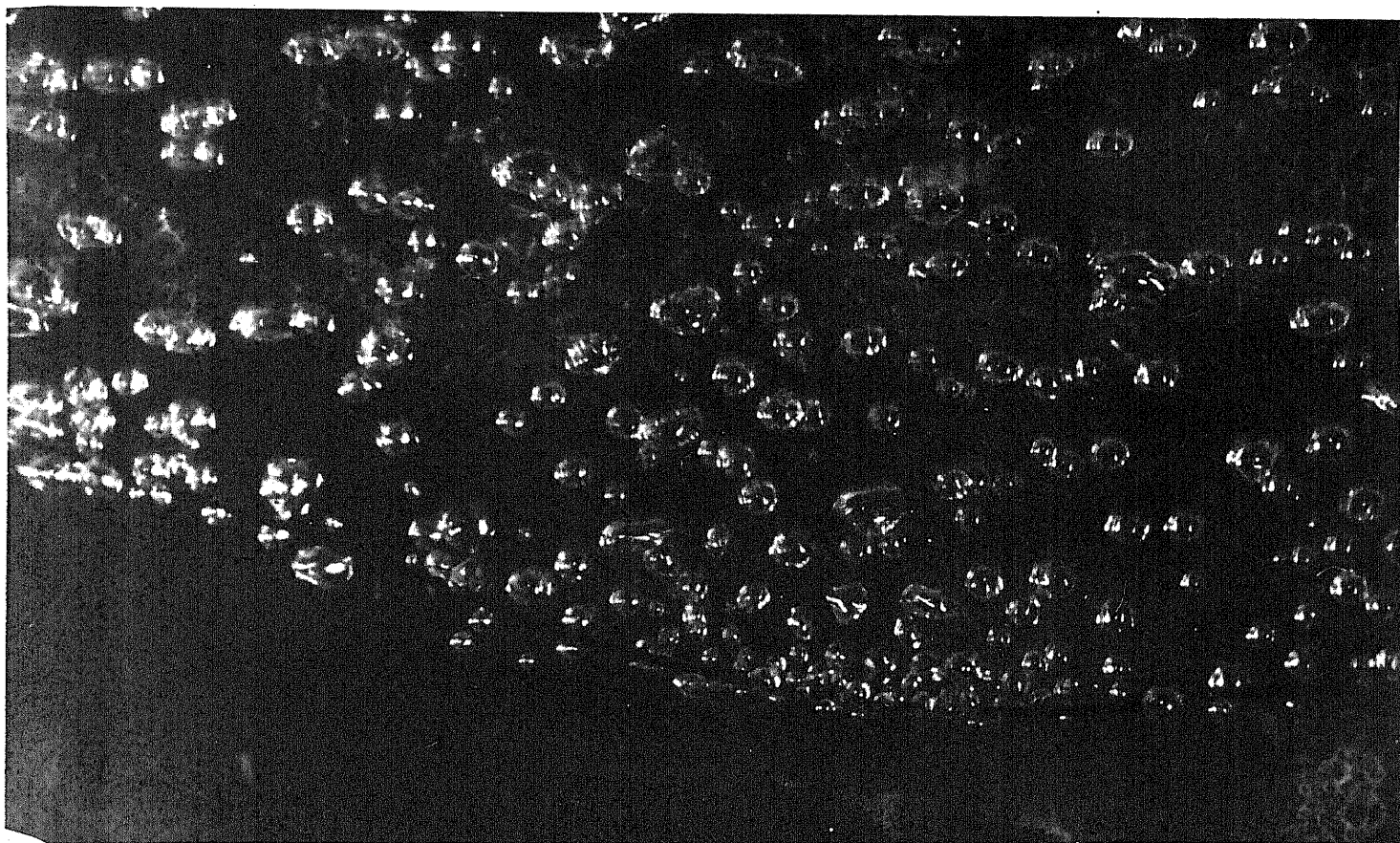


Figure 22b. Nucleate Boiling, 22.2 watts/cm², 130°C

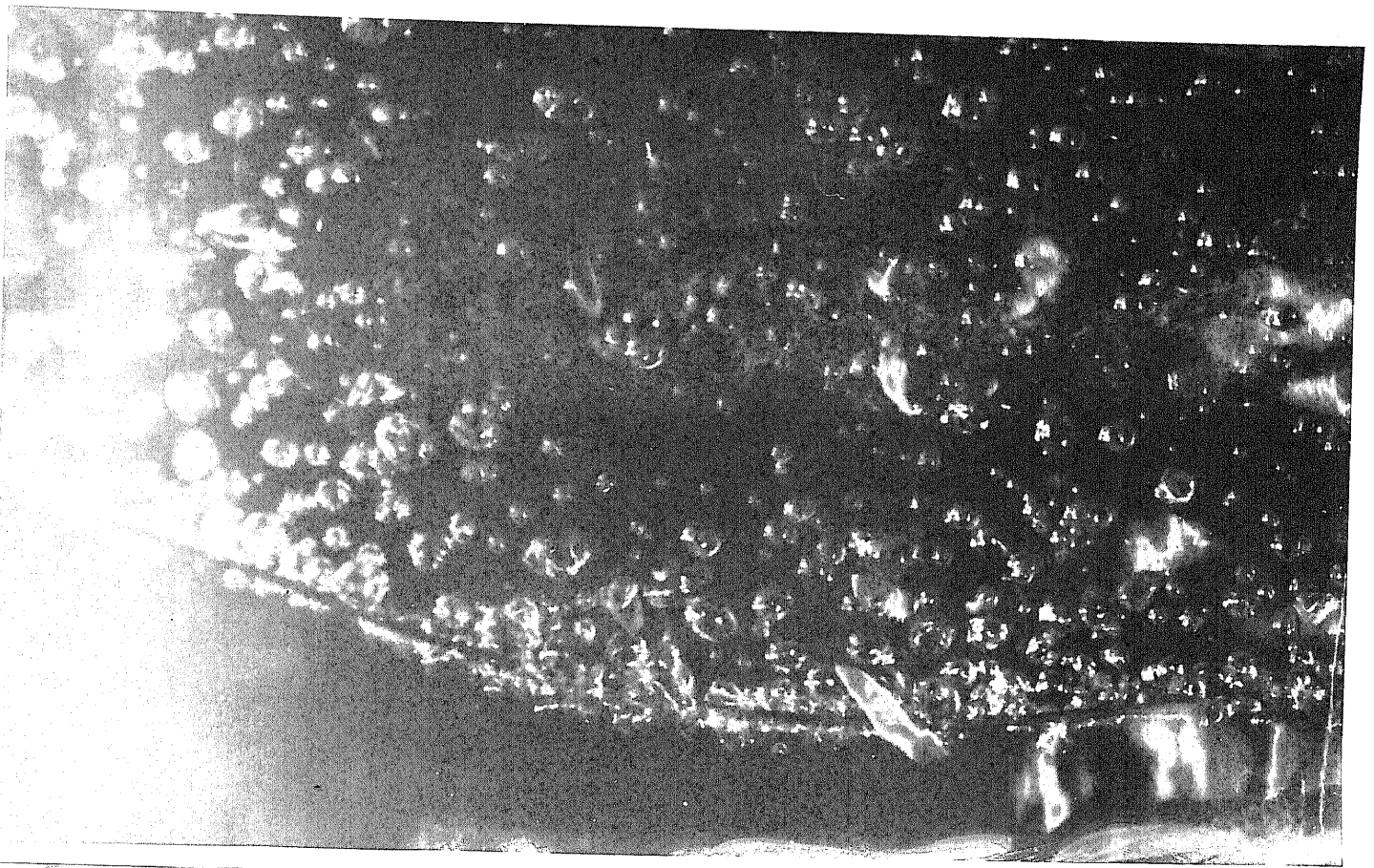


Figure 23a. Nucleate Boiling 32 watts/cm², 150°C

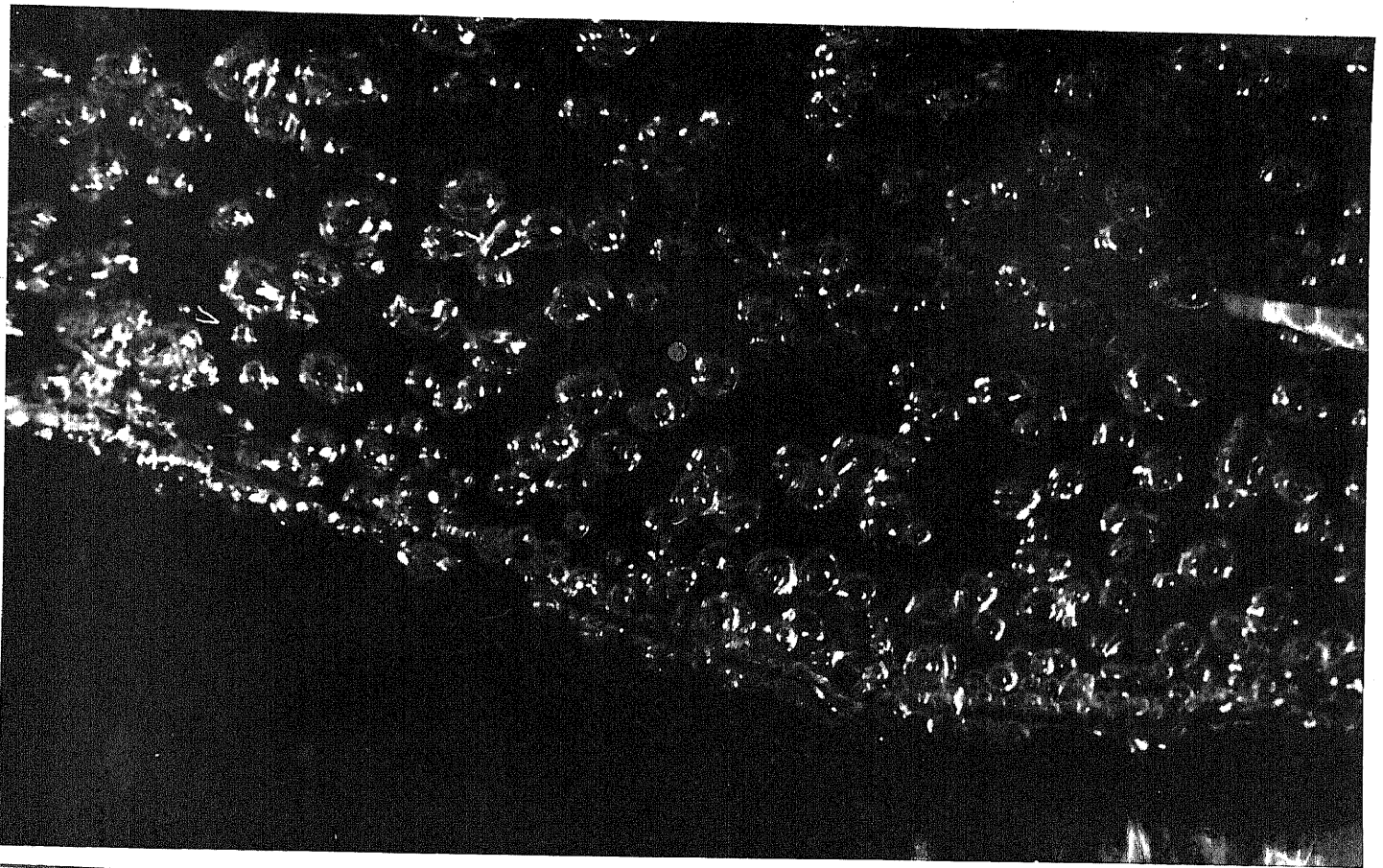


Figure 23b. Nucleate Boiling 42 watts/cm², 150°C

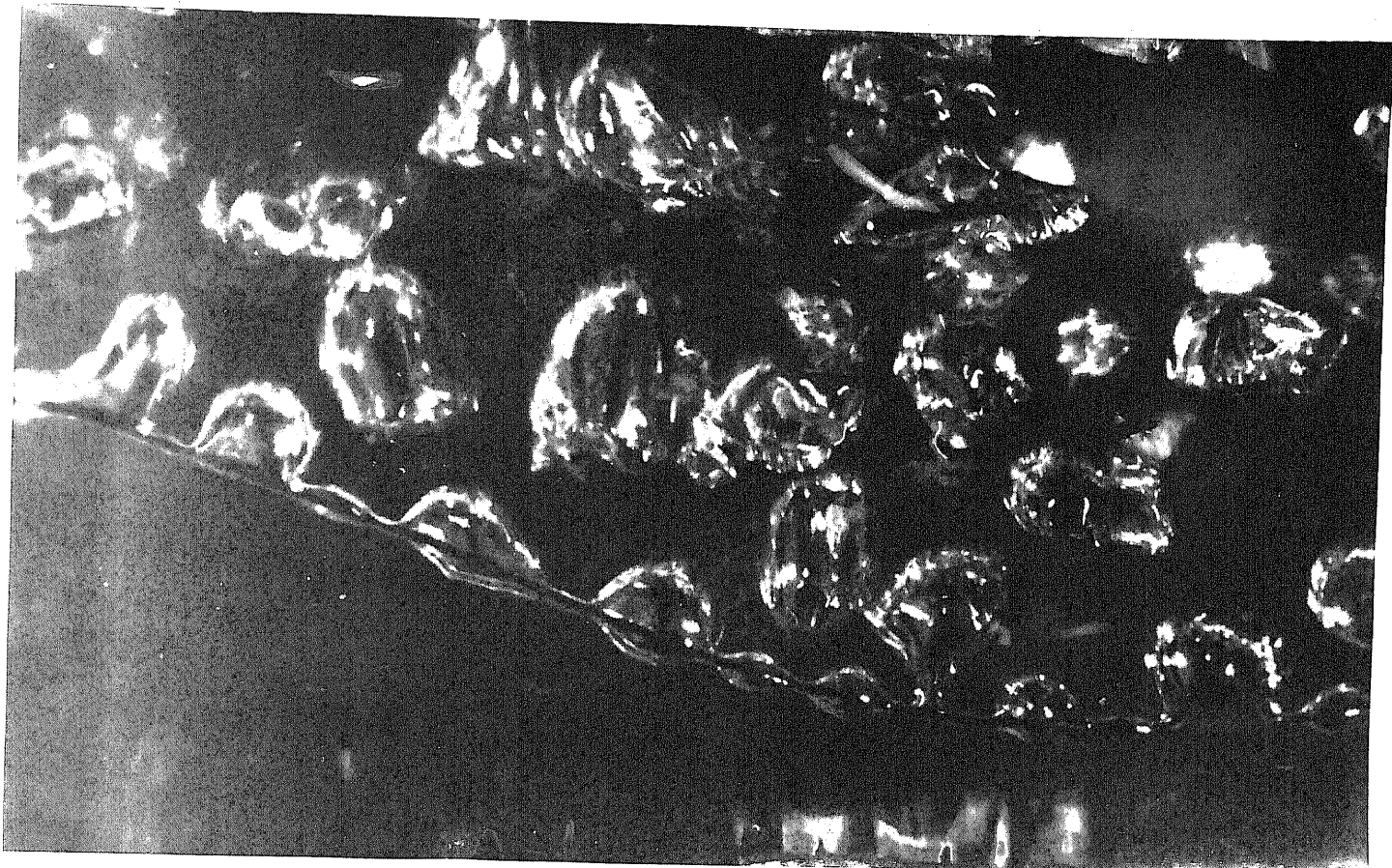


Figure 24a. Film Boiling 59.2 watts/cm², 620°C

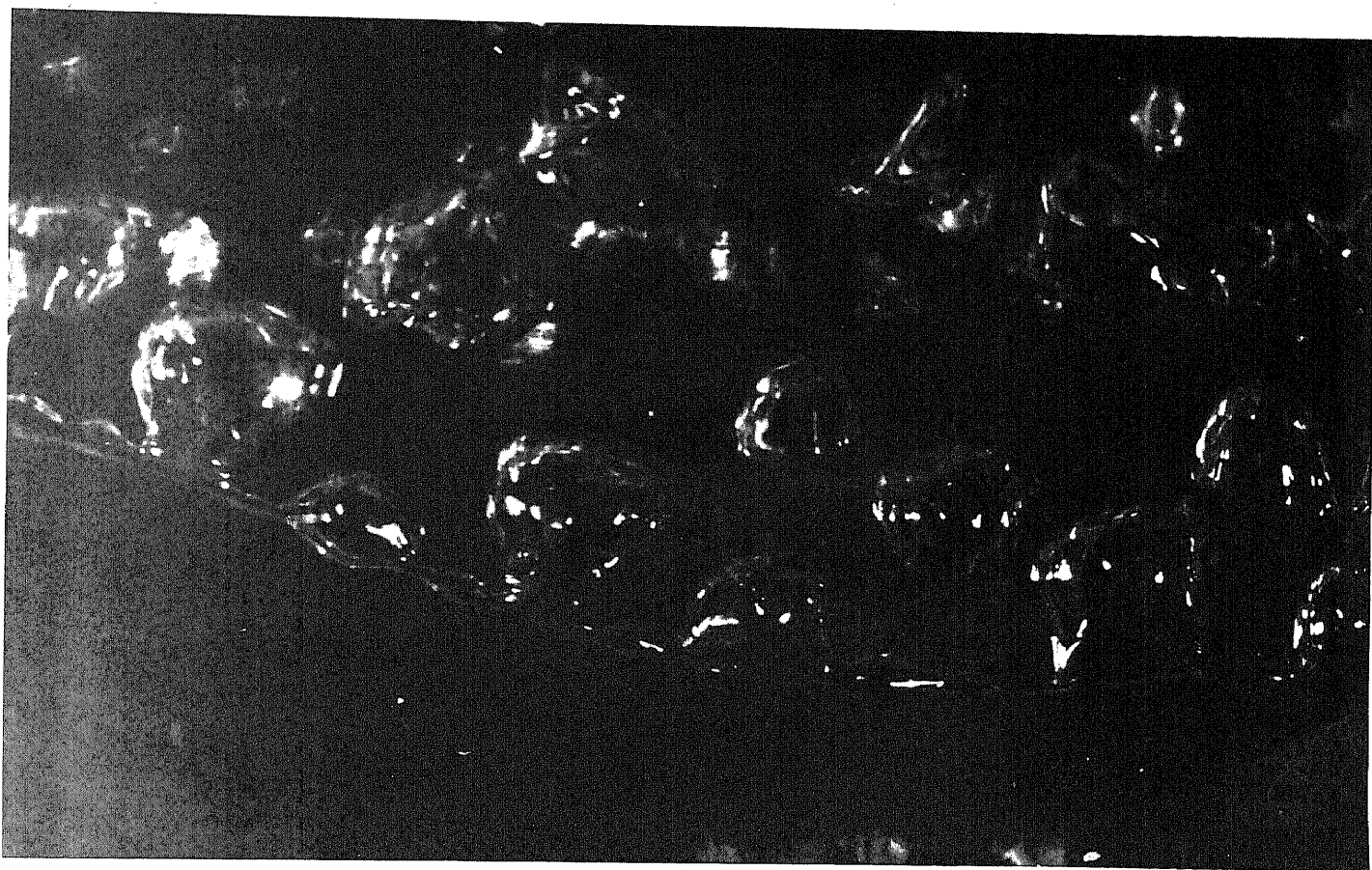


Figure 24b. Film Boiling 87 watts/cm², 790°C

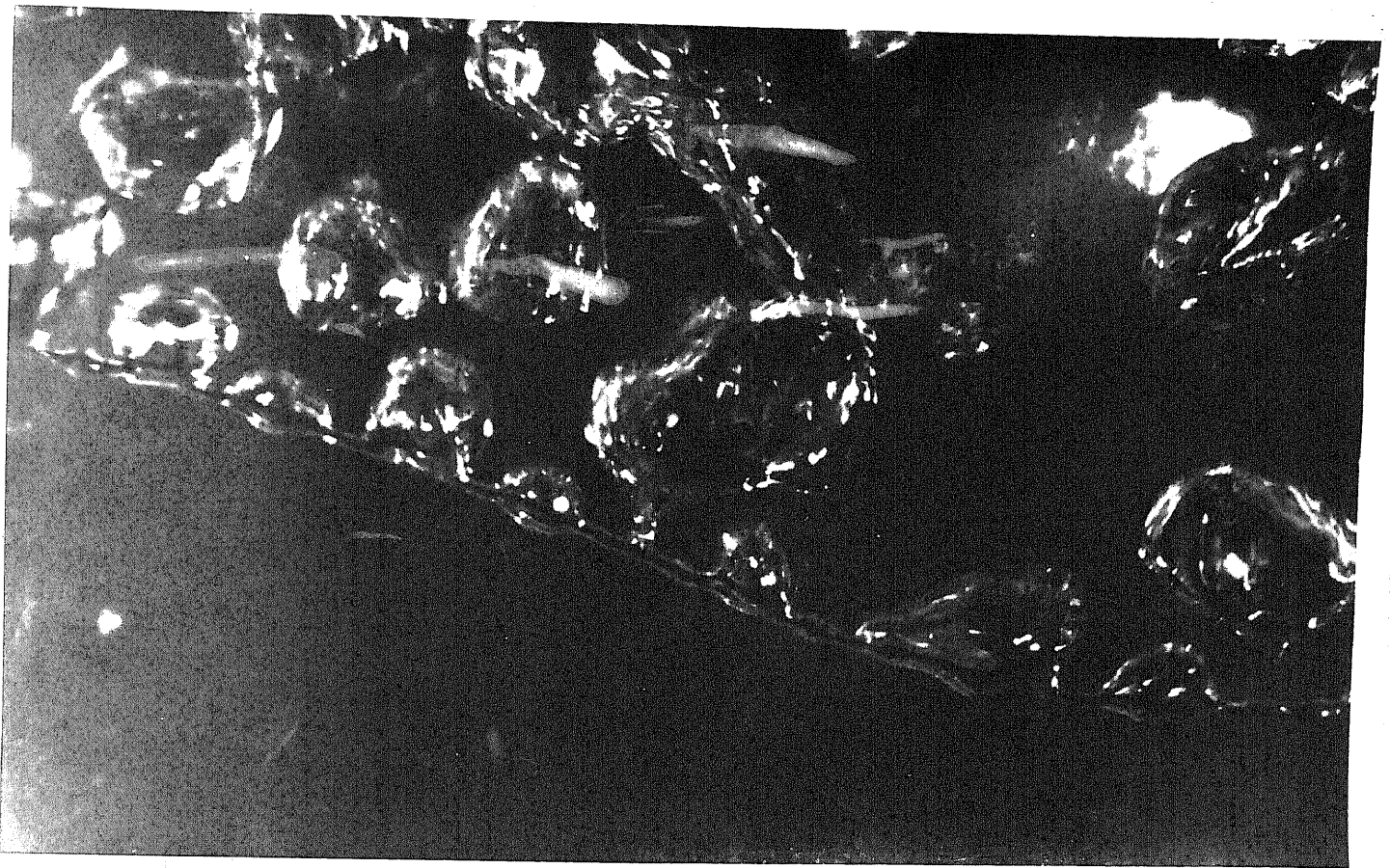


Figure 25a. Film Boiling 100 watts/cm², 850°C

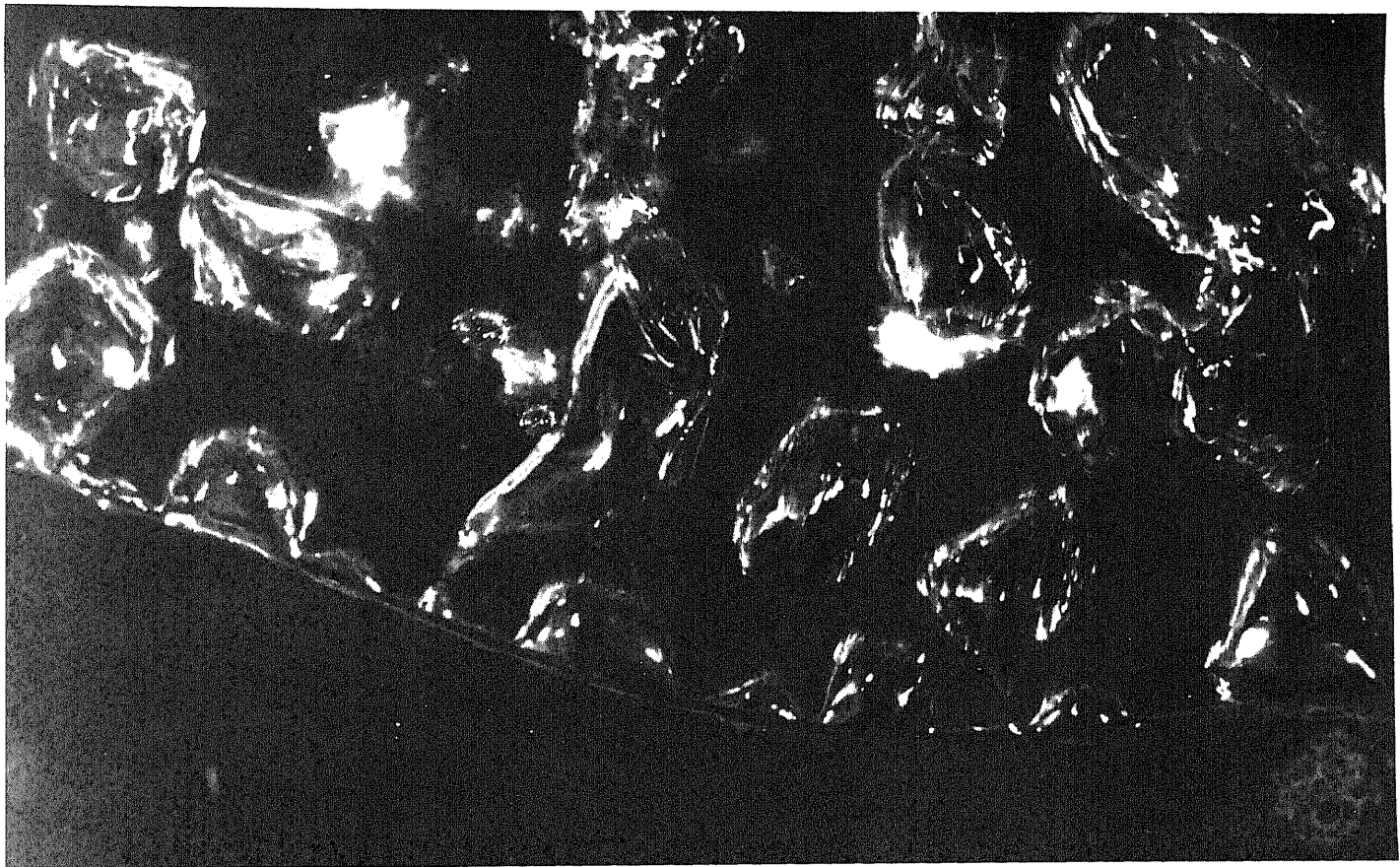


