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A DISSERTATION

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BY

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Norman, Oklahoma

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HEAT TRANSFER TO POOL BOILING MERCURY

FROM HORIZONTAL CYLINDRICAL HEATERS

AT FLUXES UP TO BURNOUT

APPROVED BY

DISSERTATION COMMITTEE

ABSTRACT

Reproducible, consistent data were obtained for pool boiling mercury at fluxes up to 1,100,000 Btu/hr-ft^2 with pool depths up to 8.5 inches above the heater. Other pool depths studied were 2 and 5 inches above the heater. The boiling surface was a 304 stainless steel horizontal cylinder 3/8 inch in diameter by 3 inches long.

Boiling water was studied preliminarily at pressures up to 200 psig to provide a basis of comparison for results obtained in the mercury study. Burnout determinations for water ranged from about 200,000 Btu/hr-ft^2 at atmospheric pressure to 790,000 Btu/hr-ft^2 at 200 psig. Nucleate boiling ΔT's for water compared quite well with existing data.

In 47 experimental mercury boiling runs, only one determination was made which might be justifiably termed burnout. This occurred with an 8.5 inch pool depth above the heater at a system pressure of 10 mm mercury. The burnout was observed at a flux level of 1,018,000 Btu/hr-ft^2, and was indicated by an instantaneous temperature rise in the heater considerably in excess of 400 degrees F. During this and other runs, temperature excursions up to 250 degrees F were observed in the heater.

Boiling curves for mercury were obtained over a pressure range from 1 mm mercury to 1143 mm mercury (45 inches), using two test heaters. It was observed that for any particular system pressure, a flux level was reached where the slope of the boiling curve decreased significantly so that subsequent increases in flux were accompanied by large increases in ΔT. The flux level at which the pronounced decrease in slope occurred, was termed the "departure flux." Departure fluxes were found to exhibit a maximum at system pressures below 25 mm mercury. Higher departure fluxes were obtained for increased pool depth.

Plotting the departure flux versus total pressure at the heater (system pressure plus static head), it was found that the maximum departure flux for each pool depth was closely predicted by the burnout correlations of Noyes and Addoms. Observed maximum departure fluxes ranged from 400,000 Btu/hr-ft^2 for a 2 inch pool depth above the heater to 950,000 Btu/hr-ft^2 for an 8.5 inch depth.

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CHAPTER I

INTRODUCTION

Boiling heat transfer has long been considered among the foremost methods of transferring large quantities of heat. Nukiyama (96) focused attention on the field of boiling heat transfer more than three decades ago. In the ensuing time, much has been undertaken, accomplished, and written in reference to this challenging subject.

As is common practice when studying natural phenomena, many varied approaches and methods of attack are employed to glean worthwhile knowledge about the underlying principles and mechanisms involved. To better understand boiling heat transfer, the investigation of many varied liquids was an obvious step. After water and many of the more common organic liquids were initially studied, liquid metals began to be scrutinized with mercury being one of the first, for obvious reasons. The interest in liquid metals has continued to increase as larger heat loads at higher temperature levels and in confined areas required better and more efficient heat transfer in nuclear power cycles. With the advent of commercial nuclear power plants, the increasing interest in liquid metals shows no sign of subsiding in the foreseeable future.

Background

Being of the greatest utility in heat transfer systems, the nucleate boiling regime has received to date more intensive study than the various other regions comprising the "typical" boiling curve. The other regions include: convective boiling, transition boiling, and film boiling. Since many authors (43,63,69,88,106) have previously defined and carefully described each of these regions, no reiteration is deemed necessary here.

A knowledge of the maximum nucleate boiling heat flux, commonly called the burnout or first critical heat flux, remains of utmost importance in the design of boiling equipment. For high heat transfer coefficients, it is desirable to operate near the maximum nucleate flux and still be certain that perturbations in the system will not cause temperature excursions which could initiate film boiling.

Efforts to predict burnout must necessarily be based on an understanding of the mechanisms involved in nucleate boiling. In the continuing search for a complete understanding of the principles involved, workers have found it necessary to investigate the various parameters which control boiling heat transfer.

Parameters Affecting Boiling Behavior

The complexity of the boiling process is well illustrated by surveying the many factors which affect the overall boiling process. These include: different liquids, surface materials, surface size, surface orientation, surface geometry, surface pretreatment, surface vibration, liquid temperature, liquid velocity, gravity, pressure, surface tension, et cetera. Considering these variables, one easily sees the difficulty of formulating an all-encompassing mechanism or correlation for boiling behavior.

For a good general review of boiling heat transfer, the reader is referred to Balzhiser, et al. (5), Jakob (65), McAdams (88), Rohsenow (106), and Westwater (119). Only the aspects affecting boiling which are considered most important and most pertinent to the present study will be discussed at any length here.

Pressure Effects

Nucleate boiling.--Cichelli and Bonilla (29) boiled various liquids at pressures ranging from atmospheric to near the critical pressure. Their nucleate boiling results clearly showed that increasing the pressure at constant heat flux decreases the thermal driving force, ΔT, which is the temperature difference between the heater surface and the bulk liquid.

Lienhard and Schrock (76) discussed the generalized displacement of the boiling curve and concluded that it is solely a function of reduced pressure and can be represented by

$$\left(\frac{\partial \ \ell n \ \Delta T_r}{\partial \ \ell n \ P_r}\right)_{q/A} = f \ (P_r) \tag{1}$$

Boiling water data taken by McAdams and co-workers (87) up to 1200 psia and by Addoms (2) up to 2465 psia showed the representative shift in ΔT.

Mesler and Banchero (91) studied boiling organic liquids under pressure and observed that bubble departure size and ΔT both decreased with increasing pressure. This coupled with the observation of Jakob (65) that $f \cdot D \approx$ constant and the development of McFadden and Grassman (89) that $f \cdot D^{\frac{1}{2}} \approx 0.56 g^{\frac{1}{2}}$ would indicate that departure frequency increased with increasing pressure.

Stanizewski (112) studied the pressure effect on bubble frequency and departure diameter and found that a pressure increase caused a decrease in bubble frequency and diameter. The $f \cdot D$ product was then necessarily decreased and it was found that this product was different for water and methyl alcohol. He also observed that a pressure increase caused a marked increase in the number of active sites.

The pressure effect on nucleate boiling has also been observed for liquid metals. Madsen and Bonilla (82) boiled sodium-potassium alloy on a low carbon content nickel surface at sub-atmospheric pressures. The expected variation of ΔT with pressure was observed and their data were correlated by

$$q/A = 134\ P^{0.25}\ (\Delta T)^{1.24} \tag{2}$$

for pressures ranging from 2 to 760 mm mercury, and fluxes from 20,000 to 135,000 Btu/hr-ft^2.

Griffith and Wallis (50) have observed that sudden increases of pressure in a boiling system can deactivate some nucleation sites on the surface. Wachters and van Andel (115) noted that deactivated sites require large superheats for reactivation. This can lead to boiling instabilities as discussed by Marto and Rohsenow (84) for their boiling sodium system. They found that reentrant cavities remained active and stabilized nucleate boiling. This will be discussed more fully in a later section concerning surface effects.

Since the primary effect of pressure is to decrease the ΔT with increasing pressure, it is well to note other ways of lowering the ΔT at constant flux levels. King (66) observed that ΔT decreased with (1) the addition of dissolved gases to the liquid, (2) solid impurities in the liquid, and (3) increasing pressure. Westwater and Santangelo (118) noted that a common fault of workers in boiling heat transfer is the lack of attention given the surface and dissolved gases in the liquid. The effect of suspended solids in the liquid has also been observed in a recent study of low heat fluxes by Elrod, et al. (42). Their work with boiling water involved pressures up to 1550 psia. Jakob (65) showed that ΔT can also be affected considerably by roughness and aging of the surface.

Pressure effects on nucleate boiling mercury have also been observed. The representative shift of ΔT with pressure was shown by Bonilla, et al. (13) though some scatter and inconsistency was exhibited. Since the inconsistency of the above data and the wide variation in other mercury data are thought to be caused by nonwetting of the surface, additional work is needed to better understand the pressure effect and the surface effect.

A further discussion of boiling mercury data will be presented in a later section devoted entirely to previous studies of mercury.

Critical fluxes.--Pressure also affects burnout, $(q/A)_{1c}$, and the minimum film boiling flux, $(q/A)_{2c}$, which is also called the second critical heat flux. For hydrocarbons, the burnout flux increases from zero at zero pressure to a maximum at approximately one-third the critical pressure, thereafter decreasing steadily to zero at the critical (29,110,122). For water, Addoms' (2) data exhibited a maximum value for $(q/A)_{1c}$ at a reduced pressure of 0.5 (cf. reference 106).

Lienhard and Schrock (75) evaluated the pressure effect on both critical fluxes for six liquids at pressures ranging from 0.58 inches mercury to atmospheric. They found that the first critical flux decreased with decreasing pressure. At very low pressures, the system went directly from convective heat transfer to film boiling, i.e., the nucleate boiling regime was absent. Rallis and Jawurek (101) also observed the absence of nucleate boiling for ethanol at pressures less than 0.3 atmospheres. At subatmospheric pressures Lienhard and Schrock found that the second critical flux decreased with decreasing pressure.

Though most liquid metal studies deal with relatively small pressure ranges, the pressure effect is easily detectable by the critical flux variation. Colver (34) boiled potassium from a horizontal "bayonet" heater and found an empirical fit for his pool boiling burnout results

$$(q/A)_{1c} = 4\ (10^5)\ P^{0.167} \tag{3}$$

for the pressure, P, varying from 0.15 to 22 psia and fluxes from 285,000 to 669,000 Btu/hr-ft^2. Similar behavior has been observed in other studies of alkali metals (23, 95).

With heater size and configuration differing in most prior work, it could certainly be questioned how much of the observed effect was due to pressure alone. After investigating this aspect, Lienhard and Watanabe (77) concluded that geometric and pressure effects on the critical fluxes were separable and the pressure effect was apparently invariant with configuration.

Since pure mercury boiling studies have usually encountered nonwetting and the accompanying absence of nucleate boiling, no mercury burnout studies have been reported. In cases where wetting was obtained for pure mercury (13, 100), the flux levels have not extended above 125,000 Btu/hr-ft^2. The data taken at this maximum level did not indicate that burnout had been approached.

For pool boiling mercury with additives, the reported flux levels have not exceeded 200,000 Btu/hr-ft^2 (13) and no indication of impending burnout was observed at this level.

It is readily apparent, then, that burnout and the pressure effect on burnout for mercury needs investigation.

Surface Effects

Nucleate boiling.--Surface characteristics such as roughness and wettability are less easily controlled than pressure, but nevertheless are capable of producing great variations in boiling behavior.

Through the years, as studies progressed through the gamut of available boiling liquids, there has been increasing interest in the effect of different surface materials. Further studies have included surfaces which were finned, pitted, grooved, etched, sandblasted, plated, smooth, dirty, clean, and even impregnated with teflon spots.

It has been found that cavities in the surface are desirable for smooth transition from natural convection heating to nucleate boiling. In addition, they seemingly are necessary for stable nucleate boiling, as will be discussed later.

Corty and Foust (36) report a "major influence of micro-roughness" on boiling surface characteristics. To this effect, they attribute the variation in slopes of boiling curves for otherwise similar systems. Observing the hysteresis effect of cavity activation, they proposed a "vapor-trapping" mechanism of nucleate boiling. Bankoff (7) concurred that "cavity-type" surfaces require low superheats for ebullition with the magnitude of the superheat being determined by the cavity size. Inert gases trapped in surface cavities will help initiate nucleation at the sites, but prolonged boiling will purge the gas from the cavity. Thereafter, only steep-walled or non-wetted cavities will serve as nucleation sites by trapping a portion of the departing bubble vapor.

A recent study by Wachters and van Andel (115) confirmed that "a cavity can only produce bubbles as long as it is continuously filled with vapor." This is in complete agreement with Corty (35) who suggested in 1951 that nucleation sites retain a portion of the vapor from departing bubbles. This is also noted by Mesler and Banchero (91), along with Ruckenstein (109). Others have observed that the active boiling site population is a function of roughness (9,50,52,59,60,71,72,114).

Clark, Strenge, and Westwater (30) reported the existence of various types of nucleation sites. Scratches, pits, and a plastic-metal interface all supported nucleation. Pits with diameters between 300 and 3000 microinches were found to be very active. Clark, et al. even observed a foreign particle on the surface which supported nucleation.

Han and Griffith (52) developed an expression for the most favorable cavity radius for nucleation

$$R_{cf} = \frac{4\ T_{sat}}{T_w - T_{sat}} \left(\frac{\sigma}{\rho_v\ \lambda}\right) \tag{4}$$

which indicates that the radius, R_{cf}, decreases with increasing wall temperature. Though meticulous care was given to the preparation of the boiling surfaces used, these investigators acknowledged the fact that "in practical terms, quantities like surface nucleation properties and bulk temperatures are just not known with sufficient precision to make a boiling curve prediction possible." Their analysis was performed for the "isolated bubble region," so would not be applicable to the "interference region" discussed by Zuber (127).

Hsu (60) developed a criterion for incipient nucleate boiling by considering his derived equation for effective cavity radii. His expression indicated that the range of effective cavity size is a function of subcooling, pressure, physical properties, and the thickness of the superheated liquid layer.

Bonilla, Grady, and Avery (14) studied nucleation from artificially scored surfaces for boiling water and mercury with additives. Parallel scratches on the surface gave optimum behavior, i.e., maximum increase of stability and heat transfer coefficient, for water when spaced about 2 to 2.5 bubble departure diameters apart. Their study constituted the first study of surface roughness for liquid metal boiling. Since the heat transfer coefficient increased considerably with closer scratch spacing down to 2 bubble departure diameters for mercury, they planned further work to see if a maximum would occur there (as it did for water) or at a smaller spacing. Their results showed that the roughness effect was more pronounced at low heat fluxes for water and at high fluxes for mercury.

Nucleation studies were extended to boiling sodium by Marto and Rohsenow (85). By fabricating doubly-reentrant cavities in 316 stainless and nickel "A" surfaces, sodium boiling was made more stable in addition to giving smoother transition from natural convection to nucleate boiling. These cavities gave the lowest boiling ΔT's obtained. Roughness alone (weld beads on the surface) gave a readily apparent decrease in ΔT though not as much as the specially prepared cavities. An aging effect was also observed and attributed to noncondensible gases being purged from surface cavities. Considering a cylindrical cavity, they derived a criterion for stable nucleate boiling.

Though reluctant to use their results as a quantitative guide for predicting stability, they showed that a comparison of the predictions for various fluid-surface systems gave a good indication of relative stability.

Having noted the role played by roughness in determining site distribution, consider the following: Novakovic and Stefanovic (94) boiled water and alcohol from a smooth quiet horizontal mercury surface. This surface should have no roughness or cavity parameters associated with it. Nevertheless, nucleation took place at preferred sites which moved irregularly over the surface. The number of nucleation sites increased with flux in the same manner as on a solid surface. The boiling curve obtained by these investigators showed the usual inflection point indicating transition from natural convection to nucleate boiling. No proposal was made to explain the existence of preferential nucleation sites on the supposedly completely smooth mercury surface. Moving sites, such as those mentioned above, have also been observed on a solid surface by Rallis and Jawurek (101) while boiling ethanol at low pressures (0.3 atmospheres).

Wettability is a surface effect which is very important though somewhat insidious. If a particular system is fully wetted, then wettability may be completely inconsequential. However, the subtle effect of wettability in a nonwetted system can be of paramount importance.

Young and Hummel (123) were able to decrease the average ΔT required for nucleation in water by impregnating the surface with unwetted teflon spots. This added stability to the boiling, with the spots continuing to be active nucleation sites down to a superheat as low as 1 degree F, where 10 to 20 degree superheats are usually required for nucleation. These spots also increased the boiling coefficient, h, up to three times its normal value.

Wachters and van Andel (115) observed that deactivated nucleation sites required relatively large superheats to be reactivated. They hypothesized that reactivation occurred by nucleation at non-wettable spots on the wall of the cavity. In a manner akin to deactivated sites, Elrod et al. (42) found that corrosion resistant materials supported higher ΔT's without nucleation than did other surfaces.

Water and the common organic boiling fluids have good wettability (low contact angles) on most surfaces used in boiling studies, so little difference is observed in their boiling behavior for similar systems (47). For this reason many early investigators found no need to include wetting effects in their studies.

Hochman's (55) excellent review of studies concerning mercury's wettability showed that mercury posed a wetting problem as early as 1913. It has been well documented that heat transfer to mercury with change of phase requires wetting of the surface for good heat transfer (13,18,31,80,81).

The use of additives has been found to be the most reliable method for obtaining heat transfer surfaces which are wetted by mercury. The most effective additives are: 0.02 percent magnesium and 0.0001 percent titanium added as elemental metal and hydride, respectively (13,31,55). Prolonged operation will sometimes enhance the surface wetting (13). Additional discussion will be given in a later section devoted to previous mercury studies.