Figure 25b. Film Boiling 111 watts/cm², 910°C

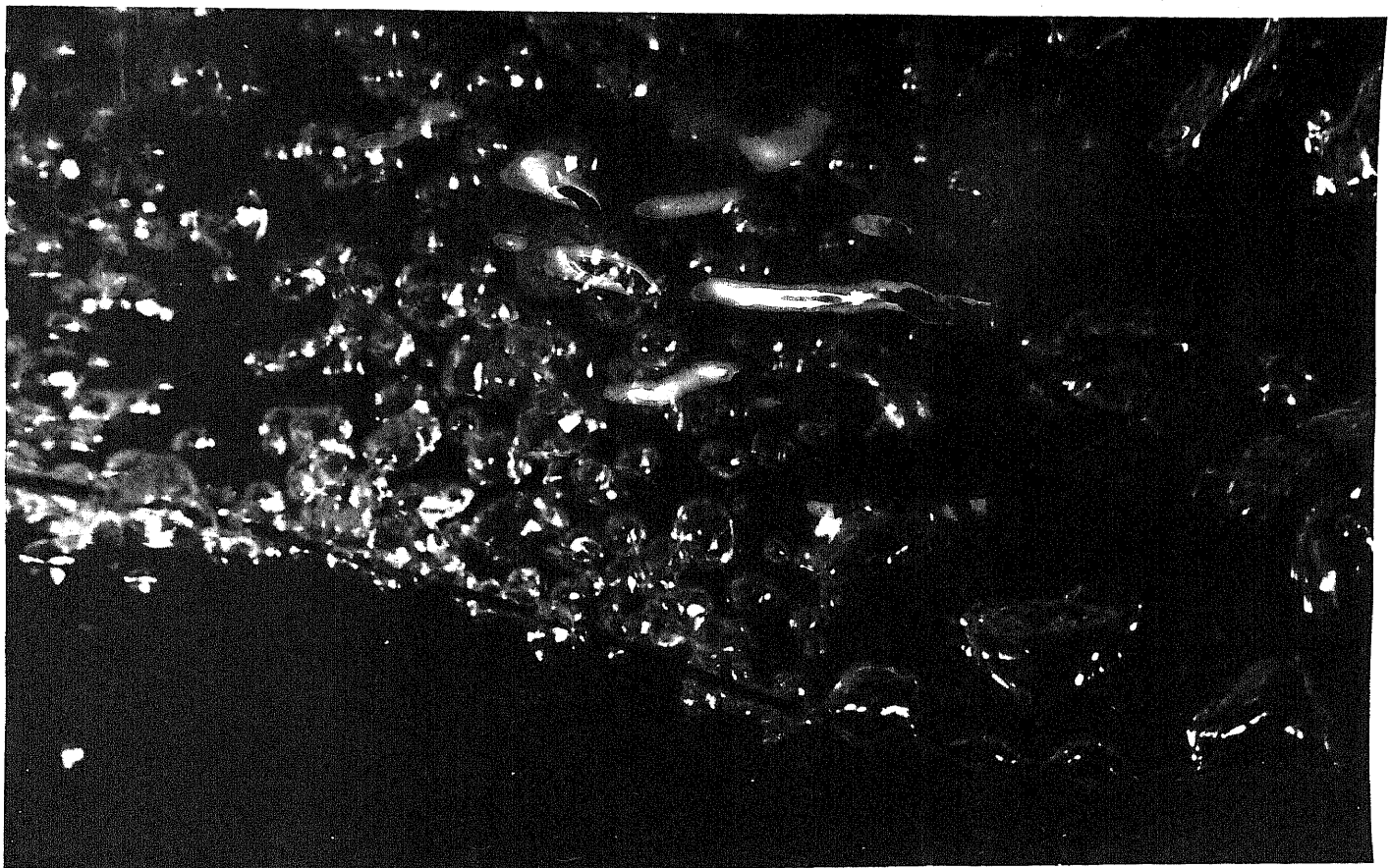


Figure 26a. Nucleate and Film Boiling on the Same Heating Wire

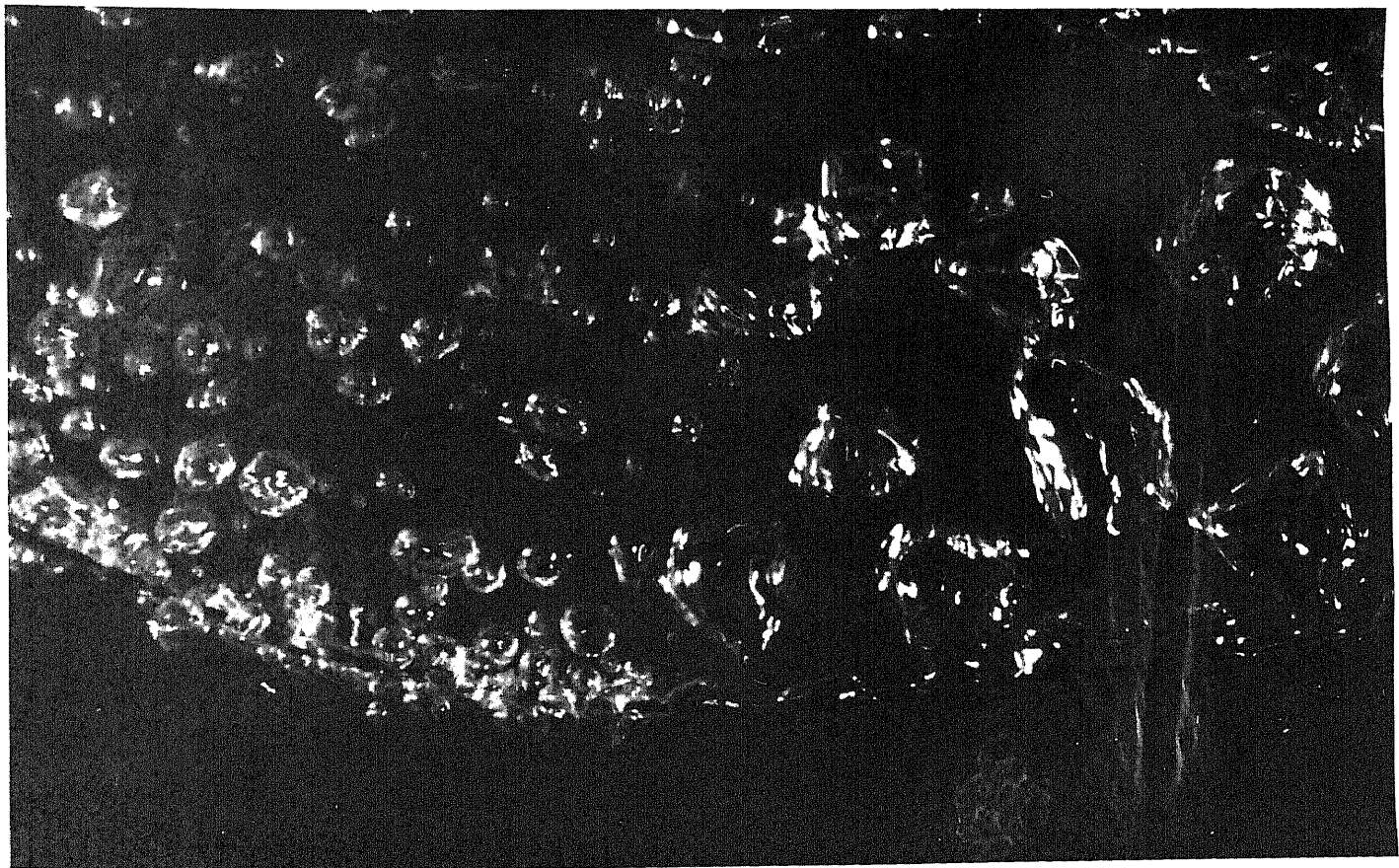


Figure 26b. nucleate and Film Boiling on the Same Heating Wire

It would be of interest to obtain quantitative heat transfer data for the systems considered in order to investigate: 1. the effect of concentration on heat flux, and 2. the existence of correlations between the critical ΔT and other physical properties. These studies would require consideration of such factors as heat dissipated through end effects, effects of diameter and length of the heating element on its temperature and the effects of film boiling on the resistance of the wire (4).

Samples of condensate and distillate were analyzed for systems that were boiled under the following conditions:

1. nucleate boiling with the heating surface submerged 2-3 cm,
2. film boiling with the heating surface submerged 2-3 cm,
3. film boiling with the heating surface submerged less than 0.25 cm,
4. nucleate boiling with the heating surface submerged less than 0.25 cm. (see Appendix II). The samples were analyzed by measuring their index of refraction with an Abbe refractometer (calibration curves are shown in Figure 28).

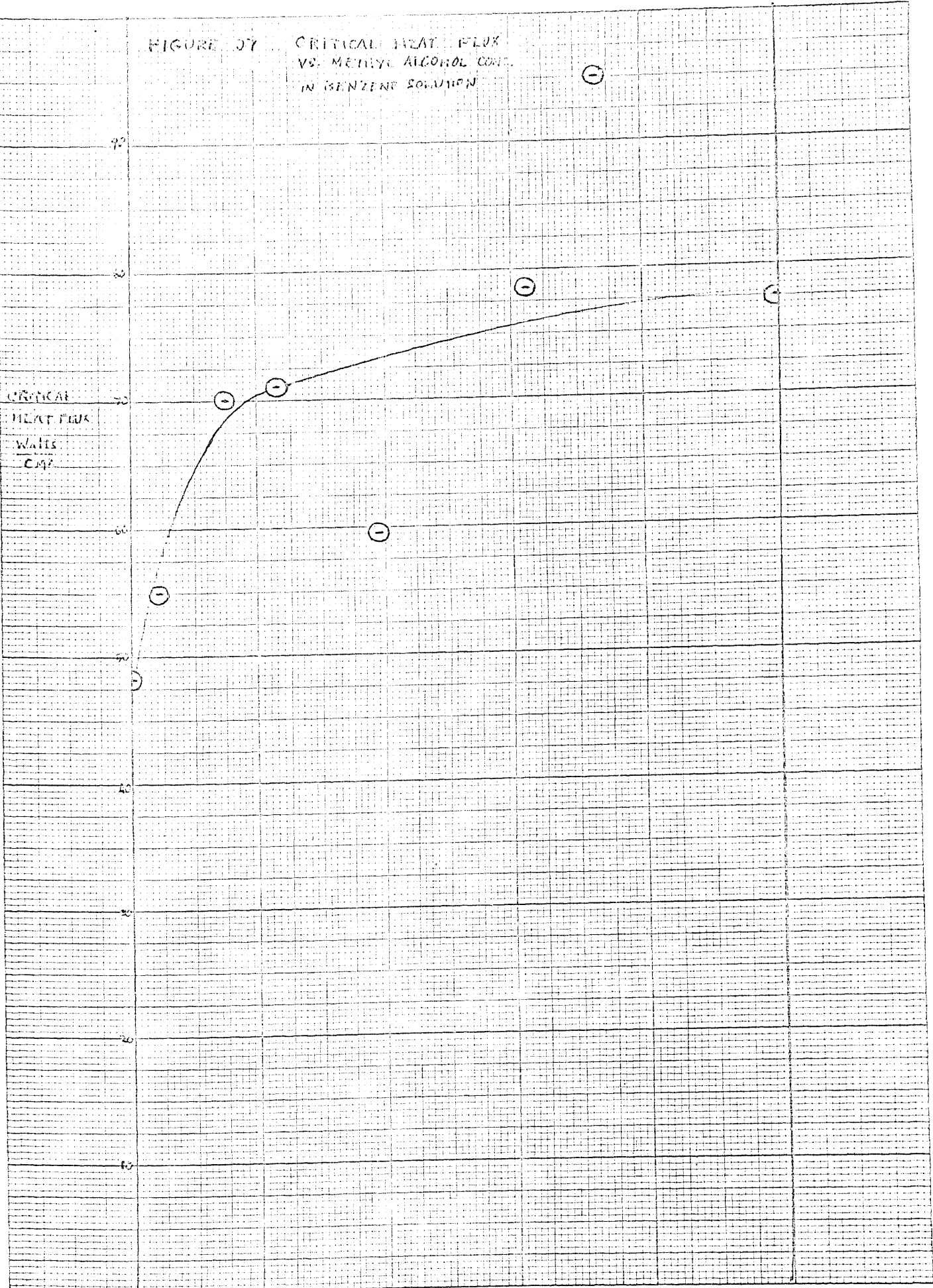
Azeotropic compositions of methyl alcohol-benzene, ethyl alcohol-benzene, iso-propyl alcohol benzene, and n-propyl alcohol-benzene remained invariant through the four boiling conditions. This is demonstrated for methyl alcohol-benzene and ethyl alcohol-benzene in Figures 29-32. Liquid vapor equilibrium data for the systems of methyl alcohol-benzene and ethyl alcohol-benzene remained invariant through the four boiling conditions (Figures 29-32). The values obtained agreed