The growing interest and subsequent work with alkali metals have not encountered wetting problems since liquid alkali metals wet all metals. On this basis, Marto and Rohsenow (85) conclude that surface characteristics must govern the boiling behavior of liquid alkali metals. Their work with doubly reentrant cavities reaffirmed the contention of Griffith and Wallis (50) that cavities always retaining vapor are more stable and allow nucleation at lower surface superheats. The work of Young and Hummel (124) with teflon spots lent further credibility to this.

Critical fluxes.--Surface effects have also accounted for some very striking results concerning the critical fluxes. Of the various materials which have been used under similar conditions, only aluminum surfaces have consistently produced higher burnout fluxes than other surfaces (4 ,9 ,59,64). These studies were performed primarily using water and common organic liquids as the boiling medium. The higher fluxes do not seem to be the result of roughness and wettability which are usually suspect in such cases.

Cichelli and Bonilla (29) studied boiling water and organic liquids from a chromium-plated copper surface. Their burnout results could be represented by

$$\frac{(q/A)_{1c}}{CP_c} = f\ (P_r) \tag{5}$$

where the constant, C, had unit value for a clean surface and equaled 1.15 for a dirty surface. This, of course, shows that $(q/A)_{1c}$ was greater for the dirty surface by a factor of 1.15.

Several authors (38,39,46,49,93) have observed that surface impurities increased the burnout flux. Morozov (93) boiled organic liquids and found that slight amounts of carbon deposited on the heated surface during some runs. In each case, subsequent determinations of burnout gave higher values than previously obtained for the clean surface.

Costello and Frea (39) obtained their lowest burnout fluxes with distilled water boiling on a clean surface. When tap water was used, higher burnout fluxes were obtained as deposits formed on the surface. Still higher burnout values ensued when wicking was placed around the heated surface. Deposits also formed in this instance.

Frea, et al. (46) also reported that deposits formed on their surface while boiling tap water.

To evaluate the roughness effect, Averin (4) found that by machining a chrome-nickel steel tube to progressively smoother finishes, the burnout flux for water first increased with smoothness until the protuberance height was about 0.025 mm (985 microinches) with a pitch of 0.074 mm (2920 microinches). Recall that Clark, et al. (30) reported that their most active cavities had diameters between 300 and 3000 microinches. Averin's subsequent smoother finish and a final polished finish both gave decreased values of the burnout flux, with the polished surface giving the smaller value of the latter two.

The effect of wettability on nucleate boiling is epitomized by its effect on the burnout flux. Gaertner (47) found that by coating a surface with a fluorocarbon film, the burnout flux was decreased such that stable film boiling was obtained at a flux of 5400 Btu/hr-ft^2 which is only 1 percent of the normal burnout heat flux. In another test, he found that silicon grease on a platinum wire also decreased the burnout flux drastically. He further observed that most metals have contact angles with water between 50 and 60 degrees so not much difference is observed. If a difference is observed, it may be discounted as experimental error or statistical deviation. Gaertner concluded that the chemical nature of the surface did control the burnout level in pool boiling as Costello and Frea (39) reported.

Averin (4) showed the definite effect of wetting upon the burnout heat flux for water boiling on a chrome-nickel steel surface. By oiling the surface after determining its critical flux level, he then observed the drastic reduction in burnout brought about by the non-wetted oil film.

Wetting difficulties have also affected burnout determinations in liquid metal studies. Adams (1) found that magnesium did not readily wet his spherical tungsten surface. Postoperative inspection of his system actually disclosed that the magnesium wetted the surface nonuniformly, i.e., portions of the surface were wetted, others were not. He concluded that the three phase contact angle, β, appeared to hold the key to the magnitude and prediction of the burnout heat flux. See Appendix A for a discussion of the macroscopic contact angle and its relation to the surface tensions involved.

Mercury's nonwetting characteristics and the resultant difficulty in getting nucleate boiling data for it has been discussed previously. A more complete discussion will be in a later section.

Other Effects

In addition to the foregoing effects, there are many others which affect boiling heat transfer significantly. Some have been studied in an effort to determine their individual contributions to the complicated phenomena of boiling. A few of these will be discussed here.

Bulk liquid temperature.--Han and Griffith (52) studied the effects of subcooling as did Bradfield (16) in more recent work. As would be expected, the critical heat flux was increased by increasing the amount of subcooling. Bradfield reported that the transition (partial film boiling) portion of the boiling curve is shifted to a higher ΔT with increased subcooling.

Rehm (103) reported that subcooled boiling should be used in agravic applications since subcooling enhances the removal force on bubbles while buoyant force is, of course, absent.

Nonuniform pool temperatures are often reported in liquid metal studies. Madsen and Bonilla (82) studied pool boiling sodium-potassium alloy. They found that mixing in the pool was insufficient to provide uniform liquid temperatures. The liquid metal near the free surface was superheated at low pressures (2 mm mercury absolute), near equilibrium temperature at pressures between 10 and 20 mm mercury, and subcooled for higher pressures.

Colver (33) found that his potassium pool was subcooled near the pool bottom and superheated in the vicinity of his bayonet heater. The free surface temperature was taken to be the equilibrium value since it "correlated better when used to determine the boiling ΔT." Madsen and Bonilla concurred that the equilibrium (free surface) temperature gave the best determination of ΔT even when nonuniform bulk temperatures existed.

Bulk liquid velocity.--The effect of liquid velocity has been studied by many investigators in forced convection studies but these will not be fully discussed here. As Bernath (9) points out, "natural" velocities exist in pool boiling which can efficiently sweep away vapor bubbles and supply fresh liquid to the surface. This of course is the basic principle utilized in a "thermal syphon loop" such as that used by Romie *et al*. (108) who attained the highest heat flux yet reported for boiling mercury.

Forced convection heat transfer is more widely used in applications, but Brooks and Bonilla (19) comment that pool boiling data are of considerable value in interpreting forced convection boiling and further state that multiplying factors may be used to convert pool boiling correlations for use in forced convection systems.

Jakob (65) was perhaps the first to realize that the agitation of a boiling liquid by rising bubbles could account for the high heat fluxes attainable in boiling systems. Later studies of forced convection by Rohsenow and Clark (107) further justified this viewpoint.

Costello, Bock, and Nichols (38) have shown that velocities on the order of 1.5 ft/sec are induced in the vicinity of a heated plate during pool boiling. They estimate that 47 percent of the total flux at burnout is apparently transferred by convection for a one-half inch wide clean heater.

Tang, _et al_. (113) conducted an experimental study of potassium amalgams during forced flow. As the concentration of potassium was decreased, a noticeable increase of ΔT was observed indicating a trend toward the behavior encountered by other authors with pure mercury.

Zuber and Staub (128) studied the stability of dry patches formed in liquid films flowing over heated surfaces. They showed that thermal effects were dominant in predicting the stability of dry patches for liquid metals of high wettability. For poor wetting liquids (such as mercury) they concluded that the dry patches could stabilize at very low heat fluxes.

Heater geometry.--Size and geometry of heaters have also been shown to have appreciable effects on the boiling heat transfer behavior of a particular system. Bernath (9) studied this and found that burnout flux values for water boiling from cylinders increased with increasing diameters up to about 0.1 inch where they leveled off to a constant value of about 475,000 Btu/hr-ft^2 for most heater materials. Aluminum gave a slightly higher maximum flux (560,000 Btu/hr-ft^2). It was also found that wall thickness was an important factor in determining the burnout flux. Bernath's work showed that burnout increased with increasing tube wall thickness up to a thickness of about 0.04 inches before leveling off.

Cole and Schulman (32) boiled toluene from a zirconium surface and obtained the critical flux as a function of wall thickness for a favorable comparison to the curves of Bernath.

Carne (24) also reported work which substantiated that previously published by Bernath. Pursuing the suggestion of Bernath concerning investigation of the composite effect of wall thickness and heater material (thermal conductivity), Carne and Charlesworth (25) make the astute observation that burnout is a function of the "thermal conductance of the surface." For thermal conductance, kt, ranging from $4.5(10^{-4})$ to $1,680(10^{-4})$ watts/degree C, the burnout flux for n-propanol increased by a factor 2 in their work.

Ivey and Morris (64) performed additional work to determine the effect of test section parameters on burnout. Their data on diameter effects agreed very closely with Bernath while their wall thickness results gave slightly higher fluxes at thicknesses corresponding to those in Bernath's work.

Pitts and Leppert (99) worked with electrically heated wires. They found that the burnout flux for water increased with diameter up to about 0.012 inch and then leveled off. This behavior was unlike that shown by Bernath where the burnout flux leveled off at the much larger diameter of 0.1 inch. Lienhard and Watanabe (77) found that the burnout flux for small wires was a complicated function of the radius at low boiling pressures.

Lienhard and Schrock (75) studied geometric effects on the critical fluxes for six liquids at pressures ranging from 0.58 inches of mercury absolute to atmospheric. They found that configuration and geometry of the heater have a greater effect upon the second critical flux than on the first.

Geometry is credited with having an appreciable effect on boiling liquid metals also. Brooks and Bonilla (19) reason that nucleate boiling data for a cylinder in a large pool of boiling metal will have a smaller slope than data for a flat surface when plotted as heat flux versus ΔT.

Heater orientation.--Orientation is documented as having perceptible effects-on boiling systems. Costello and Adams (37) explored this area in conjunction with a geometry and acceleration study. They noted little difference in the burnout heat flux for various orientations except when the surface was wholly or partially faced away from the pool surface, so that bubbles had to flow across the surface before rising.

Bernath (9) has shown that vertical tubes exhibit burnout flux values only 0.76 times that for the same tube in the horizontal position. Morozov (93) showed that a flat heating surface can withstand larger nucleate fluxes facing upward than it can while inverted. By tilting a flat plate from the horizontal position, Marcus and Dropkin (83) found that increasing angles decrease the heat transfer coefficient in the convective region while increasing it for nucleate boiling.

Boiling Mechanisms

Much insight into the boiling process can be gained by considering the various modes and mechanisms proposed for boiling heat transfer.

Gunther and Kreith (51) discussed the role of microconvection in the boiling process. Microconvection concerns bubble agitation of liquid near the heated surface. Gunther and Kreith postulated that microconvection in the superheated layer was the dominant mechanism for high fluxes with surface boiling. This was supported by the fact that forced convection and natural convection curves coincided at high fluxes indicating that bubble agitation induced liquid turbulence comparable to that achieved by forced flow over the surface. Rohsenow and Clark (107) further discussed the liquid movement induced by departing bubbles. Bubbles were proposed to push the superheated film away from the surface as they grow. Zuber (126) further proposed that the departing bubbles carry entrained superheated liquid into the bulk liquid thereby creating convective currents in the liquid adjacent to the surface. This added agitation (microconvection) then allows large fluxes to be attainable in boiling heat transfer.

Forster and Greif (44) presented a review and discussion of boiling mechanisms after which they proposed the boiling model referred to as vapor-liquid exchange. This is similar to the expanded theory of microconvection proposed at about the same time by Zuber (126). They both involve the liquid motion resulting from movement of bubbles on the surface. Forster and Grief also interjected that as bubbles leave with entrained superheated liquid, cooler bulk liquid takes their place.

Moore and Mesler (92) proposed the "micro-layer vaporization" mechanism. In their study, observations were made which indicated that during the growth of a bubble, the surface remained wetted by a thin liquid layer. As the thin layer evaporated into the growing bubble, the surface was effectively cooled. After bubble departure, the surface temperature rose as the superheated film again formed until sufficient superheating was present to support the growth of a new bubble. Thus, a rapid cycling of surface temperature occurred.

Boiling, by definition, must involve latent heat transfer but the point of interest concerns where the evaporation occurs. During convective boiling, the evaporation occurs at the free liquid surface, but during nucleate boiling, it occurs on or near the heated surface as well. The latent heat mechanism involves direct evaporation at the heated surface.

The estimated contribution to the total heat flux by each of the above-mentioned modes of transfer may be used to indicate their relative merit. Kreith, Summerfield, and Gunther (70) concluded that less than 5 percent of the heat transferred from a surface is carried as latent heat in the vapor bubbles. Their observations gave credence to the microconvection theory whereby the main portion of heat was transferred to the streams of coolant impinging on the surface. However, the work concerning microlayer vaporization performed by Moore and Mesler (92) showed that microlayer vaporization could account for 70 to 90 percent of the total heat transferred. From later observations, Hospeti (57) found a wider range of contribution, from 14 to 90 percent, but his work also indicated that the contribution decreased with increasing flux--exactly opposite to the trend observed by Moore and Mesler. In spite of these opposing views, and since the microlayer vaporization accounts for only about 1.5 to 30 percent of the total vapor generated before bubble detachment, we must conclude that latent heat transport is well above the 5 percent level reported above.

Rallis and Jawurek (101) further conclude that latent heat becomes more and more predominant as the heat flux is increased. They postulate that the latent heat fraction of the total flux tends to unity as the burnout flux is approached. They contend that the contributions of latent heat transport and natural convection account for the entire heat flux during saturated boiling.

From liquid temperature profiles determined experimentally for water, Bobst (11) calculated a conductive heat transfer term which amounted to 47 percent of the total flux for fluxes ranging from 70,000 Btu/hr-ft^2 up to burnout. Recall that Costello, et al. (38) estimated that 47 percent was transferred by convection. At first, this appears in direct contradiction to the findings of Rallis and Jawurek discussed previously; but if this "conducted" heat vaporized liquid into growing bubbles on the surface, it would still qualify as a latent heat contribution as defined by the latter authors.

Correlations

Most experimental investigations in heat transfer have the primary goals of giving a better understanding of the process involved and producing useful information to be used in designing new and improved equipment. The most convenient transmittal of experimental results is achieved through correlations. Correlations may be divided into three general classes: empirical, semi-empirical, and theoretical. The second of these would seemingly be best since it has a basis in theory and experiment rather than relying entirely on one while excluding the other.

Free convection.--Free convective heat transfer to liquid metals has not been studied very extensively. Eckert (41) derived a theoretical correlation for natural convection from vertical planes

$$\frac{h_m L}{k_\ell} = 0.68\left(\frac{Pr_\ell}{0.952 + Pr_\ell}\right)^{\frac{1}{4}} \left(Pr_\ell \; Gr_\ell\right)^{\frac{1}{4}} \qquad (6)$$

which is suggested for low Prandtl number fluids by McAdams (88).

Hyman, et al. (62) found that the constant in Equation 6 should be 0.54 for heat transfer from horizontal pipes to liquid metals. The characteristic length, L, must of course be replaced by the pipe diameter, D.

More recently, Brinmade and Desmon (17) found that their natural convection data for lithium, sodium, and tin were well represented by Eckert's original equation (Equation 6).

Nucleate boiling.--Many authors have devised nucleate boiling correlations. Limited success has been achieved though the methods of attack range over various degrees of sophistication.

Forster and Zuber (45) developed modified Nusselt and Reynolds numbers from theoretical considerations and determined empirical exponents from pool-boiling burnout heat flux and ΔT data

$$Nu = 0.0015\ Re^{0.62}\ Pr^{0.33} \tag{7}$$

where,

$$Nu = \frac{q/A}{(T_w - T_\ell)k}\left(\frac{\Delta T\ C_p\ \rho_\ell \sqrt{\pi\alpha}}{\lambda\ \rho_v}\right)\sqrt{\frac{2\sigma}{\Delta P}}\ \sqrt[4]{\frac{\rho_\ell}{\Delta P}}$$

and

$$Re = \frac{\rho_\ell}{\mu}\left(\frac{\Delta T\ C_p\ \rho_\ell \sqrt{\pi\alpha}}{\lambda\ \rho_v}\right)^2$$

Since Equation 7 was finalized using burnout data for ethanol, water, n-pentane, and benzene, Perkins and Westwater (98) tested it for methanol over a range of ΔT. The predicted boiling curve agreed well with experimental results.

Camack and Forster (21) further tested Equation 7 by comparing it to the mercury data of Bonilla, et al. (13) and the sodium data of Lyon, et al. (81). The comparison was quite encouraging for mercury, and fair agreement was shown for sodium.

Forster and Greif (44) later developed an expression

$$q/A = 4.3(10^{-5})\left(\frac{\alpha C_p \rho_\ell T_{sat}}{\sigma^{1/2}(\lambda\rho_v)^{3/2}}\right)(C_p T_{sat}\sqrt{\alpha})^{1/4}\left(\frac{\rho_\ell}{\mu}\right)^{5/8}\left(\frac{\mu C_p}{k}\right)^{1/3}\Delta P^2 \quad (8)$$

which agreed quite well with mercury boiling data. This equation also yielded fair agreement with sodium data.

Both of the preceding correlations gave good agreement when compared to Colver's (33) boiling potassium data near atmospheric pressure.

Though the equations, per se, will not be included here, other authors who have met some success in correlating nucleate boiling data include: Rohsenow (105), Chang and Snyder (27), and Levy (74).

Since surface properties have widely varying effects on ΔT, most nucleate boiling data do not possess sufficient uniformity to lend themselves readily to any general correlation. In view of this, it is well to again note the comment of Han and Griffith (52) that the governing factors "are just not known with sufficient precision to make a boiling curve prediction possible."