FIGURE 37 CRITICAL HEAT FLUX
VS. METHYL ALCOHOL CON.
IN BENZENE SOLUTION

CRITICAL
HEAT FLUX
Watts
cm²

92
80
70
60
50
40
30
20
10
0

.2 .4 .6 .8
Wt. Fraction Methanol in Benzene



2000

MOLE FRACTION ETHANOL

MOLE FRACTION METHANOL

.8 .6 .4 .2 .8 .6 .4 .2

FIGURE 28. INDEX OF REFRACTION
VS MOLE FRACTION FOR SOLUTIONS OF
ETHANOL-BENZENE, METHANOL-BENZENE

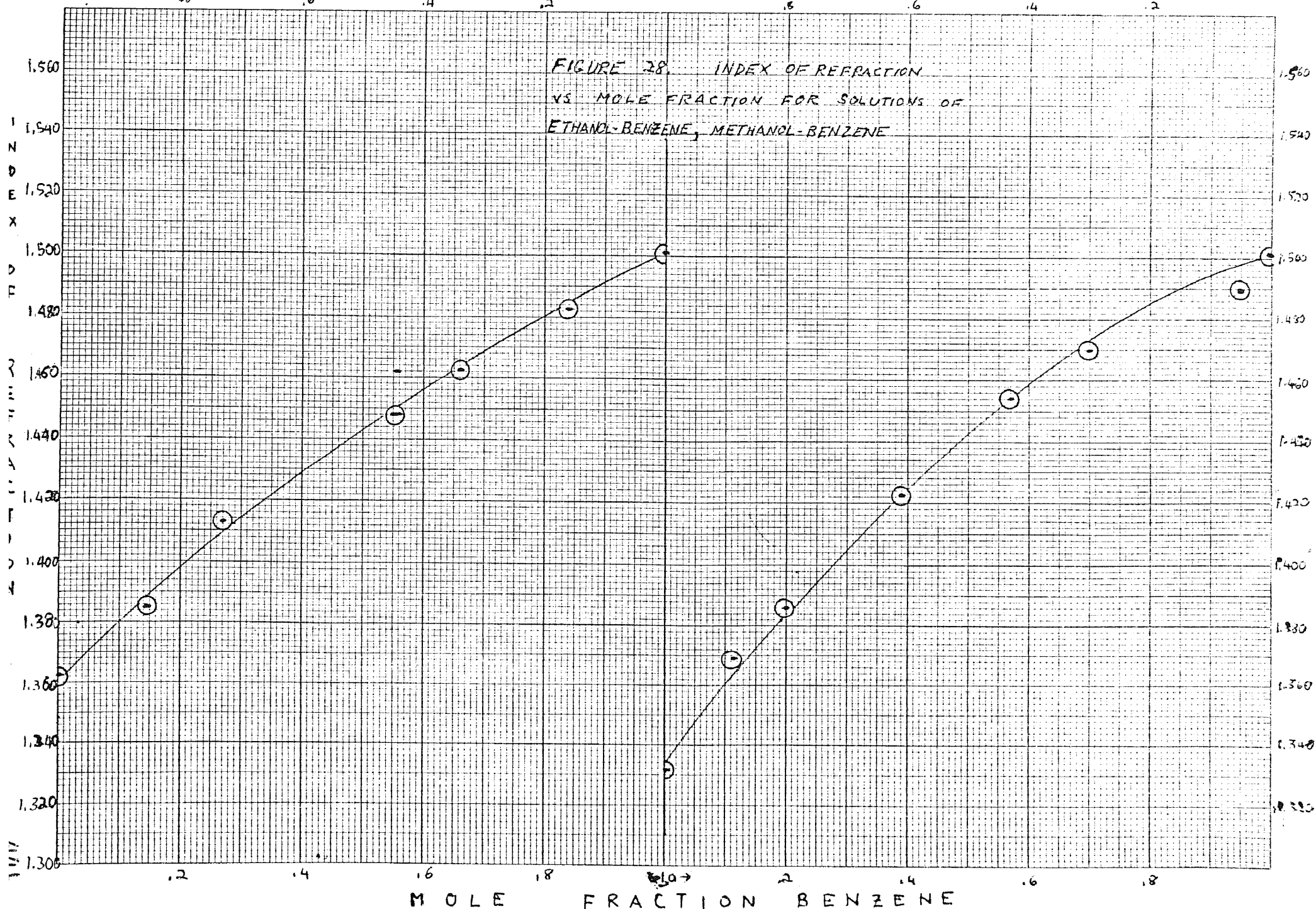
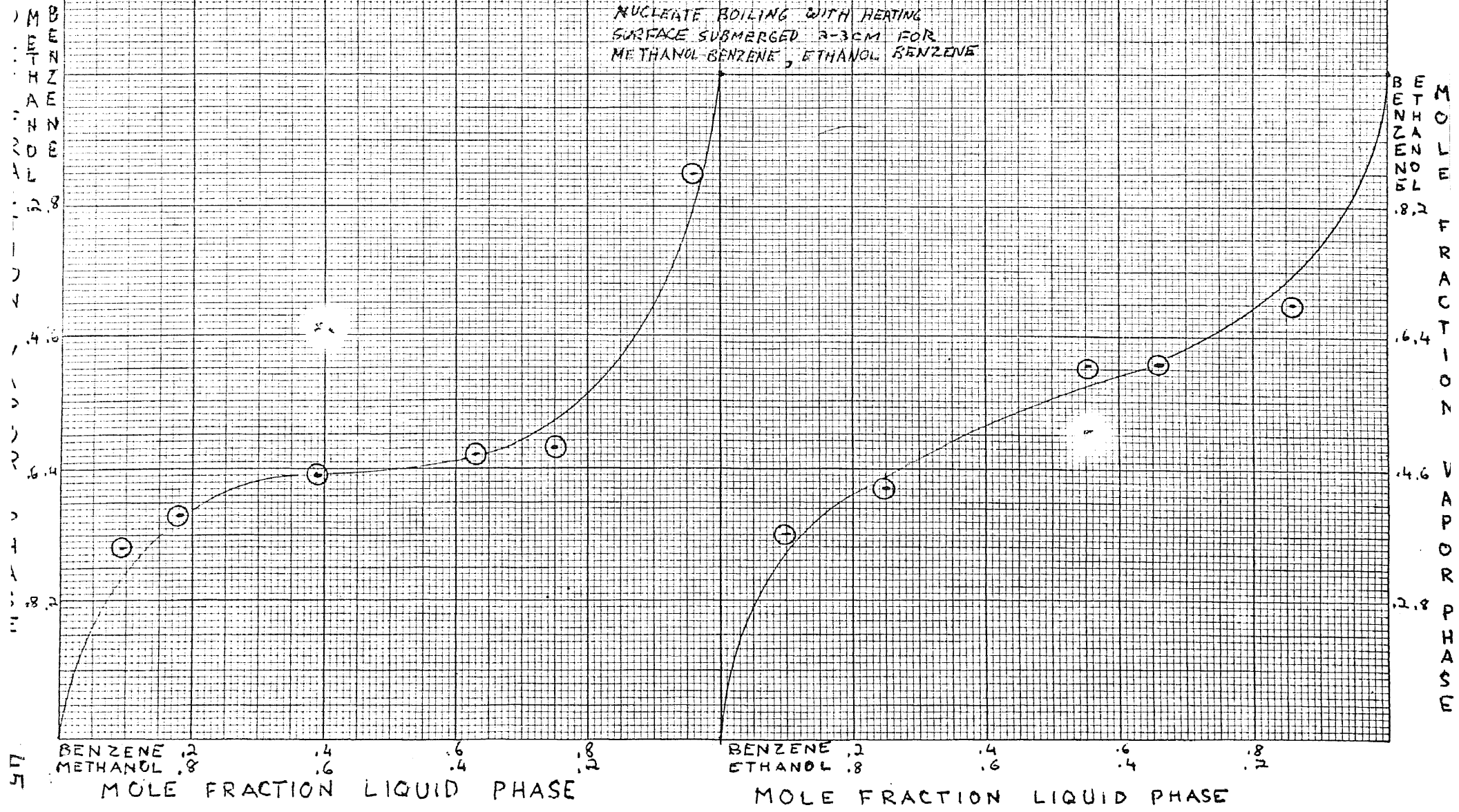


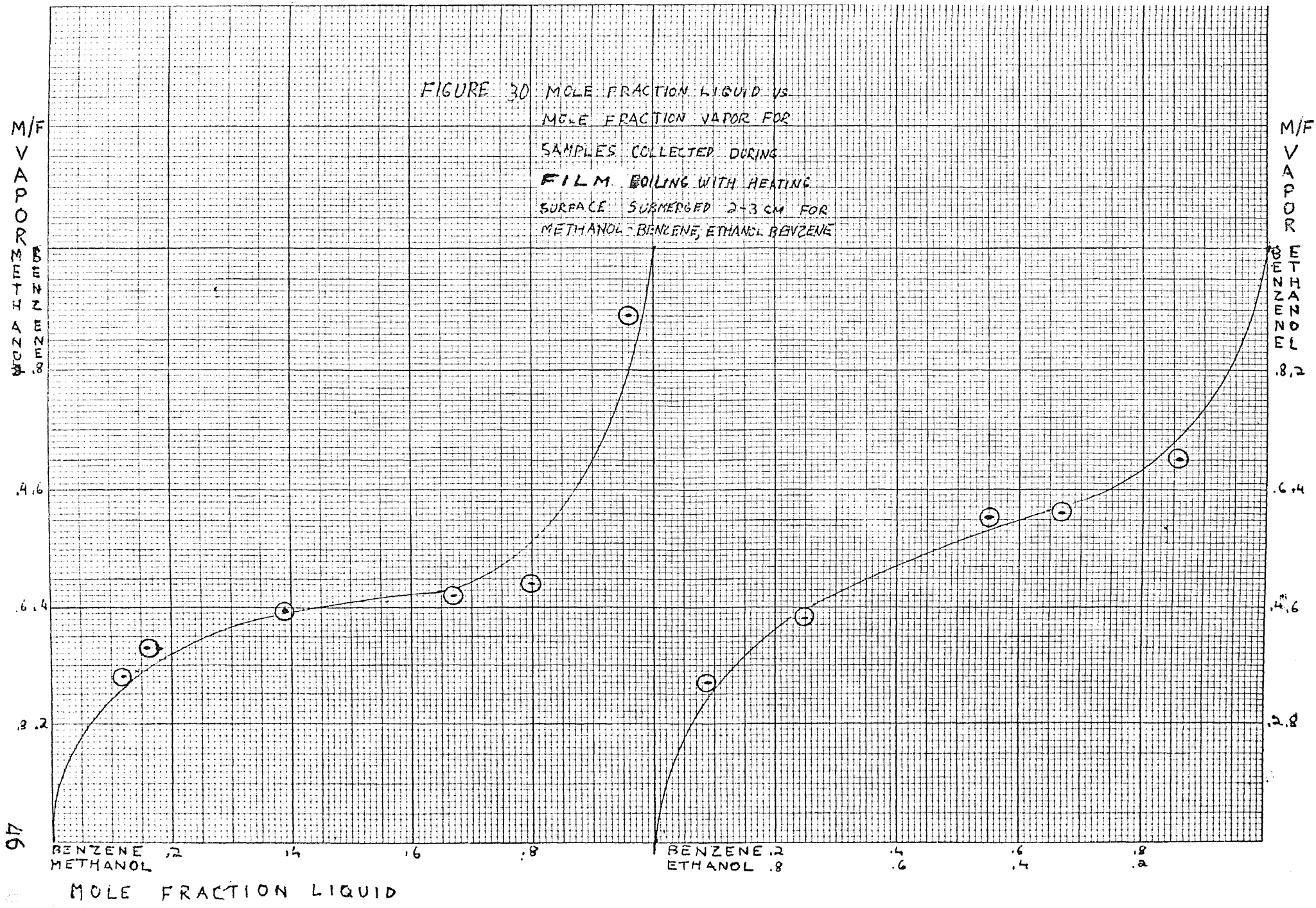
FIGURE 29 MOLE FRACTION LIQUID VS
 MOLE FRACTION VAPOR FOR
 SAMPLES COLLECTED DURING
 NUCLEATE BOILING WITH HEATING
 SURFACE SUBMERGED 2-3CM FOR
 METHANOL-BENZENE, ETHANOL-BENZENE



M/F
V
A
P
O
R

M/F
V
A
P
O
R

FIGURE 30 MOLE FRACTION LIQUID VS.
MOLE FRACTION VAPOR FOR
SAMPLES COLLECTED DURING
FILM BOILING WITH HEATING
SURFACE SUBMERGED 2-3 CM FOR
METHANOL-BENZENE, ETHANOL-BENZENE



M/F
V
A
P
O
R

FIGURE 31 MOLE FRACTION LIQUID VS
MOLE FRACTION VAPOR FOR
SAMPLES COLLECTED DURING
NUCLEATE BOILING WITH HEATING
SURFACE SUBMERGED LESS THAN 0.35 CM
FOR METHANOL-BENZENE, ETHANOL-BENZENE