Burnout.--Though many additional data have been published since Gambill (49) made his survey of boiling burnout, he does include discussion of the important variables and early correlations proposed for predicting boiling system behavior. In the absence of surface tension data, the modified Rohsenow-Griffith (104) equation was suggested by Gambill

$$(q/A)_{1c} = 143\ \lambda\ \rho_v\ (a/g)^{1/4}\left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{0.6} \tag{9}$$

For sheer simplicity, this correlation is very desirable. It showed a maximum deviation of about 11 percent when applied to Cichelli and Bonilla's (29) data for water and various organic liquids.

Kutateladze (73), Zuber (126), and others have contended that burnout is hydrodynamically controlled and therefore should be independent of surface effects. Their reasoning from this point of view indicates that the burnout flux may be considered the "flooding" point of the system. That is to say, burnout is the result of a Helmholtz instability arising when the counterflowing liquid and vapor to and from the surface reach the point where any additional vapor generation will flood the surface with vapor since insufficient liquid can reach the surface.

Kutateladze's dimensionless equation for the burnout flux is

$$(q/A)_{1c} = K\ \lambda\ \rho_v^{1/2}\ [\sigma g g_c\ (\rho_\ell - \rho_v)]^{1/4} \tag{10}$$

where

$$K = 0.13 + 4\left(\frac{\mu^2\ \{g(\rho_\ell - \rho_v)\}^{1/2}}{(\sigma g_c)^{3/2}}\right)^{0.4} \tag{11}$$

as proposed by Borishanskii (15).

Kutateladze's equation (Equation 9) arose from dimensional analysis with the constant, K, to be determined empirically. Zuber and Tribus (129) developed an equivalent expression for predicting the burnout heat flux. Their development was theoretical and produced a value of $\pi/24$ for the constant. An interesting point is the close agreement of the theoretical constant, $\pi/24=0.131$, with the empirical one, K=0.13, obtained by Kutateladze and Borishanskii.

The Kutateladze and Zuber-Tribus correlations are both fairly successful in predicting the burnout flux for water and some organic liquids, but have not agreed well with alkali metal data (33,95).

Chang and Snyder (27) indicated that surface roughness affects ΔT but not burnout. They used dimensional analysis to develop an expression for thermal eddy diffusivity with the premise that: (1) latent heat transport becomes significant only when burnout is approached, (2) bubble action destroys wave motion of natural convection, (3) eddy motion increases the effective thermal conductivity, and (4) the latent heat effect increases the effective specific heat capacity. Their expression for thermal eddy diffusivity was then used to develop a burnout correlation which was the same as Kutateladze's (Equation 6) but with a different constant. Chang and Snyder's constant was a function of contact angle and they used experimental values to determine that the constant should range from 0.17 to 0.23. Their work also indicated that burnout is caused by the two-phase flow instability previously mentioned while other correlations such as Addoms (2)

$$(q/A)_{1c} = 2.4 \lambda \rho_v \left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{1/2} \left(\frac{g\, k_\ell}{\rho_\ell\, C_{P\ell}}\right)^{1/3} \tag{12}$$

suggest a dependence on the transport properties of the liquid as well.

By including a viscosity dependence and separating the Prandtl number from Addoms' correlation for empirical determination of the exponent, Noyes (95) obtained a correlation to fit his sodium data as well as other data for water and organic liquids

$$(q/A)_{1c} = \frac{0.144 \lambda \rho_v}{Pr_\ell^{\,0.245}} \left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{1/2} \left(\frac{g g_c\, \sigma}{\rho_\ell}\right)^{1/4} \tag{13}$$

Lurie and Noyes (78) incorporated Colver's (33) potassium data and their sodium data to yield a second correlation

$$(q/A)_{1c} = 1.19 \lambda \rho_v \,(g\, \alpha)^{1/3} \left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{0.56} \left(\frac{Pr_\ell}{g/g_c}\right)^{1/12} \tag{14}$$

These two equations have since shown considerable utility in successfully predicting the critical flux for liquefied hydrocarbons and hydrocarbon mixtures (20,110,122).

In studying pool-boiling magnesium, Adams (1) found that by varying the contact angle, β, over its observed range, his equation

$$(q/A)_{1c} = \frac{2.37\,\rho_v\,\lambda\left(1 + 0.318\,\frac{\rho_\ell}{\rho_v}\right)^{1/2}\left(\frac{g g_c\,\sigma\,(\rho_\ell - \rho_v)}{\rho_\ell^2\,\beta}\right)^{1/4}}{[1 + \sqrt{\rho_v/\rho_\ell}]^2} \qquad (15)$$

gave considerable leeway in predicting the first critical heat flux. Other equations such as that of Kutateladze (Equation 10) correctly predicted the nonwetting burnout flux while Noyes' first equation (Equation 13) more nearly agreed with the wetted value predicted by Adams equation for a low contact angle.

Caswell and Balzhiser (26) have recently developed two separate correlations, one to correlate all liquid metal burnout data, and another which incorporates the Prandtl number to bring metallic and nonmetallic data together. Their correlations are

$$(q/A)_{1c} = 1.18(10^{-8})\,\frac{\lambda^2\,\rho_v\,k}{C_p\,\sigma}\left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{0.71} \qquad (16)$$

and

$$(q/A)_{1c} = 1.02(10^{-6})\,\frac{\lambda^2\,\rho_v\,k}{C_p\,\sigma}\left(\frac{\rho_\ell - \rho_v}{\rho_v}\right)^{0.65} Pr_\ell^{\,0.71} \qquad (17)$$

Good agreement is shown between the correlations and the data presented in conjunction with them. The data include potassium, sodium, and rubidium burnouts for comparing to the first equation and ethanol, pentane, benzene, and water data for the second one.

Film boiling.--Bromley (18) performed the first analytical study of film boiling and presented a correlation for film boiling from a horizontal cylinder. Rearranging his result in terms of heat flux and ΔT, it becomes

$$q/A = 0.62 \left(\frac{k_v^{\;3}\ \rho_v\ (\rho_\ell - \rho_v)\ g\ \lambda'}{D\ \mu_v} \right)^{1/4} \Delta T^{3/4} \qquad (18)$$

Lyon's (80) nonwetting mercury data are at much higher flux levels than this correlation predicts at moderate values of ΔT. The nonwetting data of Bonilla, et al. (13) are likewise higher, but not as much. It must be noted however, that the latter data were obtained from a horizontal flat surface.

In a recent study of film boiling potassium, Padilla and Balzhiser (97) found that their data were correlated within 22 percent by

$$q/A = 0.97 \left(\frac{k_v^{\;3}\ \rho_v\ (\rho_\ell - \rho_v)\ g\ \lambda'}{D_b\ \mu_v} \right)^{1/4} \Delta T^{3/4} \qquad (19)$$

which has been rearranged. The bubble diameter, D_b, is given by

$$D_b = 4.7 \sqrt{\frac{3 g_c\ \sigma}{g\ (\rho_\ell - \rho_v)}}$$

They noted however, that this correlation did not apply to film boiling mercury data nor did any of the other correlations then available.

In a cryogenic study, Sciance, Colver, and Sliepcevich (111) obtained film boiling data for liquefied methane. They found their data were best correlated by

$$\frac{q/A\ B}{k_f\ \Delta T} = 0.346 \left(\frac{B^3 g\ \rho_f\ (\rho_\ell - \rho_f)\ Pr_f\ \lambda'}{\mu_f^{\ 2}\ C_{pf}\ T_r^{\ 2}\ \Delta T} \right)^{0.276} \qquad (20)$$

This equation is a modified version of correlations by Chang (28) and Berenson (8). Sciance, et al. obtained their data from a horizontal cylinder 4 inches long by 0.811 inch diameter. However, they used the "Laplace reference length," B, in their correlation instead of heater diameter because diameter effects are negligible for heaters this size. They noted that this allowed direct comparison with flat plate data.

Previous Mercury Investigations

Lyon, et al. (80,81) are credited with having performed the first comprehensive liquid metal boiling study. In addition to pure mercury, they boiled mercury with additives, sodium, sodium-potassium alloy, and cadmium (all at atmospheric pressure). They found that pure mercury did not wet their 316 stainless steel tube (0.75 inch O.D.). The 5 inch long tube experienced ΔT's up to 1000 degrees F, but did not achieve a heat flux level higher than 30,000 Btu/hr-ft^2 for pure mercury. By using 0.1 percent sodium in the mercury, a maximum flux of 60,000 Btu/hr-ft^2 was obtained at a ΔT of about 35 degrees F. Using a different additive, 0.02 percent magnesium and 0.0001 percent titanium, a flux level of 100,000 Btu/hr-ft^2 was achieved at a 12 degree ΔT. Though it appeared that complete wetting had occurred, equipment limitations prevented the determination of a maximum flux level under wetted conditions.

Farmer (100) boiled pure mercury from a horizontal circular copper surface. He also obtained a maximum flux level of about 100,000 Btu/hr-ft^2 but at a much higher ΔT than Lyon, about 100 degrees F. Farmer attained this flux while boiling a 3.8 cm deep pool at a system pressure of 6 mm mercury. From the steep slope of the boiling curve, it appeared that a much higher flux could have been achieved before reaching the critical flux.

Bonilla, _et al_. (13) reported that pure pool-boiling mercury began wetting their low-carbon steel surface after frequent use for a few weeks over a range of temperatures and fluxes. They note that once wetted, the surface never again underwent film boiling as it had prior to being wetted. The maximum flux reported for pure mercury was 125,000 Btu/hr-ft^2. While boiling a 2 cm deep pool, they obtained nucleate boiling at 15 and 30 psig (ΔT less than 30 degrees F), but at pressures between 10 and 200 mm mercury, observed high ΔT's (up to 800 degrees F) indicative of film boiling. For a 10 cm deep pool, they obtained nucleate boiling at slightly higher ΔT's for pressures corresponding to the nucleate boiling mentioned above. For the deeper pool, nucleate boiling was also observed at lower pressure. Though some scatter was present, the representative decrease in ΔT with increasing pressure was readily evident. By varying the depth of the boiling pool, they observed a significant though inconsistent shift in the temperature difference, ΔT. Slight variations in surface condition could account for this inconsistency. By using magnesium and titanium additives in the same proportion as Lyon had done, these investigators also achieved improved system wettability. At a given ΔT, the heat flux was increased by about 25 percent. Boiling a 3.2 cm deep pool of mercury with additives at pressures from 83 to 800 mm mercury, they achieved heat flux levels up to 200,000 Btu/hr-ft^2. For some reason, the flux was not extended above this level even though the data gave no indication of approaching burnout. Recall that their fluxes for pure mercury went only to 125,000 Btu/hr-ft^2 even though wetting existed. Nevertheless, their flux of 200,000 Btu/hr-ft^2 was the highest flux reported for pool boiling mercury prior to the present study.

Romie, et al. (108) operated a thermal-syphon loop with mercury at pressures up to 33 psia. They used additives (magnesium and titanium) initially which did not facilitate wetting of the 1018 steel surface. Wetting was accomplished by copper plating the test section. They then operated at fluxes up to 600,000 Btu/hr-ft^2. This flux was really an upper limit for the actual flux since the electrical power input was dissipated in a parallel circuit comprised of the heated tube wall and the flowing mercury. The test section was located about 4 feet below the condenser in one leg of the U-loop. Therefore, a 1.5 atmosphere static head pressure equivalent was maintained above the test section in addition to the system pressure.

Boiling mercury data obtained by Korneev (68) were presented by Romie, et al. (108) for comparison purposes. It should be noted that Korneev's data showed the representative shift of ΔT for a pressure change from 1 to 10 atmospheres at low fluxes. At higher fluxes, anomalous behavior occurred. The higher pressure boiling curve actually crossed over to ΔT's which were higher than those obtained for the system at lower pressure. This perhaps resulted from surface phenomena affecting the boiling behavior.

More recent work by Merte, et al. (6) also encountered wetting problems with mercury. During initial runs with their 347 stainless steel surface, they obtained nucleate boiling and a "non-steady-state" burnout value of 68,000 Btu/hr-ft^2 at a pressure of 78.2 psia. The pool depth was 0.5 inch. The system later gave only film boiling so small amounts of magnesium were added to the mercury. This produced nucleate boiling for short periods of time but did not give a stable wetted condition. The surface was then replaced with a C-1010 carbon steel surface which was copper plated to initiate wetting. Even with this precaution, erratic behavior was reported during subsequent boiling runs. The inconsistent behavior of ΔT versus heat flux was attributed to "prior history effects or physical changes in the boiling surface."

Clark and Parkman (31) used cesium, rubidium, magnesium, and magnesium plus titanium as additives at various concentrations to test their effect on boiling mercury. With heat fluxes ranging from 5,000 to only 20,000 Btu/hr-ft^2 they judged the effectiveness of each additive on the basis of whether film or nucleate boiling occurred. In their study, as in previous ones, magnesium plus titanium proved to be most effective.

For discussion of additional mercury wettability studies, the reader is referred to the previously mentioned compilation prepared by Hochman (55).

In summary, it has been revealed that mercury's wettability has created considerable difficulty in boiling studies. In studies where wetting has been achieved, moderately high flux levels were obtained, but in no instance has the burnout flux been determined. In view of this, it would appear that such a study would be a welcome addition to the literature.

Investigation Objectives

The present work was begun as the initial step in a continuing program at the University to study the pool-boiling characteristics of high-temperature working fluids. It was intended to construct a versatile boiling apparatus adaptable to many boiling systems while incorporating a most desirable attribute--heating surfaces which are easily interchanged.

The primary goal was to obtain boiling curves for mercury up to high fluxes. It was desired to obtain wetted surfaces, if possible, without resorting to additives which are undesirable in many boiling applications (31,55). In any case, it was hoped that consistent and reproducible results could be obtained whereby some explanation could be made for the scattered and widely varying data obtained in previous studies.

CHAPTER II

EQUIPMENT DESCRIPTION

Introduction

To study the pressure dependence of the maximum nucleate boiling heat flux for mercury, it was decided to construct equipment capable of operating at pressures ranging from near 1 mm mercury (Torr) to 200 psig. This pressure range corresponds to saturation temperatures up to 1,030 degrees F (117). Of course, temperatures in the test heaters necessarily extended well above this temperature even though the investigation did not cover the entire pressure range for which the equipment was designed.

Required heat fluxes were expected to approach 10^6 Btu/hr-ft^2, so interchangeable heaters were designed to adequately perform at this level.

Fabrication materials were chosen for their availability and/or corrosion resistance. All portions of the system directly contacted by mercury were made from austenitic stainless steels, 304 or 316.

The equipment comprising the experimental set-up included the boiling vessel, test heater, condenser, knockout drum, charge vessel, manifold system, power supply, and instrumentation.

A schematic diagram of the experimental system is shown in Figure 1. Figure 2 gives an operator's view of the apparatus. The power supply and panel containing powerstats, voltmeters, ammeters and pyrometer module are out of view to the left in the picture. Vacuum pumps are located behind the enclosure.

Safety Precautions

Since mercury vapors are extremely toxic, the vessels containing mercury were completely enclosed in an airtight steel enclosure which was vented to a hood through a 2.5 inch pipe. The outer enclosure (Figure 2) had steel walls (1/8 inch thick) and external dimensions of 6 ft by 3 ft by 6 ft 8 inches tall. To shut the enclosure, a steel door was bolted across the entrance. A compressible rubber gasket (1/2 inch thick) circled the entrance and sealed the door when it was bolted in place. A circular Plexiglas window (6.5 inch diameter) in the side of the enclosure allowed visual inspection of the equipment while the enclosure door was in place.

To comply with safety regulations, a Sunshine Instruments instantaneous mercury vapor detector (#38) was used to warn of dangerous vapor concentrations. An unvulcanized rubber intake hose was connected to a Y manifold outside the enclosure. Two 1/2 inch NPT brass ball valves

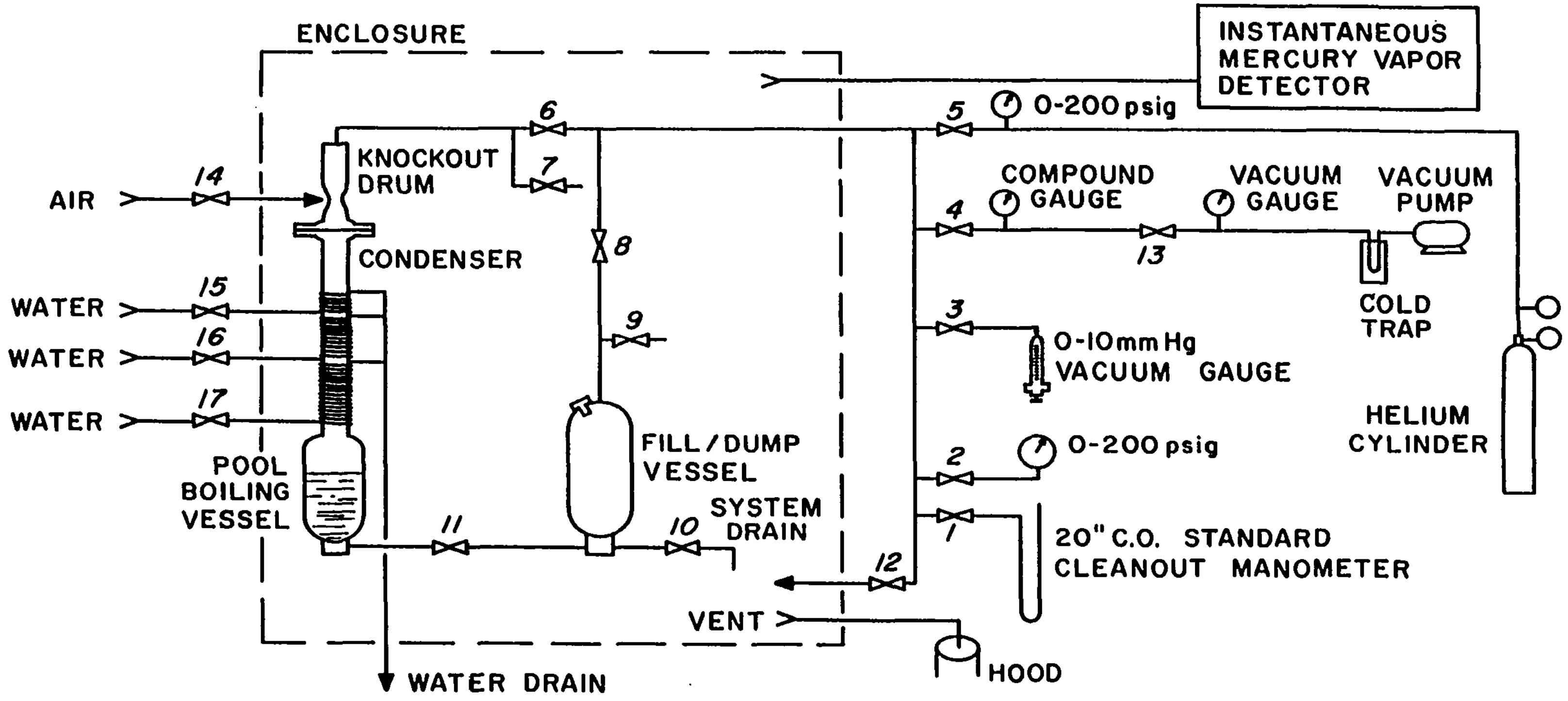


FIGURE 1. SCHEMATIC DIAGRAM OF EXPERIMENTAL APPARATUS.

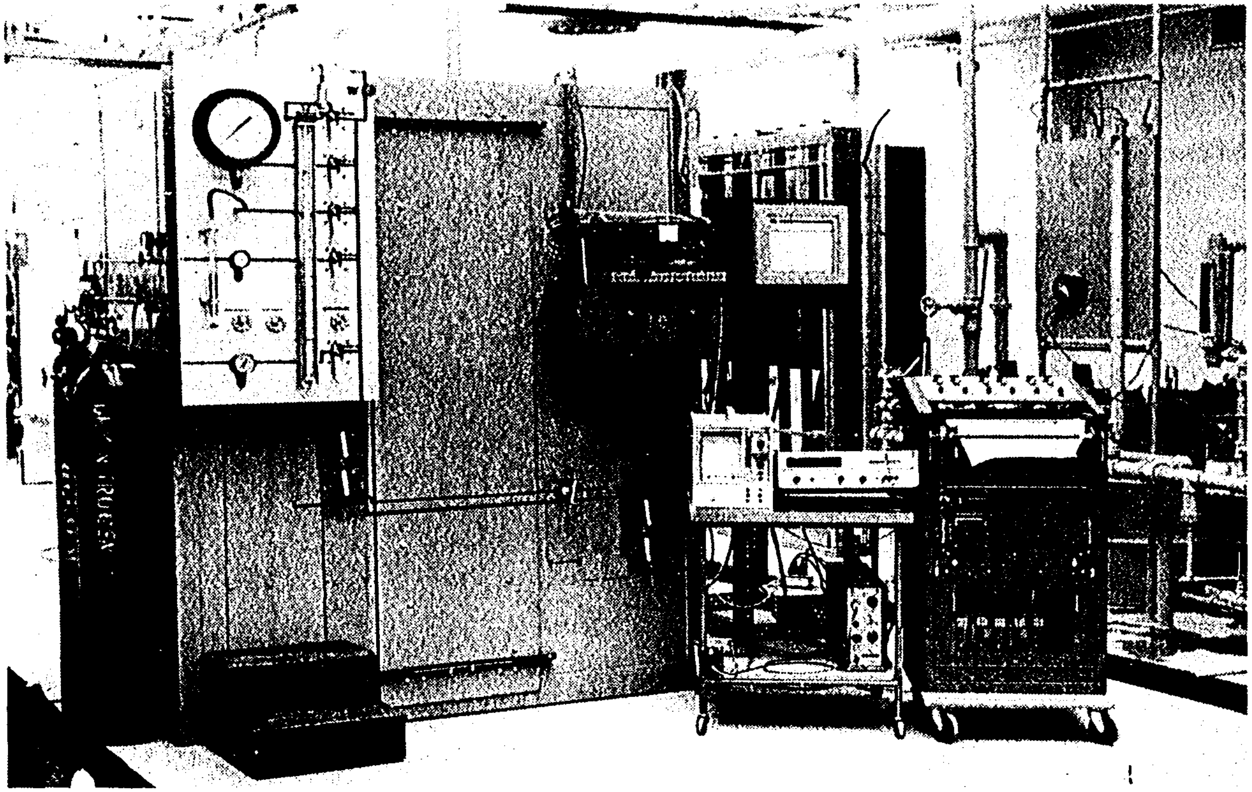


FIGURE 2. OPERATOR'S VIEW OF EXPERIMENTAL APPARATUS.

connected to 5 foot lengths of Tygon tubing allowed the detector to check two locations inside the enclosure. One of the tube inlets was placed near the test heater. The other was placed on the enclosure floor beneath the frame which held the boiling vessel.

As an added precaution, an air line entered the enclosure through one wall. This provided a means to purge the enclosure with air and sweep out mercury vapors detected by the instantaneous detector. The air of course left the system through the vent line which joined one of the large ducts provided for hoods in the Engineering Center. The particular hood system used was left on during the entire course of this work whether or not actual runs were being made.

To aid in obtaining a tight system, each component piece of equipment was vacuum checked individually as the welding was completed. Only one weld--on an auxiliary heater sheath--had to be rewelded. Once the equipment was installed, it was again tested with an NRC mass spectrometer leak detector (#925). Using a helium probe, small leaks (mostly at threaded joints) were found and eliminated. The entire system was checked, repaired, and rechecked until no leaks registered as much as 10^{-8} std cc/sec on the spectrometer.

Boiling Vessel

The boiling vessel was fabricated from an 8 inch length of 316 stainless steel seamless pipe (5.76 inch I.D. by 6.625 inch O.D.), and two 6 inch schedule 80S stainless welding caps. Figure 3 gives details and dimensions of the vessel while Figure 4a is an internal view of the placement of thermocouple wells and auxiliary heater sheaths. Table 1 gives the exact location of each thermowell. For details of an individual thermowell installation, see the exploded view in Figure 11. Note that thermowells in the boiling vessel were staggered from side to side so temperature measurements could be made at one inch intervals along the depth of boiling liquid.

The vessel was drilled and tapped for 3/4 inch NPT Swagelok fittings which held sheaths for the auxiliary heaters. A 1/2 inch NPT tap was required to accommodate the test heater (Figure 4b). Holes for the three auxiliary heaters entering through the bottom welding cap were drilled on a 2-inch radius and spaced at 120 degree intervals. The other two auxiliary heaters entered the vessel on opposite sides 5 inches from the bottom of the vessel.

To attach a fill line at the bottom of the boiling vessel, a 1.5 inch length of 2 inch diameter 316SS rod was welded to the bottom welding cap after which a hole was bored through the cap into the rod (Figure 3). When a hole was drilled and tapped in the side of the rod for a

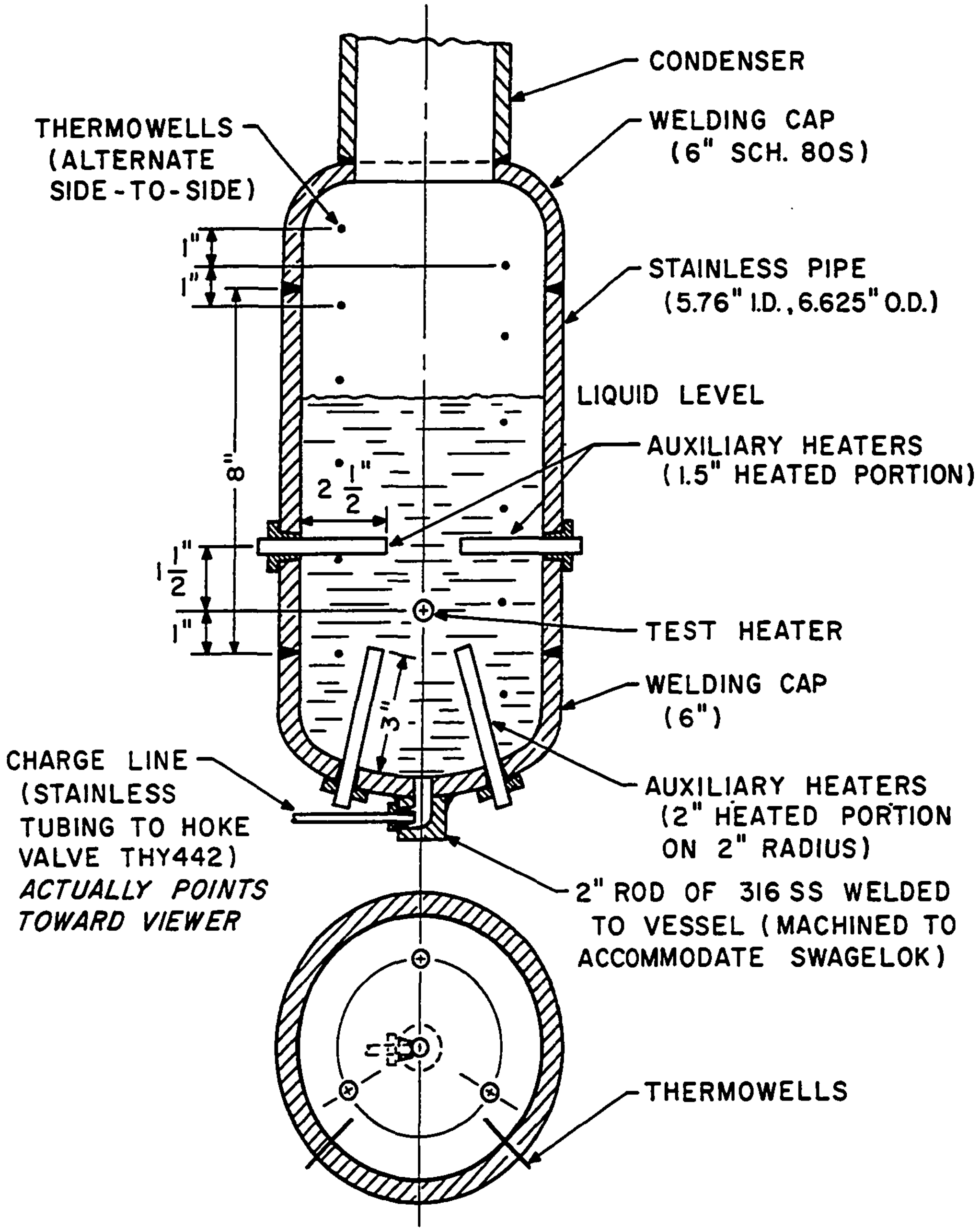
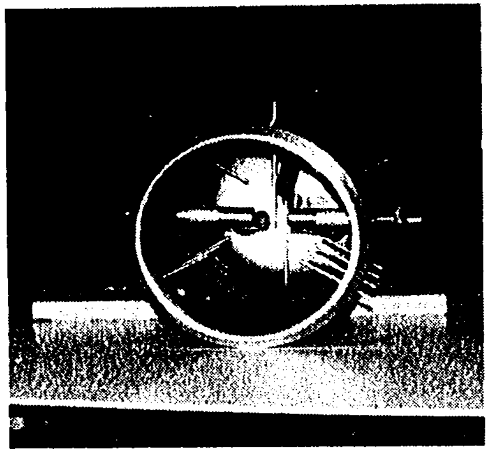
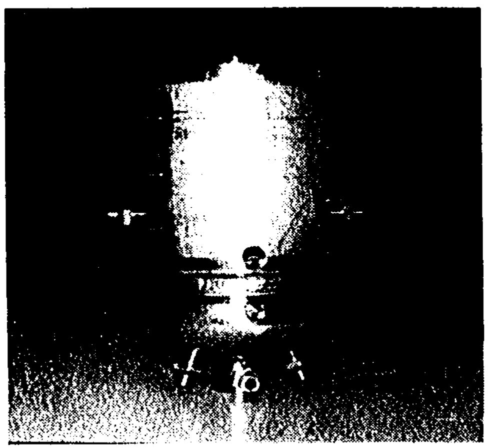


FIGURE 3. BOILING VESSEL.

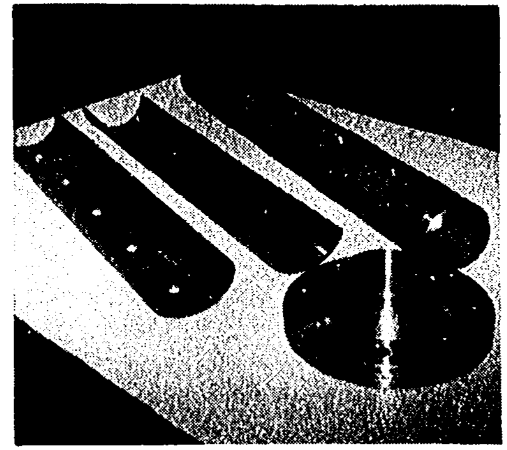


(a)

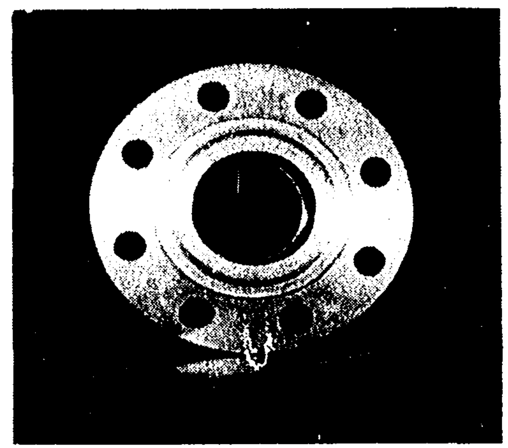


(b)

FIGURE 4.
BOILING VESSEL DURING FABRICATION.



(a)



(b)

FIGURE 5.
CONDENSER DURING FABRICATION.

TABLE 1

THERMOWELL LOCATIONS

Thermowell Number	Position	Distance into Vessel (inches)	Height from Vessel Bottom (inches)
1	Front Center	2.875	1.5
2	Left Rear	1.0	1.5
3	Right Rear	1.0	1.5
4	Right Front	1.0	3.5
Test Heater	Front Center	3.0	3.5
5	Left Front	1.0	4.5
6	Rear Center	2.875	4.5
Auxiliary Heaters	Left Side, Right Side	2.5	5.0
7	Right Front	1.0	5.5
8	Left Front	1.0	6.5
9	Right Front	1.0	7.5
10	Left Front	1.0	8.5
11	Right Front	1.0	9.5
12	Front Center	1.0	11.75
Bottom of Condenser	--	--	13.0
13	Front Center	1.0	18.0
14	Front Center	1.0	23.0
15	Front Center	1.0	28.0
16	Front Center	1.0	33.0
17	Front Center	1.0	38.0
Flange Connection		--	48.0
18	Front Center	1.0	63.0

1/2 inch NPT Swagelok male connector (#600-1-8-316), the use of an "ell" fitting was avoided. The inner edges of the hole through the bottom welding cap were rounded so that complete drainage of the system would be possible.

A hole was machined in the top welding cap to match the size pipe used for the condenser. The condenser was of course welded atop the boiling vessel.

Test Heater

The "bayonet" configuration heater has shown itself to be quite versatile and capable of producing the high flux levels required in liquid metal boiling studies (33,95). However, thermocouple placement in the heaters has presented considerable difficulty. In both Noyes' (95) and Colver's (33) work, sheathed thermocouples were brazed into grooves cut in the external surface of the heater. In both instances, extensive erosion and/or melting of the brazing material occurred during operation (especially during burnout determination). Noyes suggests that in his work, "premature burnout may have been in some way caused by the thermocouple grooves and/or the associated brazing alloy."

In at least one case, Colver's heater failed by splitting lengthwise along a thermocouple groove. Colver also encountered some difficulty in accurately extrapolating measured temperatures to the heater surface. Since the thermal conductivity of the material lying above the thermocouple was not precisely known, certain approximations were necessary.

In this study, it was hoped that by profiting from these prior investigator's experiences, an improved design could be achieved. Though the present design is similar in many aspects, the thermocouple installation represents considerable departure from the brazing method used by Noyes and Colver. It was endeavored, also, to circumvent the problem of relying solely on tight mechanical fit for thermal bonding of the thermoccuples.

The heater, per se, consisted of a 304 stainless sheath, a grooved cylinder of tinned copper for thermocouple placement, a boron nitride cylinder, and a graphite rod heating element. The individual components are shown in Figure 6.