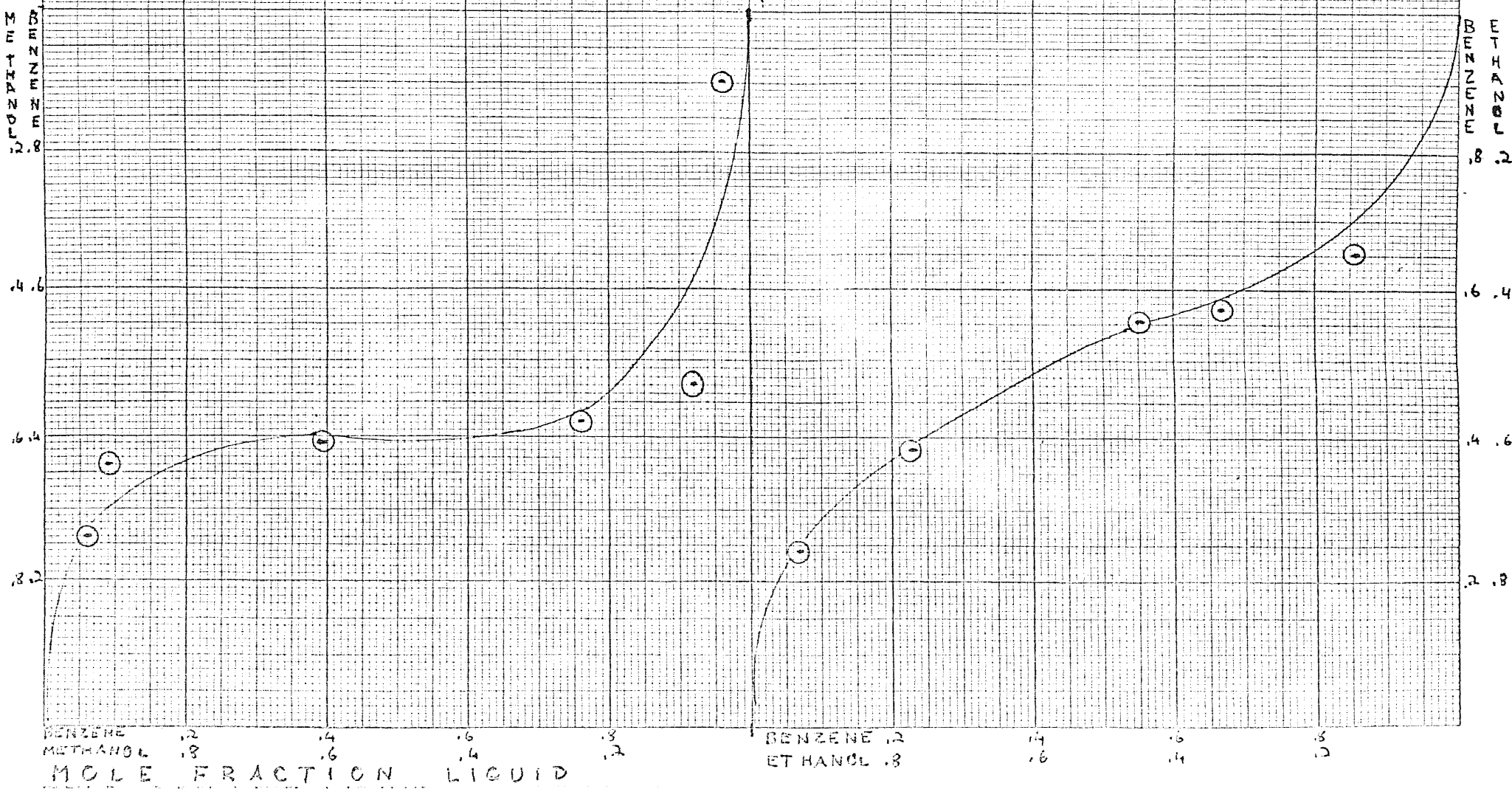
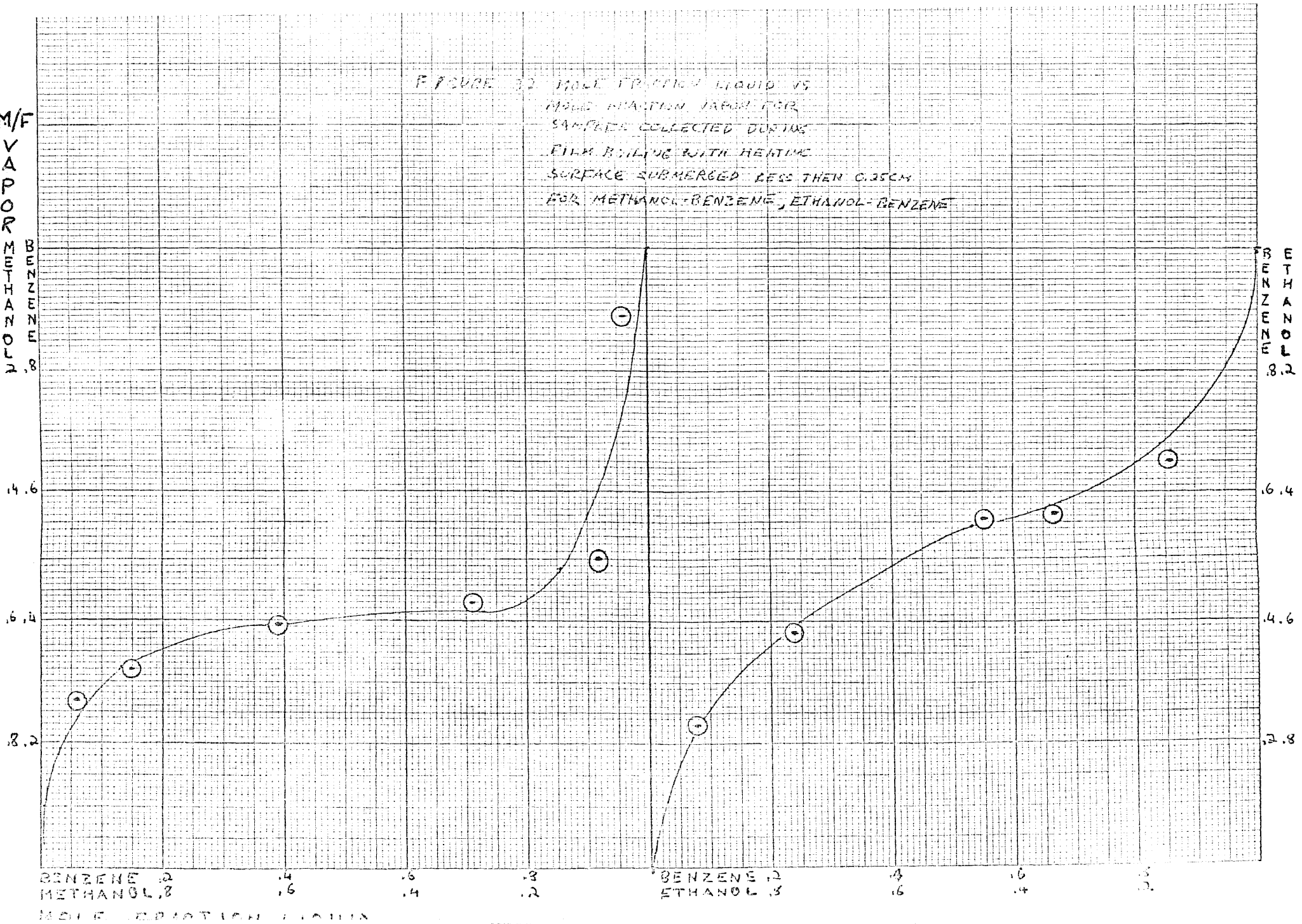


FIGURE 32 MOLE FRACTION LIQUID VS
 MOLE FRACTION VAPOR FOR
 SAMPLES COLLECTED DURING
 FILM BOILING WITH HEATING
 SURFACE SUBMERGED LESS THAN 0.35CM
 FOR METHANOL-BENZENE, ETHANOL-BENZENE

M/F
VAPOR
LIQUID



BENZENE .2
 METHANOL .8
 .4 .6
 .2 .4 .6 .8
 MOLE FRACTION LIQUID

BENZENE .2
 ETHANOL .8
 .4 .6
 .2 .4 .6 .8

with literature values (25) (26) within experimental error.

The invariance of azeotropic composition and liquid vapor equilibrium data between nucleate and film boiling indicate that both film boiling and nucleate boiling are equilibrium vaporization processes where the composition of the vapor produced is in equilibrium with the remaining liquid, rather than either a diffusional vaporization where the loss of a component from the liquid is controlled by molecular diffusion of vapors through the atmosphere, or a bulk vaporization where infinitesimal layers of liquid are vaporized in bulk with the overall composition remaining constant. Godleski and Bell (27) approached the problem of film boiling binary liquids by measuring liquid composition changes for discontinuous liquid masses during film boiling and also reached the conclusion that film boiling was an equilibrium vaporization.

The invariance of azeotropic composition and liquid vapor equilibrium data taken with the heating wire submerged less than 0.25 cm. compared with that data taken when the heating wire was submerged 2-3 cm. (see Figures 29-32) indicates that bubble growth and vaporization occurring in the bulk of the liquid after the bubble leaves the heating surface is also an equilibrium vaporization.

In order to complement the results obtained in this study for minimum boiling azeotropes, maximum boiling

azeotropes should be investigated also. Studies of maximum boiling azeotropes involving chloroform were attempted but the chloroform decomposed in the film boiling region and the investigation of these systems was discontinued. However, the decomposition of chloroform raises another problem for future study. That is, the effect of the pyrolysis on heat transfer and liquid vapor equilibrium curves in the film boiling region should be investigated.

APPENDIX I

Nonenclature

Nomenclature

A, a	area	
D	diameter	
F_e	radiation emmissivity factor	
g	acceleration of gravity	
h	heat transfer coefficient	
h'	heat transfer coefficient of convection	
h_r	heat transfer coefficient of radiation	
i	current	
k_v	thermal conductivity of vapor	
P	power	
ρ_v	density of vapor	
ρ_L	density of liquid	
Q, q	heat	
r	resistance	
r_t	resistance at temperature t	
r_o	resistance at 0 C	
T, t	temperature	
T_L	temperature of liquid (absolute)	
T_s	temperature of surface (absolute)	
ΔT	difference in temperature	
v	voltage	
λ	heat of vaporization	
μ_v	viscosity of vapor	
σ, σ'	Steffan-Boltzmn constant	
Dimensionless Groups ¹		
Nu	Nusselt number	total heat transfer/conductive heat transfer
Pr	Prandelt number	momentum diffusivity/ thermal diffusivity
Re	Reynolds number	inertia forces/viscous forces

¹Handbook of Chem. and Phys. Chemical Rubber Co. 47th ed.
p.F-205 (1966)

APPENDIX II

Boiling Heat Transfer Data

Where samples of condensate and distillate were taken this notation follows the wire temperature:

- *1. Samples collected under nucleate boiling. Heating wire submerged 2-3 cm.
- *2. Samples collected under film boiling. Heating wire submerged 2-3 cm.
- *3. Samples collected under film boiling. Heating wire submerged less than 0,25 cm.
- *4. Samples collected under nucleate boiling. Heating wire submerged less than 0.25 cm.