A detailed view of the assembled test section is shown in Figure 7. The use of a Swagelok male connector (#600-1-8-316) allowed easy interchange of heaters while providing a leak-free seal through the use of Silver Goop thread lubricant and antiseize compound. Manufactured by Crawford Fitting company, Silver Goop may be used effectively in high temperature service up to 2100F.

As shown in Figures 6 and 7, the tubing connection portion of the Swagelok fitting was machined off, leaving only a 1/16 inch lip protruding from the outer face. The centerline hole in the fitting was then reamed to allow a

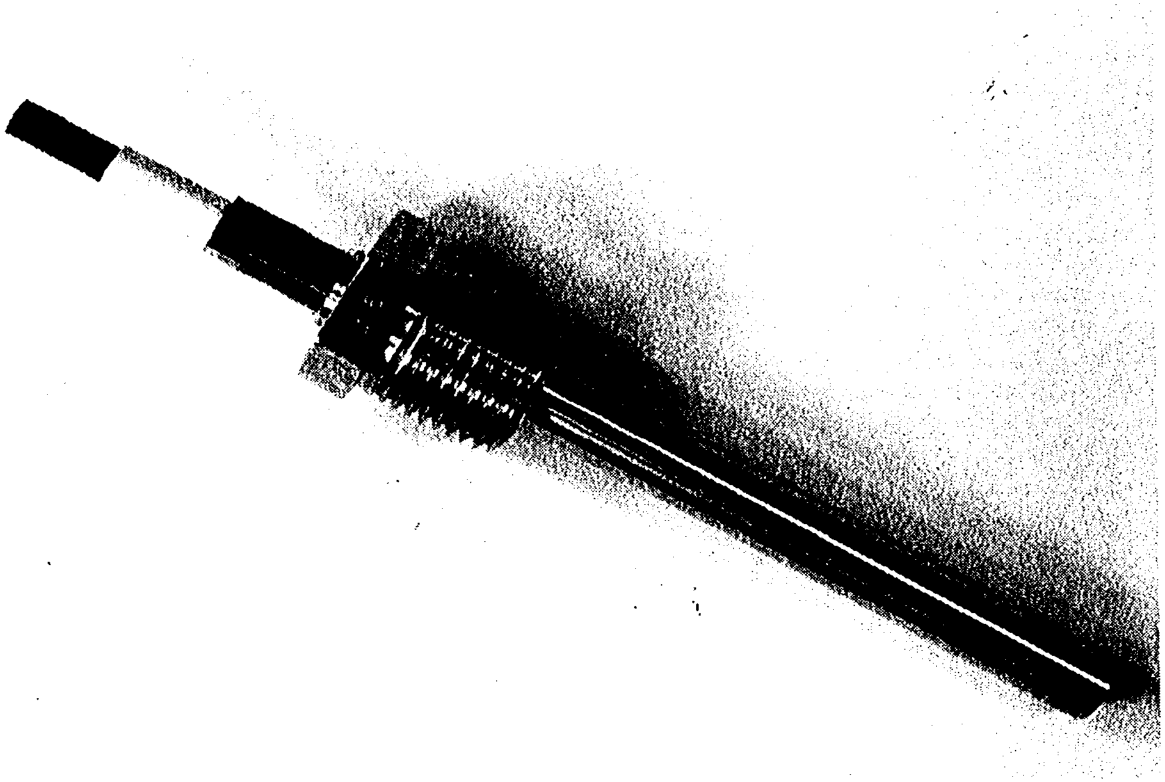


FIGURE 6. COMPONENT PIECES OF TEST HEATER.

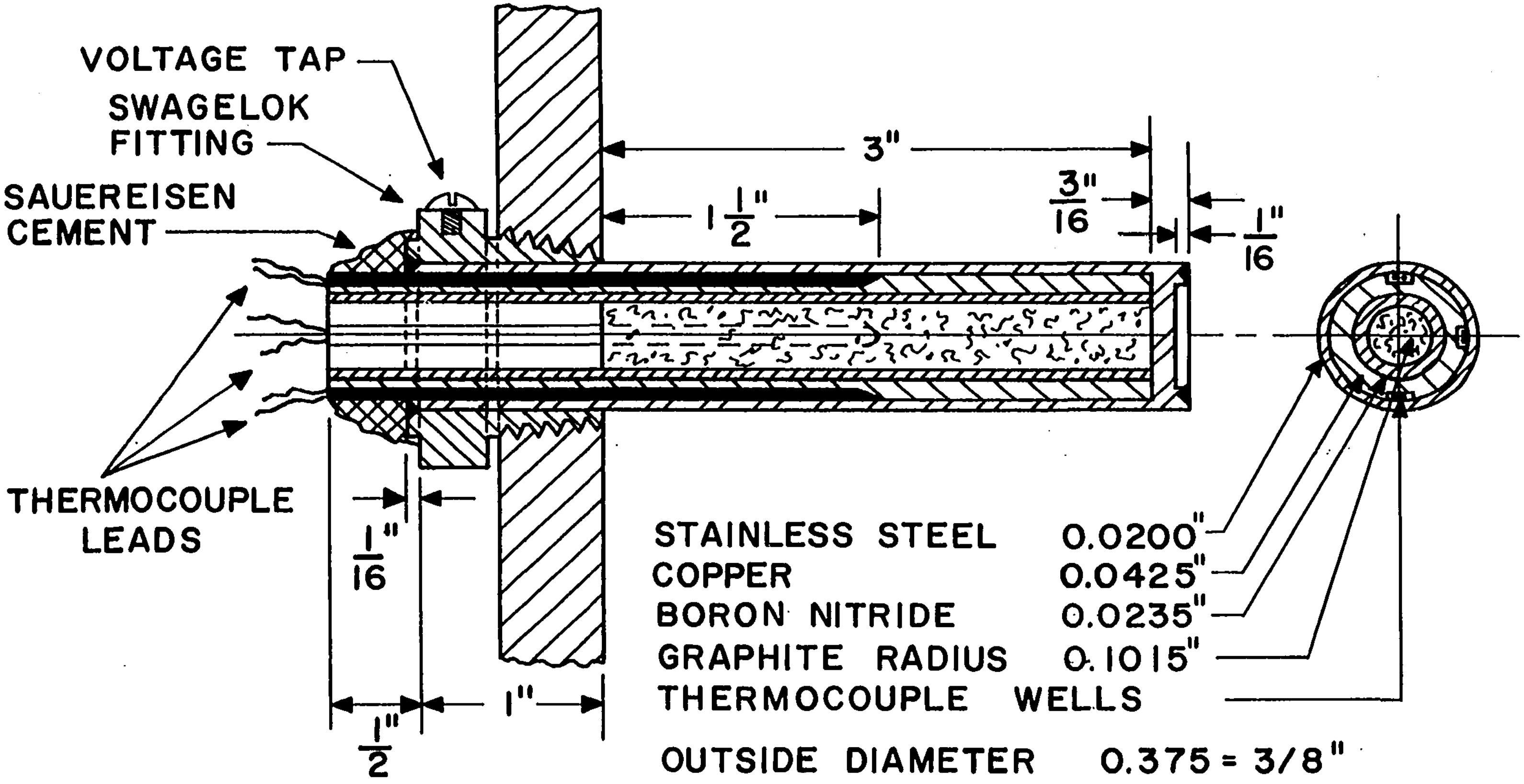


Figure 7. Details of Test Heater.

4.25 inch length of 3/8 inch diameter 304 stainless tubing to be pressfitted into it. A plug with a 1/16 inch lip machined on it was then pressfitted into the opposite end of the tubing. The tube wall was 0.020 inch thick, so the lips on the Swagelok and plug were made the same thickness to allow uniform heat generation while circumferential welds were made. Otherwise, the two materials would not melt and flow simultaneously to form a high strength weld.

To complete the heater sheath, two opposite hex flats on the Swagelok fitting were drilled and tapped for a voltage tap connection. The sheath was, of course, vacuum tested for leaks as an added check on the weld quality. The surface finish on the heater will be discussed in the next section.

The copper cylinder was made from a length of 3/8 inch diameter hard drawn phosphorized copper tubing (Alloy #122). With 0.065 inch walls, the tube's 0.245 inch inside diameter was directly reamed to 1/4 inch. The outside diameter was then machined to 0.335 inches for a tight fit inside the stainless sheath. The outside of the copper tube was then tinned with 50/50 wire solder, i.e., 50 percent tin, 50 percent lead with no flux core. The surface was first smeared with Kester soldering paste, then heated with a propane torch until it was hot enough for application of the solder.

Once the surface was completely tinned, all excess solder was wiped away leaving a smooth shiny surface. The inside surface was then carefully cleaned with a rifle cleaning kit to remove oxides formed during the tinning operation. Thermocouple grooves (0.050 inch wide by 0.025 inch deep) were then milled longitudinally in the copper surface. Test Heaters A and B had three grooves extending to the midpoint of the three inch heated portion of the heater. Heater 1 was equipped with one groove extending to the midpoint as before, but the other two extended to within 1/4 inch of each end, respectively. Heater 2 was made the same as Heater 1 but with a fourth groove extending to the midpoint of the heated section. The placement of thermocouples near the ends of the heater allowed a determination of longitudinal temperature variation.

To electrically insulate the inner heating element from the metal sheath, boron nitride was used. In a 3/8 inch diameter solid rod of boron nitride, a 3/16 inch diameter hole was drilled through the entire 4.5 inch length. The cylinder was then reamed to 13/64 inch inside diameter. The outside was machined to 1/4 inch to fit tightly inside the copper cylinder. Due to the brittle nature of boron nitride it was necessary to insert a mandrel into the cylinder to lend stability while machining the outside to size.

Three inch length graphite heating elements were machined from 1/4 inch solid rods. They were made slightly undersized to allow for expansion during operation. The diameter was made about 1 or 2 thousandths of an inch smaller than the 13/64 inch hole in the boron nitride.

Test Heater A was assembled by simply sliding all the composite pieces together. Doubly insulated 30 gauge Chromel-Alumel thermocouple wire (#52-0079) from West Instrument Corporation was used. The outside insulation binding the individually wrapped wires was removed along a length equal to the groove length into which the thermocouple was fitted. The inner fiberglass insulation impregnated with resin made each wire about 0.025 inch in diameter. This inner insulation was removed from about 1/8 inch of each wire. A thermocouple was then made by discharging a capacitor across the contacting wires held together by copper leads. Argon gas was played over the junction when the arc was made and sufficiently long afterward to allow the wires to cool. All thermocouples used in this study were made in a like manner.

Data from Test Heater A exhibited high calculated values of ΔT for nucleate boiling water. This was attributed to interfacial thermal resistance to heat flow causing a temperature drop across the stainless steel-copper interface. For this reason, subsequent heaters were assembled in a different manner. Thermocouples for Heater B were placed into their respective grooves with the bead lying far enough up the inclined section of the groove to slightly protrude above the surface of the copper cylinder. Small wires were then used to gird the cylinder and thermocouples. Using the same solder and paste previously used to tin the copper, the thermocouple beads were then covered with solder which completely filled the groove in the vicinity of the beads. The inner surface of the stainless sheath was then treated with Stay-Clean solder flux which is recommended for all soldering purposes including stainless steel, Monel, and chrome. The copper with the installed thermocouples (girding wires were now removed) was then forced into the stainless sheath by placing them endwise within the jaws of a vice. Representative data was then obtained from the heater (see Chapter IV).

The same technique was employed for assembling Heater 1 except the inner surface of the stainless sheath was treated by the Watts (116) technique (see next section on heater surface preparation). In addition, a low-melting (100.4F) Indalloy solder (#8) was used to cover the entire surface of the copper as the cylinder was forced into the stainless sheath.

Since the writer contracted mercury poisoning at the time Heater 1 was assembled, it was decided not to use the Indalloy solder (which contained 4 percent mercury) for assembling Heater 2. Instead, the remarkable ternary eutectic alloy (Viking LS 232) manufactured by Navan, Inc. was used. Since this material is liquid at room temperature, no heating was required during heater assemblage as it was when using low-melting solder. The use of Viking alloy also precluded further use of Watts' technique for treating the inner surface of the stainless sheath. This alloy is a eutectic composition of mercury-indium-thallium and has the "unique ability to wet virtually all materials--non-metallic--as well as metallic--to form contacts of very low electrical and thermal resistance." This property made it ideal for the present application to reduce interfacial thermal resistance.

Once the heater was completely assembled, with thermocouples in place, Sauereisen Electrotemp Cement (#8) was used to cover all the exposed copper surface and to pot the thermocouple leads in place to avoid undue flexing and possibly breaking them.

Though precise and tedious machining was involved in fabricating each heater, there was no instance where expensive material was scrapped due to breakage or other failure. Indeed, the only piece that had to be remade was the copper cylinder for Test Heater 1 which was deformed while milling grooves in its outer surface.

Heater surface treatment.--Test Heaters A and B were assembled and used as received from the machinist. He had finished the commercial surface in a lathe with 400C grit silicon carbide paper. Heaters 1 and 2 were treated differently in an attempt to get some idea of the enigmatic effect that surfaces have on boiling mercury.

Test Heater 1 was further smoothed with 600 grit paper. A final finish was obtained by hand rubbing the surface with crocus cloth. Previous studies (6 ,55) have shown that mercury does not readily wet stainless steel. It was decided to silver the surface by the technique described by Watt, O'Connor, and Holland (116). They found that the interfacial electrical resistance between mercury and a surface could be effectively reduced by this method. It was hoped that the thermal resistance would also be reduced and perhaps complete wetting would be achieved. The inner surface of the heater sheath was also silvered prior to sliding the tinned copper into it. The surface was silvered by the following procedure: the Heater was, (1) immersed in concentrated nitric acid for two minutes, (2) rinsed with distilled water, (3) immersed in hydrochloric acid for two minutes, and (4) immersed in clean mercury until it was installed in the system.

Since other investigators have achieved wetted surfaces by plating them with a material which was wetted by mercury, Test Heater 2 was silver plated to further test this method. The commercial plating was applied to the surface prepared by the machinist without further polishing by this investigator.

Test Heater Installation

An installed test heater is shown in Figure 8 prior to putting the insulation in place. It can be seen that a 9.5 inch by 4 inch wide mild steel plate served as the base platform for the installation. A slotted piece of angle iron was used as a pressure plate to compress the spring-loaded mechanism (Figure 9) and provide intimate contact between the current-carrying components, which included the copper rod, molybdenum plunger rod, graphite heating element, and the end of the heater sheath. The sheath around the spring contained an aluminum piston configuration which could be pushed forward against the spring by screwing in the bolt through the pressure plate. The slotted angle iron placement served as a coarse adjustment for spring compression with the bolt serving as a fine adjustment. For operation, the bolt was always screwed in tightly enough to completely compress the spring which required 25 lb_f. This corresponded to 780 psi on the 0.202 inch diameter graphite rod if the entire force were transmitted through the molybdenum plunger rod.

Figure 9 shows details of the spring-loaded portion of the power circuit including voltage taps which allowed measurement of the voltage drop across the heater from the most practical and proximate positions. In each case, the tap was located on the particular material which directly contacted the graphite heating element.

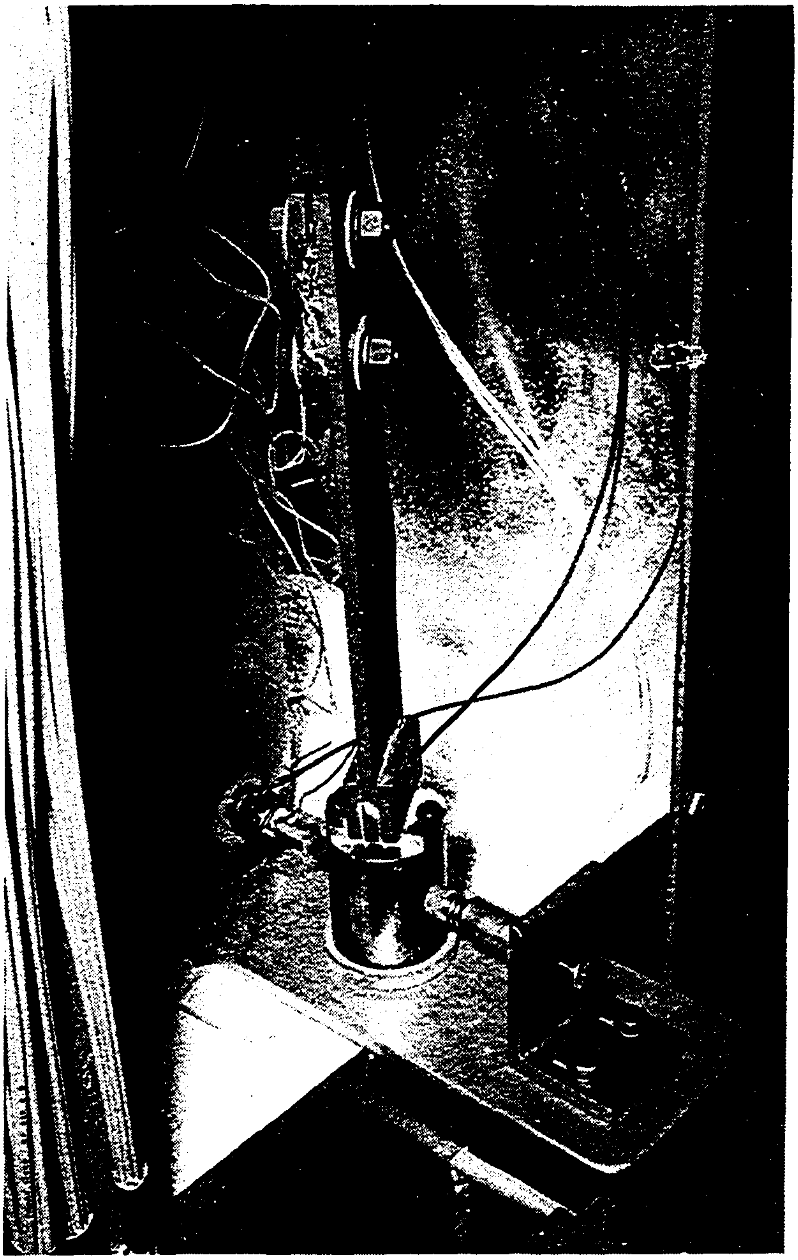


FIGURE 8. INSTALLED TEST HEATER.

To furnish power to the heater, one lead from a D-C rectifier was bolted to the 2 inch diameter copper bar as shown in Figure 8. The power circuit was completed by bolting the other D-C lead to the flange connection at the top of the condenser. Note that machined pieces of lava were used for electrical insulation where needed (Figure 9).

Molybdenum Corrosion Protection

Molybdenum was chosen for the plunger rod for its particular combination of high electrical conductivity, relatively low thermal conductivity, and high melting point. In previous applications (23,33,95), molybdenum had shown the capability of conducting large current densities required for this type of work. The previous designs had not encountered extreme corrosion difficulties with molybdenum since it had been blanketed with inert gas (or a vacuum). However, such a blanket was not present in this equipment and could not easily be added when the problem arose during early runs, so other prophylactic measures were required. For corrosion resistance, plating was a logical possibility. However, refractory metals such as molybdenum and tungsten are not easily plated as the result of difficult-to-remove oxide films.

From a review of the literature, it was found that some success had been achieved in protecting these metals by electroplating several alternating layers of chrome and

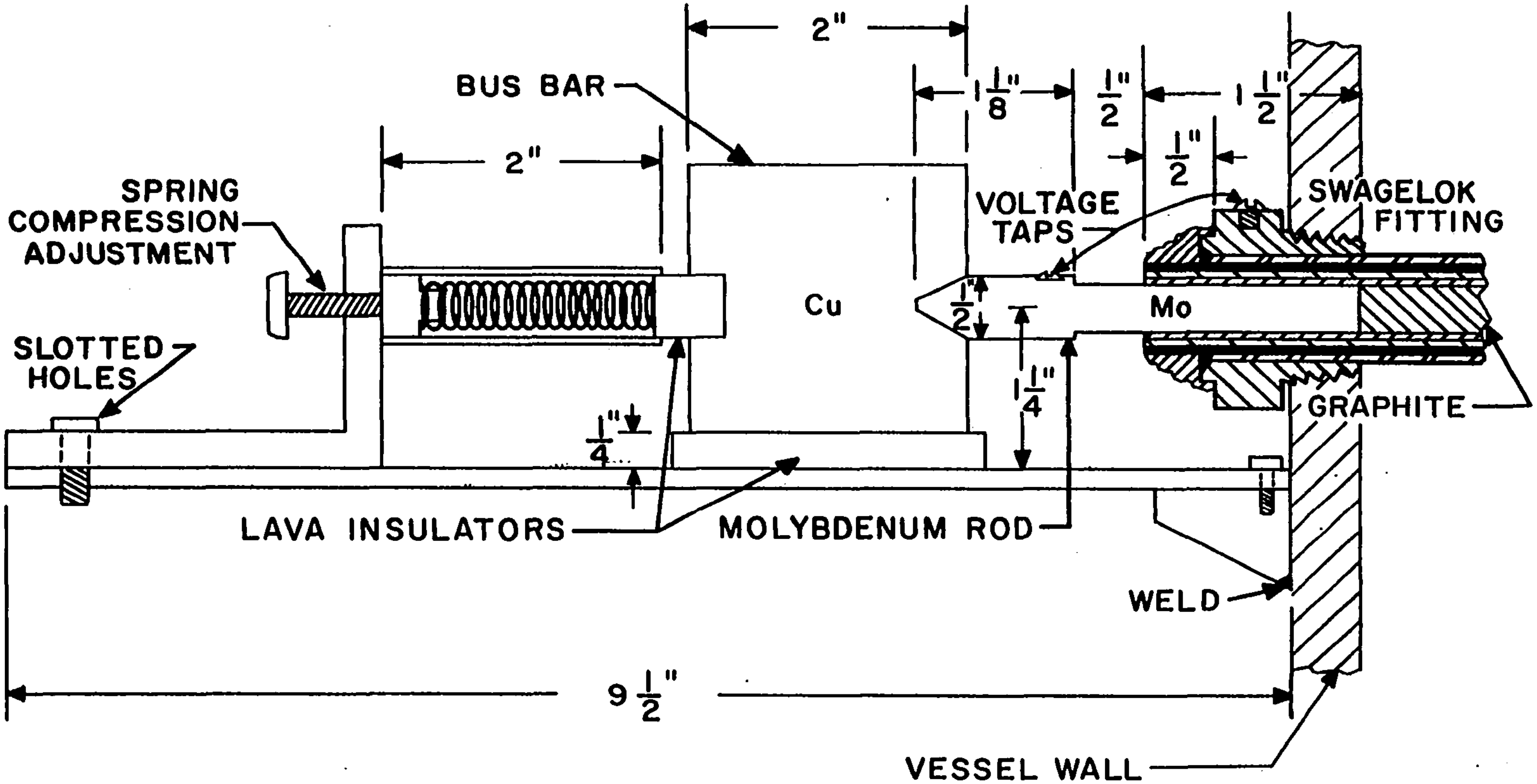


Figure 9. Power Circuit Spring Mechanism.

nickel (22,54,61,67). Details were sketchy and the procedure was extremely time-consuming since vacuum annealing was needed after each layer to achieve good adherence of the plating.

A more recent method for plating tungsten was found (86) which seemed to hold some promise of success in applying it to molybdenum. After a few trial-and-error attempts, which ended when the plating cracked and peeled from the surface, the following procedure was used:

(1) The relatively clean piece of molybdenum (cleaned in sulfuric acid after previous plating failures) was etched in a mixture of hydrofluoric acid and nitric acid. A yellowish-brown froth formed on the surface and termination of the procedure was considered at this point since it was felt that surface oxides were being formed instead of being removed. The procedure was continued, but, in future attempts to plate molybdenum, this step might beneficially be excluded.

(2) The etched molybdenum was then anodically etched in a 30 percent solution of potassium hydroxide for 3 or 4 minutes. The hydroxide solution was maintained at 130F and the current density was held at 200 amp/ft^2.

(3) The piece was rinsed and immediately placed in a strike solution containing 250 g/l chromic acid and 2.5 g/l sulfuric acid. The bath temperature was 150F with a current density of 200 amp/ft^2 maintained for 2 minutes.

(4) The chrome plating was then activated for further deposition in a 50/50 hydrochloric acid-water solution for about 3 seconds.

(5) After rinsing, a second strike treatment was performed in a solution of 240 g/l nickel sulfate and 40 g/l sulfuric acid at room temperature and a current density of 75 amp/ft^2 for 3 or 4 minutes.

(6) A proprietary rhodium solution was then used to plate over the nickel layer, which served as a diffusion barrier preventing the base material from diffusing to the surface and corroding at high temperatures. Rhodium plating is corrosion resistant and possesses excellent electrical contact properties.

(7) To assure maximum adherence of the plating, the piece was vacuum annealed in a Brew Furnace (#420-B) at about 2500F for 8 hours. The temperature was, of course, increased to and decreased from this high level in a gradual manner.

Only the reduced diameter section of the molybdenum, which contacted the graphite and therefore experienced the highest temperature extremes, was plated.

For added protection against oxidation, a 6 inch diameter semi-cylinder of Fiberfrax insulation was inverted over the molybdenum rod before covering the heater installation with Perlite insulation. The void formed by the inverted semi-cylinder was continuously purged by nitrogen during operation at high temperatures.

Condenser

A flanged condenser was constructed from a 30 inch length of 316SS seamless pipe (3.35 inch I.D. by 4.0 inch O.D.). Five thermowells were spaced at five inch intervals along its length (Figure 5). An iron pipe was split in half longitudinally, tinned inside with soft solder, clamped around the stainless pipe and spot-welded to hold securely. This was done to lessen chances of damaging the stainless steel by thermal shock and to give a surface to which cooling coils were more easily soldered.

Three pairs of brass clamps were made to screw onto the iron pipe and hold each end of three sets of copper coils which were wound around and soft-soldered to the iron pipe (Figure 10). By chucking the condenser in a lathe and clamping one end of the copper tubing, the tubing could be held in tension while the lathe was turned manually until the proper number of coils were made around the condenser. The other end of the tubing was then clamped and held securely for application of solder. Three sets of coils were made with 5, 10, and 15 coils, respectively (Figure 10). Since acid flux was used for soldering, a bicarbonate of soda solution was used to thoroughly wash the condenser and neutralize the acid.

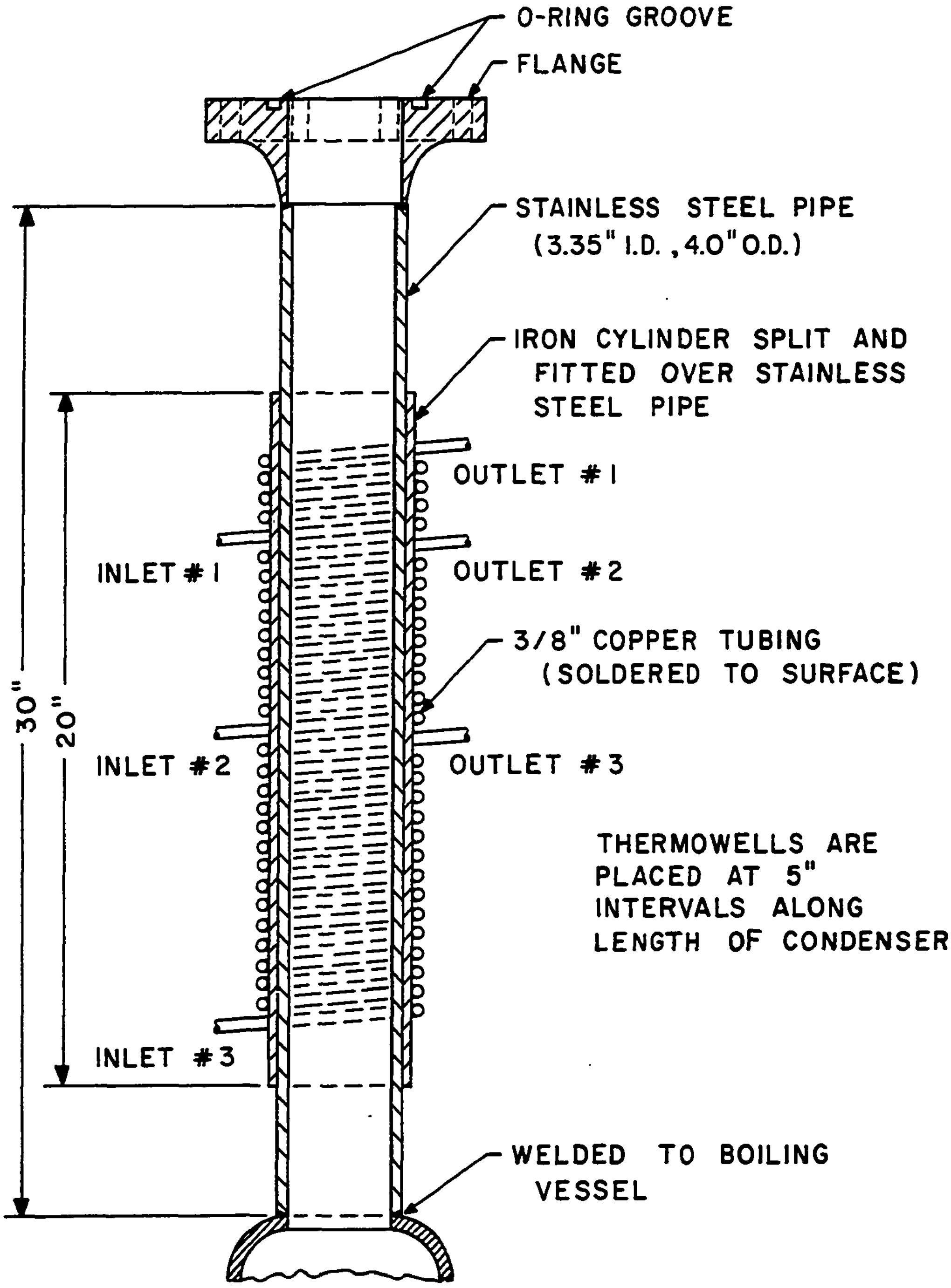


FIGURE 10. CONDENSER.

One end of the condenser was then welded to the boiling vessel and the other end to a 3.5 inch schedule 40S flange. An O-ring groove was machined in the flange to accommodate a Viton rubber O-ring which could withstand temperatures up to 600F. All machining was performed before welding the flange to the condenser.

Knockout Drum

A matching flange to the one above served as a base for the knockout drum. The flange connection allowed access to the boiling vessel. Two schedule 40S concentric reducers were joined to the flange as shown in Figure 11. Reducing the cross-sectional area in this manner effectively reduced the diffusion rate of mercury vapor past this point. The air stream used for purging the enclosure was directed at this reduced section to give additional condensing capacity by forced convection heat transfer.

The top reducer was welded to an 8 inch length of 316 SS pipe (4 inch I.D. by 4.5 inch O.D.). This pipe contained a cylinder of stainless steel gauze rolled from a 4 inch wide strip. The gauze was to facilitate condensation of any vapor that migrated past the condenser and was, of course, inserted prior to welding the various pieces together. A thermowell was also installed in the knockout drum above the stainless gauze (Figure 11).

A top for the knockout drum was fashioned from a 1/4 inch stainless steel plate. A single hole was drilled

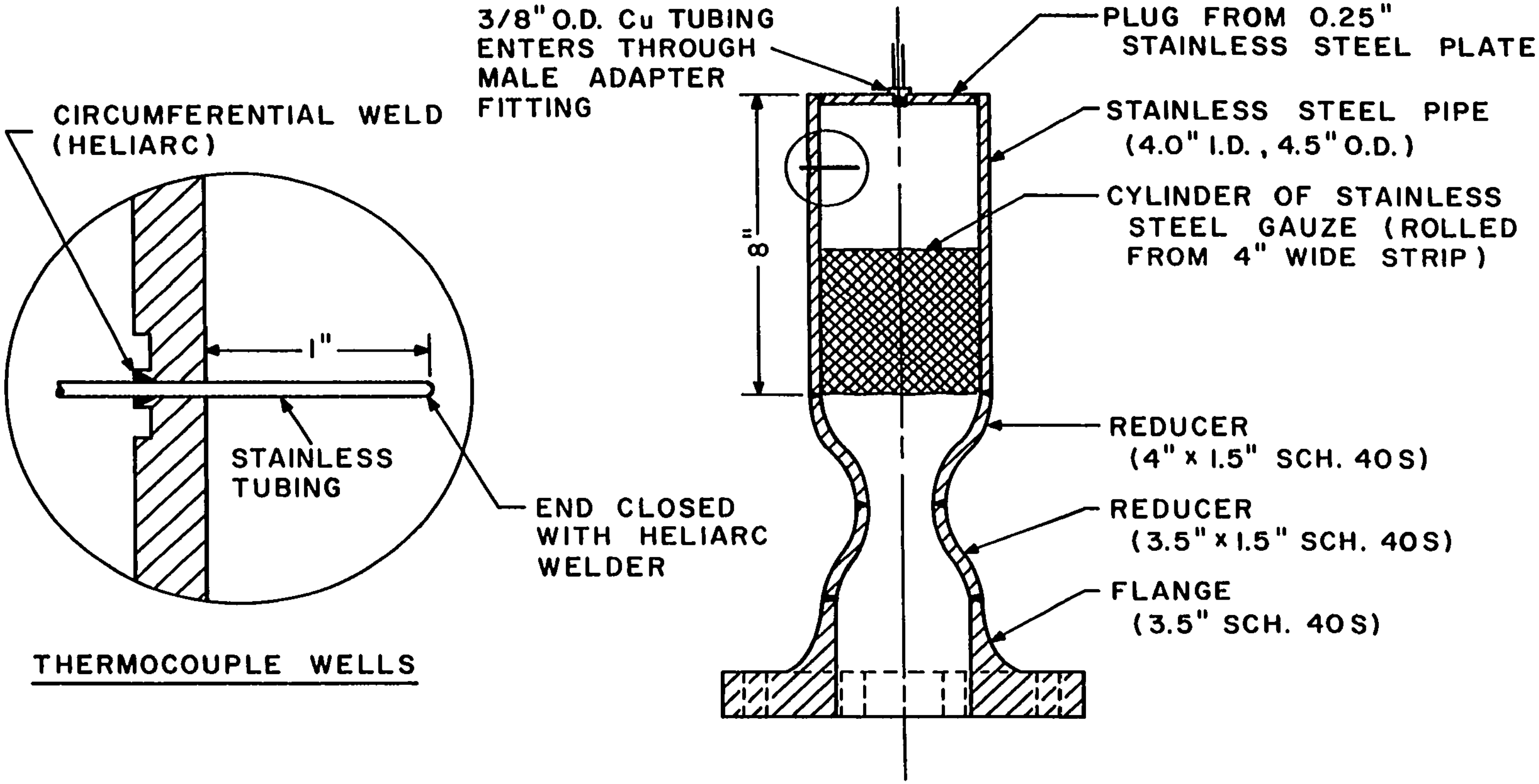


FIGURE 11. KNOCKOUT DRUM AND THERMOWELL INSTALLATION.