Methyl Alcohol

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
6.2	1.15	.1855	7.13	15.12	75
6.6	1.2	.1818	7.92	16.79	70
6.9	1.3	.1884	8.97	19.02	87
7.2	1.35	.1875	9.72	20.61	85
7.6	1.43	.1881	10.87	23.04	87
8.0	1.5	.1875	12.00	25.44	85
8.4	1.6	.1905	13.44	28.49	90
8.8	1.65	.1875	14.52	30.78	85
9.2	1.7	.1848	15.64	33.16	80
9.7	1.8	.1856	17.46	37.02	80
10.2	1.9	.1862	19.38	41.08	82
10.8	2.0	.1851	21.60	45.79	80
11.2	2.1	.1875	23.52	49.86	85
11.8	2.25	.1907	26.55	56.29	90
12.3	2.4	.1951	29.52	62.58	100
10.7	2.0	.1869	21.40	45.36	82
11.3	2.15	.1902	24.30	51.52	90
11.8	2.3	.1949	27.14	57.54	100
12.5	2.4	.1920	30.00	63.60	92
13.0	2.5	.1923	32.50	68.90	92
13.8	2.65	.1920	36.54	77.46	92
10.8	6.4	.5926	69.12	146.53	930
10.5	6.0	.5714	63.00	133.56	895
10.0	5.6	.5600	56.00	118.72	865
9.7	5.25	.5412	50.93	107.97	825
9.4	4.75	.5053	44.65	94.66	745
9.0	4.35	.4833	39.15	83.00	700
8.6	3.9	.4535	33.54	71.10	635
8.4	3.5	.4166	29.40	62.33	560
8.1	3.3	.4125	26.73	56.67	550
8.0	3.0	.3750	24.00	50.88	475
7.8	2.85	.3659	22.23	47.12	455
6.2	1.1	.1774	6.82	13.31	60

Ethyl Alcohol.

i amps	v volts	q/a watts/cm. ²	t°C.	r ohms
7.5	1.5	23.6	90	.2
8.5	1.8	31.9	110	.212
9.4	1.95	38.4	108	.208
10.1	2.15	45.3	111	.213
11.1	2.35	55.5	109	.211
11.9	2.55	76	120	.214
12.8	2.8	95.8	125	.218
13.5	3	115	145	.222
11.1	6.2	160	835	.558
10.5	5.7	132	810	.544
10	5.1	107	740	.510
9.5	4.5	99.2	670	.475
9	3.9	72.8	570	.428
8.4	3.3	58	500	.394
7.8	2.7	50	505	.396
7.5	1.6	25	120	.214

Normal Propyl Alcohol

i amperes	v volts	q/a watts/cm ²	t°C	r ohms
6.9	1.7	24.5	180	.244
7.6	1.9	30.0	190	.251
8.3	2.1	36.2	200	.253
9.1	2.3	43.6	200	.253
10.0	2.5	52.2	190	.250
10.6	2.65	58.6	190	.251
9.5	4.55	90.0	675	.479
10	5.1	106	740	.51
10.4	5.6	121.5	800	.54
9.9	5.05	104	740	.511
9.4	4.55	89.5	690	.483
8.9	4.0	74.3	610	.45
8.3	3.4	58.7	590	.437
7.8	2.9	47.3	450	.373
7.2	2.3	34.5	340	.320
6.9	1.6	21.6	160	.232
7.8	1.8	29.2	160	.231
8.4	2.0	35.2	170	.238
9.2	2.1	40.2	150	.227
10	2.4	50.1	175	.24
9.5	4.5	89.0	670	.475
9.9	5.1	105	750	.518
10.3	5.6	120	810	.542

Isopropyl Alcohol

i amps	v volts	q/a watts/cm ²	t°C.	r ohms
6.9	1.5	21.3	125	.218
7.7	1.7	27	140	.221
8.5	1.8	31.6	140	.222
9.2	2.1	39.9	150	.228
10	2.3	47.4	153	.23
10.7-8	2.4-5	84.5-93	153	.232
9.5	4.4	86.2	640	.464
9.9-10	5.0	102.5	750	.50-.51
10.3	5.6	119	810	.545
9.9	5.1	103.5	770	.515
9.5	4.5	88.5	660	.474
8.8	3.9	72.5	600	.443
8.2	3.4	57.5	530	.413
7.7	2.9	46.2	455	.373
7.2	2.3	34.3	340	.32
6.9	1.5	21.3	125	.218

Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
7.2	1.35	.1875	9.72	20.60	85
7.6	1.45	.1908	11.02	23.39	90
7.9	1.5	.190	11.85	25.15	90
8.3	1.6	.193	13.28	28.18	92
8.8	1.7	.193	14.96	31.74	92
9.2	1.8	.1957	16.56	35.14	98
9.8	1.9	.194	18.62	39.51	98
10.1	2.0	.198	20.2	42.86	105
10.6	2.1	.1981	22.26	47.24	105
9.6	4.8	.5000	46.08	97.78	740
9.2	4.5	.4891	41.40	87.85	710
8.9	4.1	.4607	36.48	77.43	650
8.5	3.8	.4470	32.30	68.54	630
8.1	3.4	.4198	27.54	58.43	570
7.8	3.1	.3974	24.18	51.31	520
7.5	2.8	.3733	21.38	45.37	470
7.2	2.55	.3542	18.36	38.96	430
7.05	2.4	.3404	16.92	35.90	400
7.0	2.2	.3143	15.40	32.68	350
6.8	2.1	.3088	14.28	30.30	330

4.5% wt. Methyl Alcohol, 95.5% wt. Benzene

i Amps	v Volts	r Ohms	q Watts	q/a watts/Cm ²	t ^o C
8.2	1.6	.1951	13.12	25.32	90 *1
7.5	2.9	.3866	21.75	41.98	490 *2, *3
8.2	1.8	.2195	14.76	28.49	130 *4
8.5	1.8	.2117	15.30	29.53	120
8.9	1.9	.2134	16.91	32.64	125
9.4	2.0	.2127	18.80	36.28	125
10.0	2.1	.2100	21.00	40.53	115
10.5	2.2	.2095	23.10	44.58	115
11.0	2.4	.2181	26.40	50.95	130
11.5	2.5	.2173	28.75	55.49	128
10	5.6	.5600	56.00	108.08	840
9.7	5.2	.5360	50.44	97.35	780
9.3	4.8	.5161	44.64	86.16	740
9.0	4.4	.4888	39.60	76.43	690
8.7	4.0	.4597	34.80	67.16	630
8.3	3.6	.4337	29.88	57.67	590
8.0	3.3	.4125	26.40	50.95	530
7.7	3.0	.3896	23.10	44.58	490

15% wt. Methyl Alcohol, 85% Benzene by wt.

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t° C
9.9	1.9	.191	18.81	40.63	125 *1
8.1	3.2	.395	25.92	55.99	540 *2, *3
8.6	1.7	.197	14.62	31.58	135 *4
9.6	1.85	.192	17.76	38.36	125
10	1.9	.1900	190	41.04	120
10.5	2.0	.1905	21.00	45.36	120
11.1	2.15	.1936	23.87	51.56	127
11.7	2.3	.1965	26.91	58.19	135
12.2	2.4	.1967	29.28	63.24	135
12.8	2.55	.1992	32.64	70.50	140
10.7	6.3	.5887	67.41	145.61	950
10.2	5.8	.5686	59.16	127.79	900
10.0	5.3	.5300	53.00	114.48	830
9.7	4.9	.5051	47.53	102.66	770
9.2	4.5	.4891	41.40	89.42	730
8.9	4.1	.4606	36.49	78.82	680
8.6	3.7	.4302	31.82	69.73	610
8.3	3.5	.4216	29.05	62.75	600

23.1% wt. Methyl Alcohol, 76.9% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ² t°C	
8.4	1.7	.2023	14.28	30.84	140
8.9	1.75	.1966	15.57	33.63	125 *1, *4
9.3	1.85	.1989	17.20	37.15	135
9.9	1.95	.1969	19.30	41.69	125
10.3	2.05	.1990	21.12	45.62	135
10.9	2.2	.2018	23.98	51.79	140
11.4	2.3	.2018	26.22	56.64	145
12.0	2.4	.2000	28.80	62.20	140
12.5	2.5	.2000	31.25	67.50	140
9.6	1.9	.1979	18.24	39.40	130
10.0	2.0	.2000	20.00	43.20	140
10.5	2.1	.2000	22.05	47.63	140
11.1	2.2	.1981	24.42	52.75	130
11.8	2.35	.1991	27.73	59.89	135
12.2	2.5	.2049	30.50	65.88	155
12.8	2.6	.2031	33.28	71.88	150
10.8	6.4	.5925	69.12	149.29	950
10.2	5.9	.5784	60.18	129.99	920
10.0	5.4	.5400	54.00	116.64	840
9.8	5.0	.5102	49.00	105.84	780
9.3	4.5	.4838	41.85	90.39	730
9.0	4.2	.4666	37.80	81.65	690
8.5	3.8	.4470	32.30	69.77	650
8.3	3.5	.4217	29.05	62.75	610
8.1	3.3	.4074	26.73	57.73	570 *2, *3
8.1	1.65	.2037	13.37	28.87	150

39.1% wt. Methyl Alcohol, 60.9% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t °C
7.4	1.1	.1486	8.14	17.58	50
7.8	1.2	.1538	9.36	20.21	55
8.2	1.3	.1585	10.66	23.03	58
8.7	1.35	.1552	11.74	25.36	58 81, 84
9.1	1.4	.1538	12.74	27.51	58
10.0	1.6	.1600	16.00	34.56	60
10.5	1.65	.1572	17.33	37.43	57
7.7	1.2	.1558	9.24	19.96	55
8.0	1.3	.1625	10.40	22.46	65
8.5	1.3	.1529	11.05	23.86	50
9.0	1.4	.1555	12.60	27.22	55
9.5	1.5	.1579	14.25	30.78	57
9.9	1.6	.1616	15.84	34.21	63
10.3	1.65	.1602	16.99	36.70	60
10.9	1.75	.1605	19.08	41.21	61
8.0	1.2	.1500	9.60	20.73	50
8.3	1.03	.1566	10.79	23.31	58
8.8	1.4	.1591	12.32	26.61	58
9.3	1.45	.1559	13.48	29.12	56
9.9	1.55	.1566	15.34	33.14	56
10.2	1.6	.1569	16.32	35.25	56
10.8	1.7	.1574	18.36	39.66	57
11.2	1.8	.1607	20.16	43.55	62
8.9	1.4	.1573	12.46	26.91	57
9.4	1.5	.1565	14.10	30.46	56
10.2	1.6	.1569	16.32	35.25	56
11	1.7	.1545	18.70	40.39	54
11.5	1.8	.1565	20.70	44.71	36
12	1.9	.1583	22.80	49.25	58
12.5	2.0	.1600	25.00	54.00	60
10	1.6	.1600	16.00	34.56	60
10.5	1.65	.1571	17.32	37.41	57

39.1% wt. Methyl Alcohol, 60.9% wt. Benzene (cont.)

i	v	r	q	q/a	t
11.1	1.75	.1576	19.43	41.97	57
11.8	1.85	.1567	21.83	47.15	56
12.4	2.0	.1613	24.80	53.56	61
13	2.1	.1615	27.30	58.97	61
11	5.5	.5000	60.50	130.68	750
10.5	5.1	.4857	53.55	115.66	720
10.2	4.7	.4607	47.94	103.55	670
9.9	4.3	.4343	42.57	91.82	610
9.5	3.9	.4105	37.05	80.03	560
9.1	3.6	.3956	32.76	70.76	530
8.8	3.3	.3750	29.04	62.73	490 : *2,*3