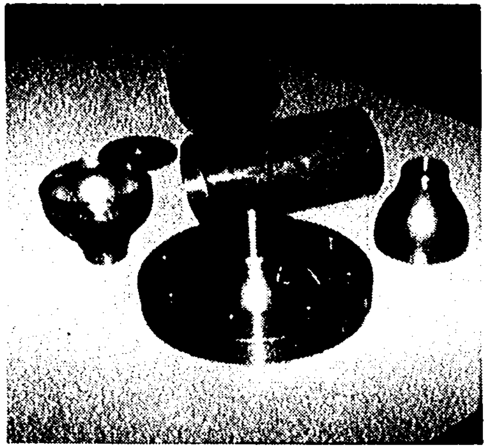
and tapped in it for a 1/2 inch NPT fitting to connect the vessel to the manifold system. The circular plate was machined to fit tightly in place while being welded onto the pipe.

Figures 12 and 13 show the knockout drum and boiling vessel at various stages of completion.

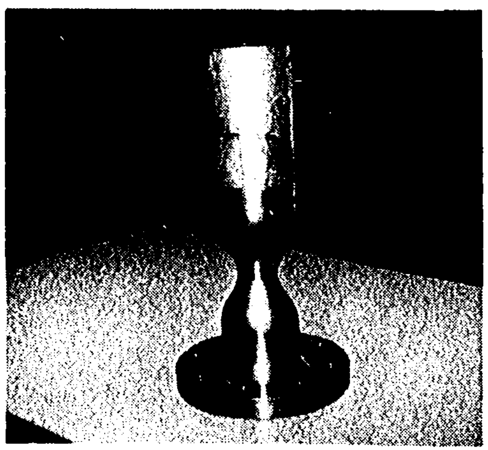
Frame

To support the boiling vessel, a frame was constructed from 2.5 inch by 2.5 inch by 1/4 inch angle iron (Figure 14). The frame was made 4 ft 4 inches tall while being 17 inches square in a horizontal plane. A 17 inch square of 1/4 inch steel plate was cut and made to bolt onto the top of the frame. After cutting a circular hole in the plate to fit around the condenser and drilling 8 holes to match those in the flanges, the plate was split in half so it could slide together under the lower flange and be bolted in place. Flange bolts were used which extended through both flanges and the plate. When in place in the enclosure, the frame was leveled by the use of height adjustment screws provided at each corner of the base. The frame was then braced against lateral movement by iron bars bolted to the frame and to the steel enclosure.

An aluminum plate lying flat in the base of the frame, and galvanized sheet metal bolted to the sides of the frame, formed a container around the boiling vessel

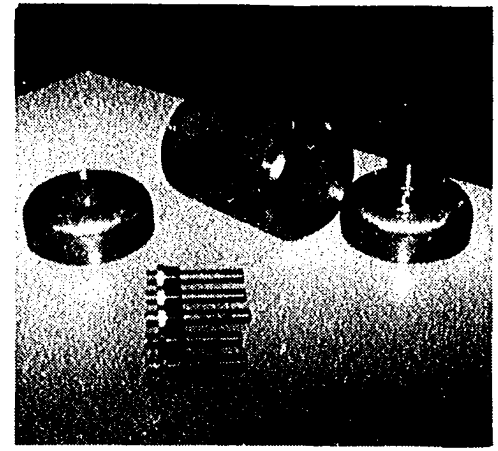


(a)

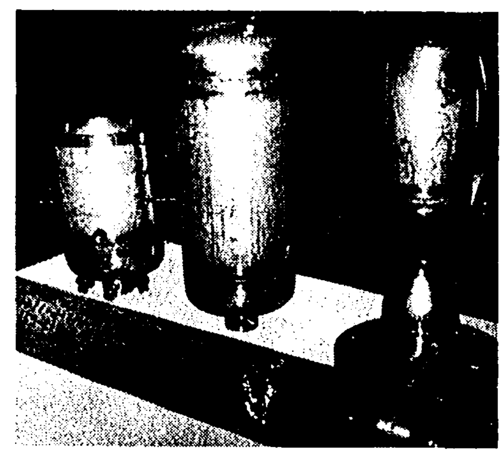


(b)

FIGURE 12.
KNOCKOUT DRUM DURING FABRICATION.



(a)



(b)

FIGURE 13.
OTHER SHOTS DURING FABRICATION.

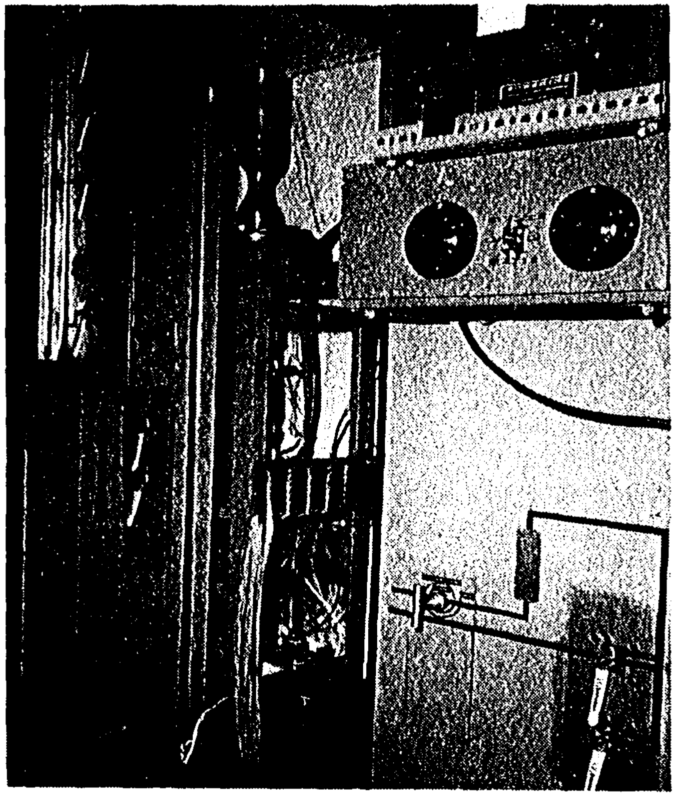


FIGURE 14.
GENERAL VIEW OF INSTALLED EQUIPMENT.

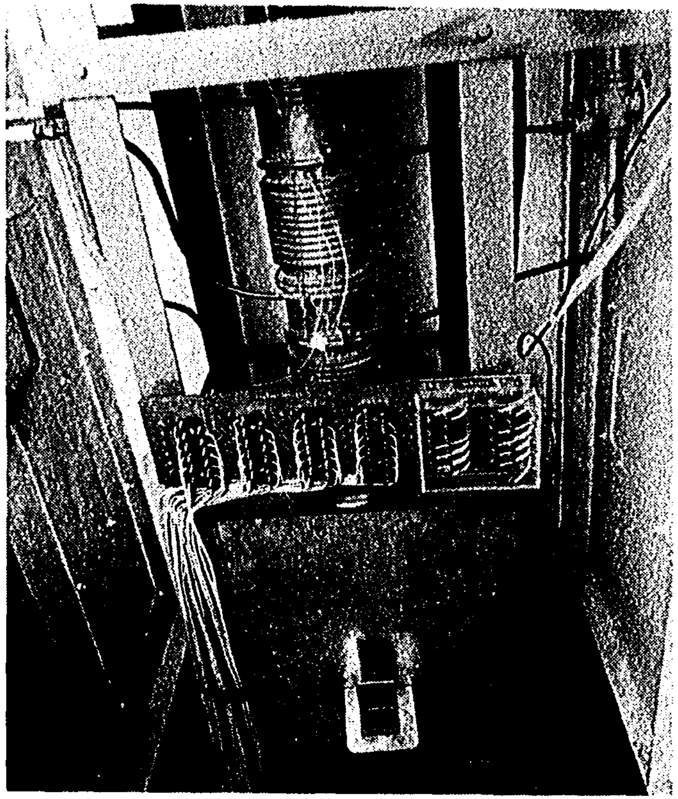


FIGURE 15.
BOILING VESSEL FRAME AND TERMINAL BOARD.

(Figure 15), which was filled with Perlite (pelletized alumina) to diminish heat losses from the boiling vessel.

Charge Vessel

A charge vessel was formed from a 12 inch length of 6 inch stainless pipe. A welding cap joined to each end of the pipe completed the container. In the same manner as the boiling vessel, the charge vessel was fitted for connections at the top and bottom (Figure 16). A "tee" configuration was installed at the bottom to allow hookup to a THY-442 Hoke bellows valve located between the charge vessel and the boiling vessel. Thick-walled (0.083 inch) 3/8 inch stainless tubing with Swagelok unions (#600-6-316) and connectors (#600-1-8-316) made the required junctions. A Jamesbury ball valve connected to the other side of the tee allowed draining of the system.

In Figure 16, note the flexible shaft leading to the bellows valve which allowed remote operation of the valve when the enclosure door was in place. Also observe the fill plug in the top of the charge vessel. A good seal was obtained by using an O-ring plug which required hand-tightening only.

Auxiliary Heaters

Auxiliary heating required to maintain the pool at saturation temperature was supplied by 5 Watlow firerods. They entered the vessel through the sheaths shown in

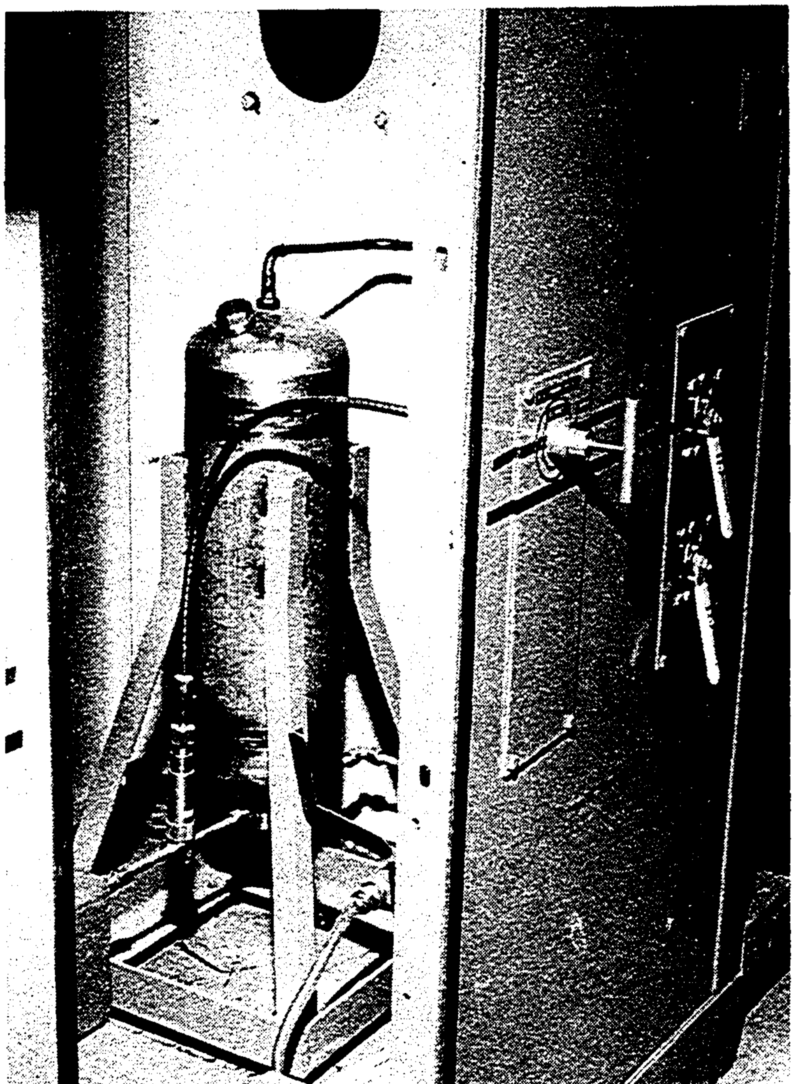


FIGURE 16. CHARGE VESSEL.

Figure 13a. The sheaths were fabricated by boring out 3/4 inch NPT Swagelok connectors (#810-1-12-316) to accommodate 316 stainless tubing (5/8 inch O.D. by 0.495 inch I.D.). Circumferential welds sealed the tubing to the Swagelok and plugged the ends of the tubes. The welding procedure caused slight inward deformation of the tube walls so it was necessary to ream them to allow entrance of the firerods. Figure 13a shows that two of the auxiliary sheaths are shorter (2.5 inches long) than the other three (3 inches long). The two short ones entered the boiling vessel on diametrically opposite sides and contained Watlow firerods with 1.5 inch heated sections (300 watt maximum). The longer ones entered through the bottom of the boiling vessel and held firerods with 2 inch heated sections (400 watt maximum). The diameter of the firerods by manufacturer's specifications was 0.495±0.002 inches. The firerods were made with inconel sheaths and nickel leads and, through their life would be shortened, they could have operated continuously at temperatures up to 1800F.

The firerods were ordered with 1/4 inch cold free ends and 1.5 inch cold lead ends. This allowed the heated sections to be entirely within the boiling vessel. The firerods filled all but the outer 1/2 inch length of the heater sheaths so asbestos stripping was packed into the void space to prevent the heaters from sliding out of the sheaths (especially the near-vertical sheaths in the bottom of the vessel). With the strong vibration experienced during mercury boiling, the packing was assuredly needed.

Thermowells and Thermocouples

In the exploded view of Figure 11, it can be seen that the wall of the vessel had to be specially prepared for welding in the small diameter stainless tubing (0.125 inch O.D. by 0.075 inch I.D.) for thermocouple wells. The small protrusion from the wall was required in order to attain even heating with the Heliarc welder. This was accomplished by making the protrusion thickness equal to the wall thickness of the tubing.

Once the weld was completed, the thermowell was reamed to allow insertion of McDanel refractory spaghetti (#2T164116). The above catalog number identifies the spaghetti as double-bore thermocouple insulation with 1/64 inch bore size and 1/16 inch outside diameter. For each thermowell, a piece of spaghetti 1/2 inch longer than the well was fitted with an uninsulated 28-gauge Chromel-Alumel thermocouple made from Hoskins thermocouple wire (#3G-178). Each thermocouple was made with leads long enough to reach terminal boards attached to the boiling vessel frame (Figure 15). Small-bore polyvinylchloride (PVC) tubing was slipped over the bare leads of each thermocouple. From the terminal boards, 20-gauge TemTex Chromel-Alumel lead wire (#TT-1-KX-20) with PVC insulation was used to lead outside the enclosure.

For airtight transition of lead wires through the enclosure wall, 1/2 inch NPT close nipples were installed in the wall and held securely by lock nuts. Leads were then passed through the nipples and sealed with General-Electric silicone rubber cement.

Two 11-position Leeds and Northrup thermocouple switches were used for selective readings of the thermocouple output. The additional instrumentation used is discussed in a later section.

Manifold System

The system was equipped to obtain data over the pressure range from about 1 mm mercury to 200 psig. This required the use of vacuum pumps for subatmospheric pressures and a helium cylinder to provide pressures above atmospheric. The vacuum pumps and helium cylinder were connected to the system through a manifold arrangement as shown in Figure 1. Proper use of the valves allowed the system or any part thereof to be adjusted to the desired pressure level. Placement of the valves on front of the enclosure (Figure 2) along with a graphical display of the flow diagram allowed pressure adjustments to be made easily and conveniently.

As previously mentioned, the transfer line connecting the fill vessel and boiling vessel was 3/8 inch diameter stainless steel tubing. The same type tubing was used for the system drain line leading to a 1/2 inch NPT Jamesbury ball valve (#AHV-36-TT). Aside from the stainless tubing used where the boiling liquid would be contacted, all other lines in the system were made from 3/8 inch diameter soft copper tubing. All junctions of the copper tubing were made by using 3/8 inch "sweat" fittings. The tubing was joined to each valve with 1/2 inch NPT copper male adapters.

Noting that each valve in Figure 1 is numbered consecutively, valves number 1 through 10 are Jamesbury ball valves identical to the one specified above. These valves contain Teflon sockets and seals which are good to 450 psia at temperatures up to 300F. Being specifically fabricated for high-vacuum service, they are good for vacuums as low as 10^{-8} Torr. Ball valves are very convenient for quick opening and closing since only 1/4 turn is required.