62.2% wt. Methyl Alcohol, 37.8% Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm. ²	t°C
8.9	1.5	.1685	13.35	28.83	79
9.4	1.6	.1702	15.04	32.49	80
9.9	1.7	.1717	16.83	36.35	80
10.4	1.8	.1730	18.72	40.44	81
11.0	1.9	.1727	20.90	45.14	81
11.6	2.0	.1724	23.20	50.11	81
12.1	2.1	.1736	25.41	54.88	82
12.8	2.25	.1757	28.80	62.21	85
10.7	1.8	.1682	19.26	41.60	79
11.2	1.9	.1696	21.28	45.96	80 *1, *4
11.9	2.0	.1680	23.80	51.41	79
12.5	2.15	.1720	26.88	58.06	81
13.1	2.3	.1756	29.90	64.58	85
13.8	2.4	.1739	33.12	71.53	83
14.5	2.5	.1724	36.25	78.30	81
11.5	6.0	.5217	69.00	149.04	810
11.0	5.5	.5000	60.50	130.68	760
10.6	5.2	.4905	55.12	119.05	730
10.1	4.7	.4653	47.47	102.54	690
9.8	4.2	.4286	41.16	88.90	610
9.5	4.0	.4210	38.00	82.08	590
9.0	3.65	.4055	32.85	70.95	560 *2, *5
8.5	3.25	.3823	27.62	59.65	510
8.5	1.4	.1647	11.90	25.70	75

73.0% wt. Methyl Alcohol, 27.0% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t °C	
9.0	1.8	.2000	16.20	34.99	130	*1, *4
8.0	3.15	.4375	25.20	54/43	620	
8.9	1.8	.2022	16.02	34.60	135	
9.4	1.9	.2021	17.86	38.58	135	
9.9	2.0	.2020	19.80	42.77	135	
10.5	2.1	.2000	22.05	47.63	130	
11.1	2.2	.1982	24.42	52.75	125	
11.6	2.3	.1983	26.68	57.63	125	
12.1	2.4	.1983	29.04	62.73	125	
12.8	2.5	.1953	32.00	69.12	120	
13.2	2.7	.2045	35.64	76.98	140	
13.6	2.8	.2058	38.08	82.25	140	
12.5	2.5	.2000	31.25	67.50	130	
12.9	2.6	.2016	33.54	72.45	133	
13.5	2.8	.2074	37.80	81.64	145	
14.2	2.9	.2042	41.18	88.95	138	
12.2	2.5	.2049	30.50	65.88	140	
13.0	2.6	.2000	33.8	73.01	130	
13.5	2.75	.2037	37.13	80.20	137	
14.2	2.9	.2042	41.18	88.95	138	
14.9	3.0	.2013	44.70	96.55	131	
11.5	7.0	.6087	80.50	173.88	970	
11.0	6.5	.5909	71.50	154.44	930	
10.5	6.1	.5810	64.05	138.34	920	
10.2	5.7	.5588	58.14	125.58	870	
9.9	5.2	.5252	51.48	111.20	800	
9.5	4.8	.5053	45.60	98.50	760	
9.1	4.4	.4835	40.04	86.49	720	
8.9	4.05	.4551	36.04	77.84	650	
8.6	3.8	.4418	32.68	70.59	630	*2, *4
8.4	3.55	.4226	29.82	64.4.	600	
8.2	3.3	.4024	27.06	58.45	550	
8.0	3.1	.3875	24.8	53.57	510	
7.9	2.85	.3607	22.52	48.64	470	
7.8	2.6	.3333	20.28	43.80	400	
7.8	2.3	.2949	17.94	38.75	325	

9% wt. Ethyl Alcohol, 91% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
8.3	1.7	.205	14.1	27.2	90
7.9	3.3	.418	26.1	50.3	510
8.6	1.85	.215	15.9	30.7	108 *1,*4
8.9	1.9	.214	16.9	32.6	110
9.4	2.0	.213	18.8	36.2	103
9.9	2.1	.212	20.8	40.2	103
10.3	2.3	.223	23.7	45.7	115
11.0	2.4	.218	26.4	50.9	110
11.5	2.55	.222	29.3	56.5	113
12	2.7	.225	32.4	62.4	115
10.2	6.1	.597	62.2	120	900
10.0	5.7	.570	57.0	110	840
9.8	5.2	.531	50.8	98.0	750
9.3	4.8	.516	44.6	86.0	710
8.9	4.4	.494	39.1	75.4	690
8.6	4.0	.465	34.4	66.3	620
8.3	3.6	.434	29.8	57.5	560
7.9	3.3	.418	26.1	50.3	510 *3,*2

22.9% wt. Ethyl Alcohol, 77.1% wt Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm	t C
8.8	1.85	.210	16.25	31.4	100 *1, *4
7.9	3.2	.405	25.15	48.8	500 *2, *3
8.0	3.0	.375	24.0	46.2	440
8.9	1.9	.213	16.9	32.6	103
9.3	2.0	.215	17.8	34.2	105
9.9	2.1	.212	20.8	40.2	103
10.3	2.2	.214	22.7	43.8	105
11	2.4	.218	26.4	50.9	110
11.5	2.5	.217	28.8	55.6	110
12	2.6	.217	31.2	60.2	110
12.7	2.7	.213	34.2	66.0	103
10.4	5.9	.566	61.5	118	830
10	5.5	.550	55.0	106	800
9.8	5.1	.521	50.0	96.5	730
9.3	4.7	.506	43.6	84.2	710
8.9	4.2	.472	37.4	72.1	640
8.6	3.8	.443	32.7	63.0	570
8.2	3.5	.427	28.8	55.5	550
8.0	3.2	.400	25.6	49.3	490

32.4% wt. Ethyl Alcohol, 67.6% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t °C
9.0	1.5	.1667	13.5	29.16	75 *1,*4
9.4	1.6	.1702	15.04	32.49	80
10.0	1.7	.1700	17.00	36.72	80
10.4	1.8	.1731	18.72	40.44	85
11.1	1.9	.1712	21.09	45.55	82
11.6	2.0	.1724	23.20	50.11	83
12.1	2.1	.1736	25.46	57.15	85
12.8	2.2	.1719	28.16	60.86	82
10.0	1.7	.1700	17.00	36.72	80
10.5	1.8	.1714	18.90	40.82	82
11.1	1.9	.1712	21.09	45.55	82
11.8	2.0	.1695	23.60	50.98	79
12.4	2.1	.1693	26.04	56.25	79
13	2.25	.1731	29.25	63.18	85
13.6	2.35	.1728	31.96	69.03	84
11	5.5	.5000	60.50	130.68	760
10.7	5.1	.4766	54.57	117.87	700
10.2	4.8	.4706	48.96	105.75	690
10.0	4.4	.4400	44	95.04	625
9.5	4.0	.4210	38.00	82.08	590
9.1	3.6	.3956	32.76	70.76	550 *2,*3
8.8	3.3	.3750	29.04	62.73	500

56.8% wt. Ethyl Alcohol, 43.2% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
8.8	1.8	.202	15.85	30.6	80 *1,*4
8.1	3.3	.407	26.8	51.6	500 *2,*4
8.7	1.8	.207	15.7	30.1	85
9.0	1.9	.211	17.1	33.0	85
9.6	2.0	.209	19.2	37.0	85
10.0	2.1	.210	21.0	40.5	85
10.6	2.3	.217	24.4	47.0	87
11.1	2.4	.216	26.6	51.3	87
11.7	2.5	.214	29.2	56.2	87
10.4	2.2	.213	22.9	44.2	86
9.2	1.9	.206	17.5	33.8	85
9.8	2.0	.204	19.6	37.8	85
10.1	2.15	.213	21.7	41.8	86
10.8	2.3	.213	24.8	47.8	86
11.4	2.4	.210	27.4	52.8	85
11.9	2.5	.210	29.8	57.4	85
10.1	5.8	.573	58.6	113	840
9.9	5.4	.546	53.4	103	795
9.5	5.0	.526	47.5	91.5	750
9.1	4.5	.494	41.0	71.2	290
8.8	4.1	.466	36.1	69.5	620
8.4	3.8	.452	31.9	61.5	590
8.1	3.4	.419	27.5	53.0	530

78% wt. Ethyl Alcohol, 22% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
9.2	1.9	.207	17.5	33.8	95 *1,*4
8.2	3.4	.414	27.8	53.6	510
8.0	3.5	.437	28.0	54.0	550*3,*2
9.1	1.9	.209	17.3	33.4	95
9.6	2.0	.208	19.2	37.0	95
10.1	2.2	.218	22.2	42.8	100
10.8	2.3	.213	24.8	47.8	100
11.3	2.4	.212	27.2	52.5	100
11.9	2.6	.218	30.9	59.7	100
12.3	2.7	.220	33.2	64.0	100
10.2	5.7	.558	55.5	106.0	820
9.9	5.3	.535	52.5	101	770
9.6	4.9	.511	47.0	90.7	710
9.1	4.4	.484	40.0	77.2	670
8.9	4.0	.450	35.6	68.5	590
8.5	3.7	.435	31.4	60.5	560
8.1	3.4	.420	27.5	53.1	530

33.7% wt. Isopropyl Alcohol, 66.3% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t °C
8.9	1.9	.213	16.9	32.6	103 *1,*4
8.0	3.3	.413	26.4	50.9	510 *2,*3
8.9	1.9	.213	16.9	32.6	103
9.4	2.0	.213	18.8	36.3	103
9.9	2.1	.212	20.8	40.1	103
10.4	2.25	.216	23.4	45.2	106
11.1	2.4	.216	26.6	51.3	106
11.6	2.5	.216	29.0	55.9	106
12.1	2.7	.223	32.6	62.8	113
10.1	5.5	.545	55.5	107	790
9.9	5.2	.526	51.5	99.2	740
9.5	4.8	.505	45.6	88	700
9.1	4.3	.472	39.2	75.6	630
8.7	4.0	.459	34.8	68.1	590
8.3	3.6	.434	29.9	57.6	560
8.0	3.3	.413	26.4	50.9	510

17.1% wt. Normal Propyl Alcohol, 82.9% wt. Benzene

i amps	v volts	r ohms	q watts	q/a watts/cm ²	t°C
8.5	1.85	.218	15.7	30.3	110 *1,*4
8.0	3.5	.438	28.0	54.0	560 *2,*3
9.0	2.0	.222	18.0	34.7	113
9.5	2.1	.221	19.9	38.4	113
10.0	2.2	.220	22.0	42/4	112
10.8	2.4	.222	25.9	49.9	113
11.2	2.5	.223	28.0	54.0	113
11.7	2.6	.222	30.2	58.2	113
10.1	5.9	.584	57.6	111	880
9.9	5.4	.546	53.5	103	790
9.4	5.0	.533	47.0	90.6	760
9.1	4.7	.516	42.8	82.4	720
8.8	4.2	.476	37.0	71.3	640
8.5	3.8	.448	32.3	62.2	610
8.1	3.5	.432	28.4	54.6	550
7.8	3.2	.410	25.0	48.2	510

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