Valve number 11 in Figure 1 is a Hoke bellows valve (#THY-442), rated at a maximum operating pressure of 600 psia at a temperature of 1200F. With a 316 stainless body and a 347 stainless bellows which is seal-welded to the body, all wetted parts of the valve are metal. The valve was furnished with 3 inch extensions of 3/8 inch diameter 316 stainless tubing (0.065 inch walls) so the Swagelok male connector leading from the fill vessel accommodated one of the extensions. The other extension was joined by a Swagelok union (#600-6-316) to the thick-walled stainless tubing leading to the boiling vessel.

Valves number 12 and 13 are 1/4 inch Hammond needle valves. They allow fine adjustment of the system pressure (or vacuum), since ball valves are not satisfactory for adjustment purposes. Note that the outlet from valve 12 re-enters the enclosure so that emerging gases are vented to the hood from inside the enclosure.

Valves number 14 through 17 are 1/2 inch Wolverine Brass globe valves. Valve 14 was used only when it was desired to purge the enclosure with air. Valves 15, 16, and 17 were always adjusted to allow a slow but steady flow of water through the condenser coils. This was necessary to assure that the soft solder holding the coils in place would not melt during high temperature operation.

Helium flow into the system was adjusted by an Airco regulator (#806-1115) made specifically for helium service. It was supplied with Airco pressure gauges--4000 psia for the inlet side and 1000 psia for the outlet. A slow flow of nitrogen over the molybdenum rod was achieved by using a Matheson regulator supplied with Matheson gauges--3000 psia and 200 psia.

To provide rapid evacuation of the system (0.45 ft^3), two Kinney high vacuum mechanical pumps (#KC-8) were connected in parallel to the system. They were powered by a 3-phase, 1 horsepower General Electric induction motor. A conventional liquid nitrogen cold trap removed all condensible material from the evacuated gases to prevent contamination of the vacuum pump oil. Figure 17 shows the vacuum pumps, cold trap, air line, power leads, gas cylinders, etcetera.

The types of pressure gauges and vacuum gauges used are listed in Figure 1 for clarity. For pressure runs (above the capability of the mercury manometer) a 10 inch diameter 0-200 psig Marsh gauge was used. It was calibrated with an Ashcroft dead-weight gauge tester (#1300). For the calibration curve, see Appendix B. A mercury manometer was used for subatmospheric runs from 1 inch of mercury to atmospheric pressure. For 0-10 Torr pressures, a Gilmont cartesian-diver vacuum gauge (#G-1300) was used.

Power Supply

A 20 KVA Udylite rectifier (#2-IP2-10-01) supplied D-C power to the test heater. A stepless variable transformer controlled the output from 0-1000 amperes at 0-20 volts. A dual output from this rectifier is possible, 0-2000 amperes at 0-10 volts, but the former range was used for the entirety of the present investigation. A-C input to the rectifier was 230 volt, 3 phase, 60 cycles. The output is specified to have no more than 5 percent ripple. The rectifier is shown in Figure 18.

Where rigid leads were feasible in the power circuit, copper plates 4 inches wide and 1/4 inch thick were used. When flexible leads were needed, two or three strands of 0000 AWG copper cable were used. For airtight transition

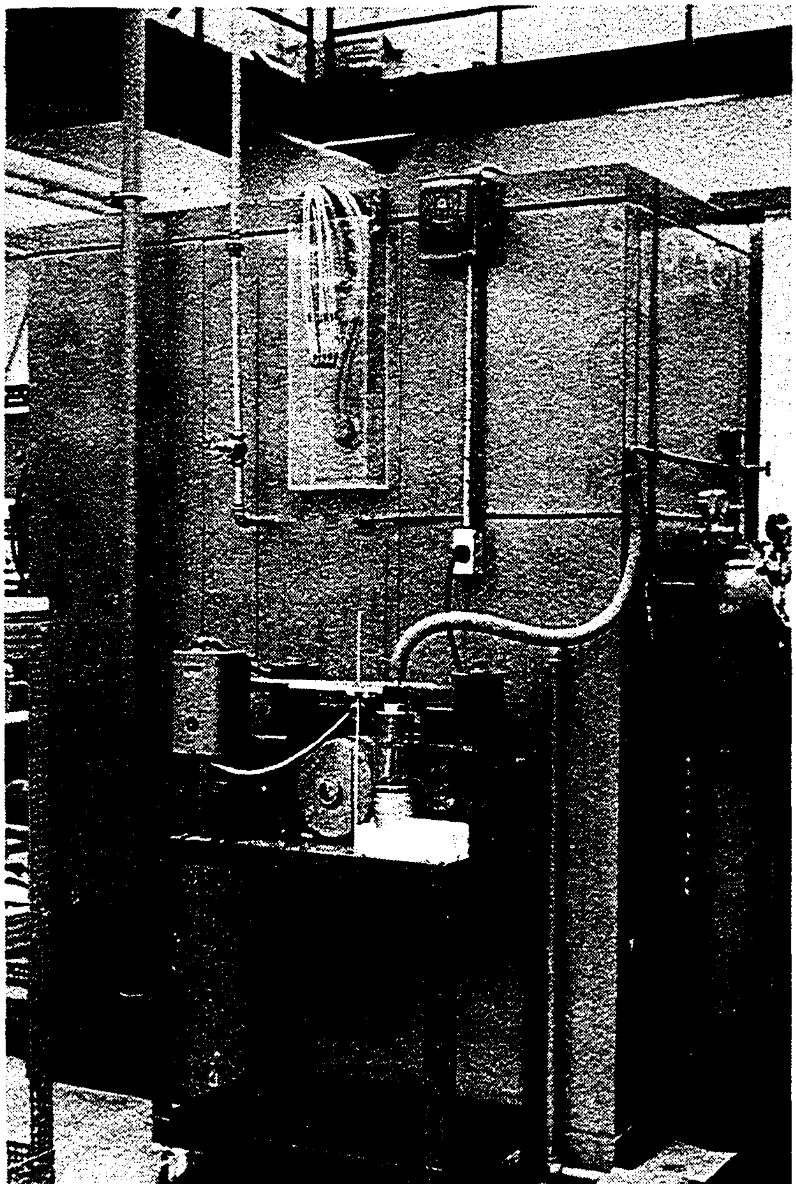


FIGURE 17. VACUUM PUMPS AND OTHER AUXILIARIES.

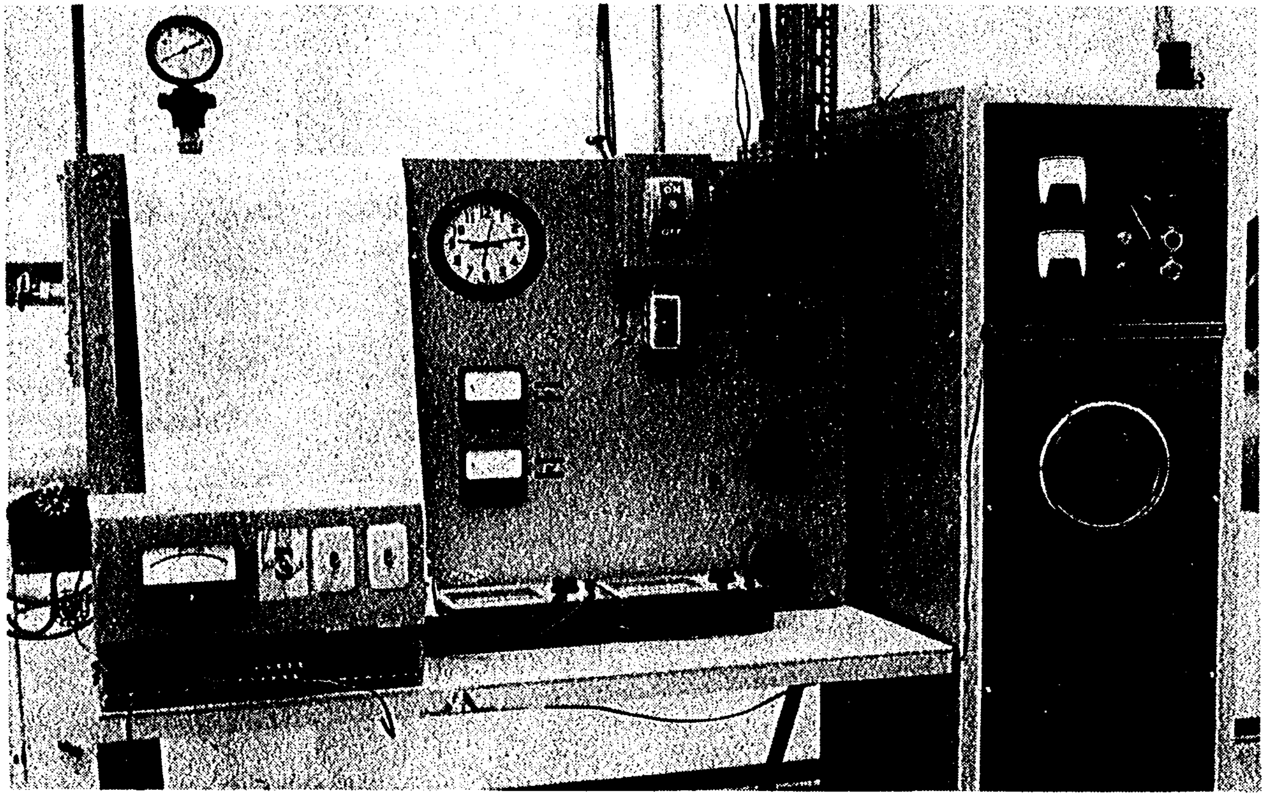


FIGURE 18. CONTROL PANEL AND RECTIFIER.

of the leads through the enclosure wall, 2 inch lengths of 2 inch diameter copper rod were potted into 2.5 inch NPT close nipples using an epoxy resin. Lock nuts held the resulting glands securely in holes made through the enclosure wall and they were sealed with General Electric silicone rubber cement. The copper rods were drilled and tapped for 1/4 inch stove bolts and using pieces of copper plate, bared ends of the copper cable were bolted to the glands (Figure 17). The lead connection at the heater is shown in Figure 8.

To protect against catastrophic failure of test heaters, a controlling pyrometer (#603-L) and control module (#905-A) by Assembly Products was wired into the rectifier cutoff to automatically turn off the rectifier when temperatures in the heater exceeded the set-point value which could be set at any desired level between 0 and 2500F. The pyrometer is shown on the left end of the bench in Figure 18. Since accurate temperature measurements could not be obtained from a heater thermocouple while it was connected to the pyrometer, a system of plugs and jacks was provided to allow the recording equipment and the pyrometer to be quickly switched back and forth to any desired thermocouple. The heater circuit and pyrometer layout is shown in Figure 19.

The rectifier had a self-contained voltmeter and an ammeter which was connected to an external 50 mv, 2000 amp shunt. For more accurate readings, a 50 mv, 800 amp shunt was used along with a calibrated Simpson multi-range D-C millivoltmeter (#1704) to measure the amperage. Voltage leads from the taps shown in Figure 9 were connected in parallel to a calibrated Simpson multi-range D-C voltmeter (#1700) and one channel of a Sanborn 6-channel recorder (#150). Though the recorder readings did not yield the accuracy afforded by the meter, the continuous voltage trace along with simultaneous thermocouple traces gave an easily discernible record of each power increase and resultant temperature increase.

Four Superior powerstats (#S649) were installed in the control panel (Figure 18) and all were wired to the terminal board inside the enclosure. Only two of these were ultimately used to power the auxiliary heaters with the remaining two being in reserve in case of failure or for easy addition of auxiliary heating for the exterior of the boiling vessel. In order to use only one voltmeter and one ammeter for monitoring input to the auxiliary heaters it was necessary to use the switching circuit shown in Figure 20. A double-throw, 2-pole switch was connected to a 0-150 volt AC Simpson voltmeter (#59). In order to switch the 0-10 ampere AC Simpson ammeter (#59) from one circuit to the other while maintaining both closed circuits, a double-throw 4-pole switch was required. Each powerstat

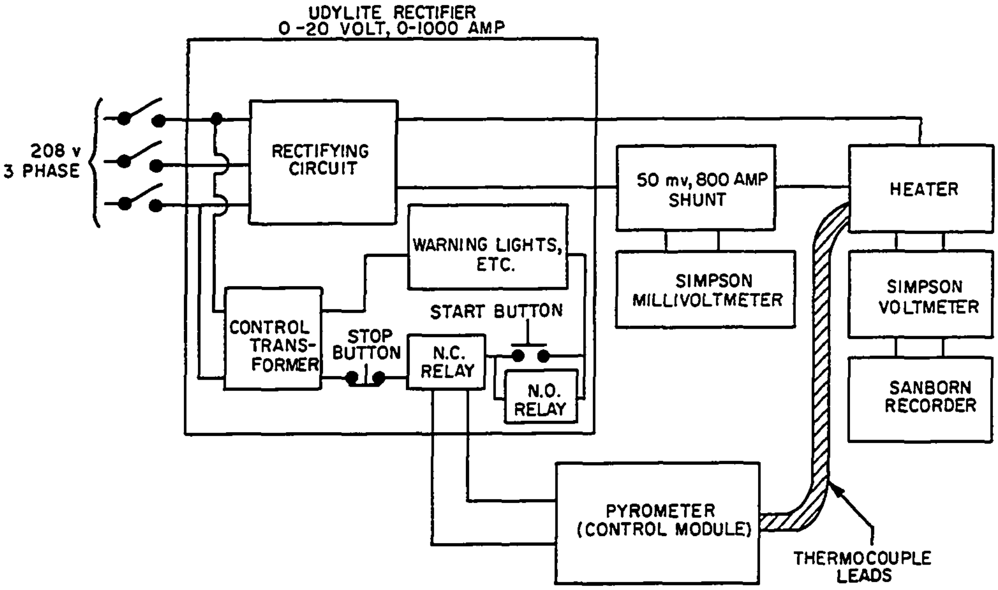


Figure 19. Test Heater Power Circuit.

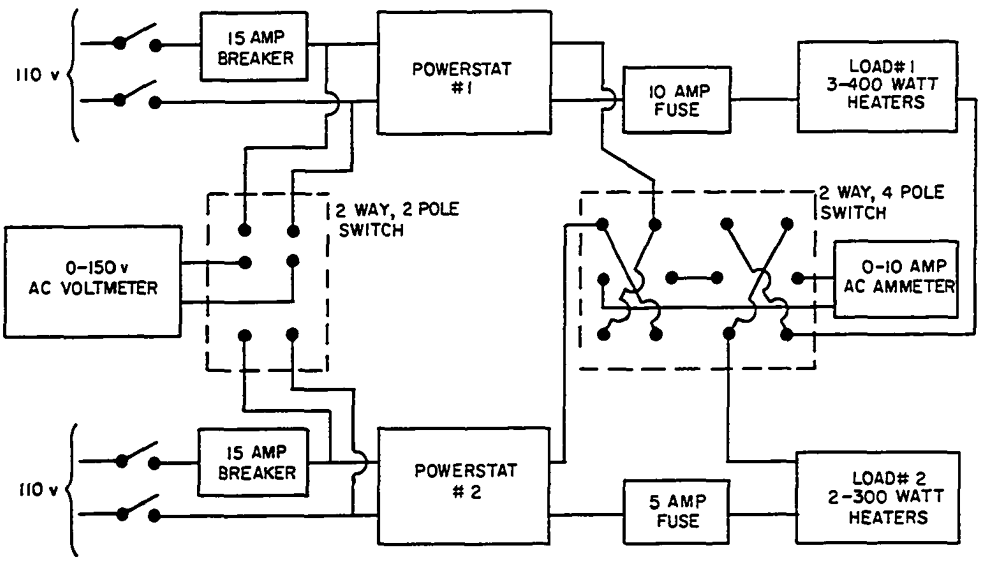


Figure 20. Auxiliary Heating Circuits.

output was fused for its maximum operating amperage and the input to each powerstat contained a 15 amp breaker.

Instrumentation

As previously mentioned, two 11-position Leeds and Northrup thermocouple switches were used to obtain selective readings. For added convenience, a 3-way double-pole switch was employed so that signals from each thermocouple could be relayed to a Hewlett-Packard digital voltmeter (#3460A) without changing leads (Figure 21).

For monitoring pool and vapor temperatures, a Leeds and Northrup Speedomax W 12-point recorder was connected to the top 4 thermocouples in the pool (for an 8.5 inch liquid level) and 8 others located in the vapor space above the boiling pool. With these twelve thermocouples being monitored point-wise at 6 second intervals, each individual output was recorded every 72 seconds. Though this recorder was not run continuously, its sporadic use gave a quick and definitive check of the pool depth and pool temperature uniformity (see Chapter III).

Thermocouples (number 19, 20, 21, and 22) from test heaters were connected to the pyrometer, oscillographic recorder, and 6-channel recorder, respectively. A Hewlett-Packard direct writing oscillographic recorder (#7701A) with a high gain DC amplifier (#8803A) had variable range and zero suppression. These characteristics along with exceptionally fast response (20 milliseconds for 10-90

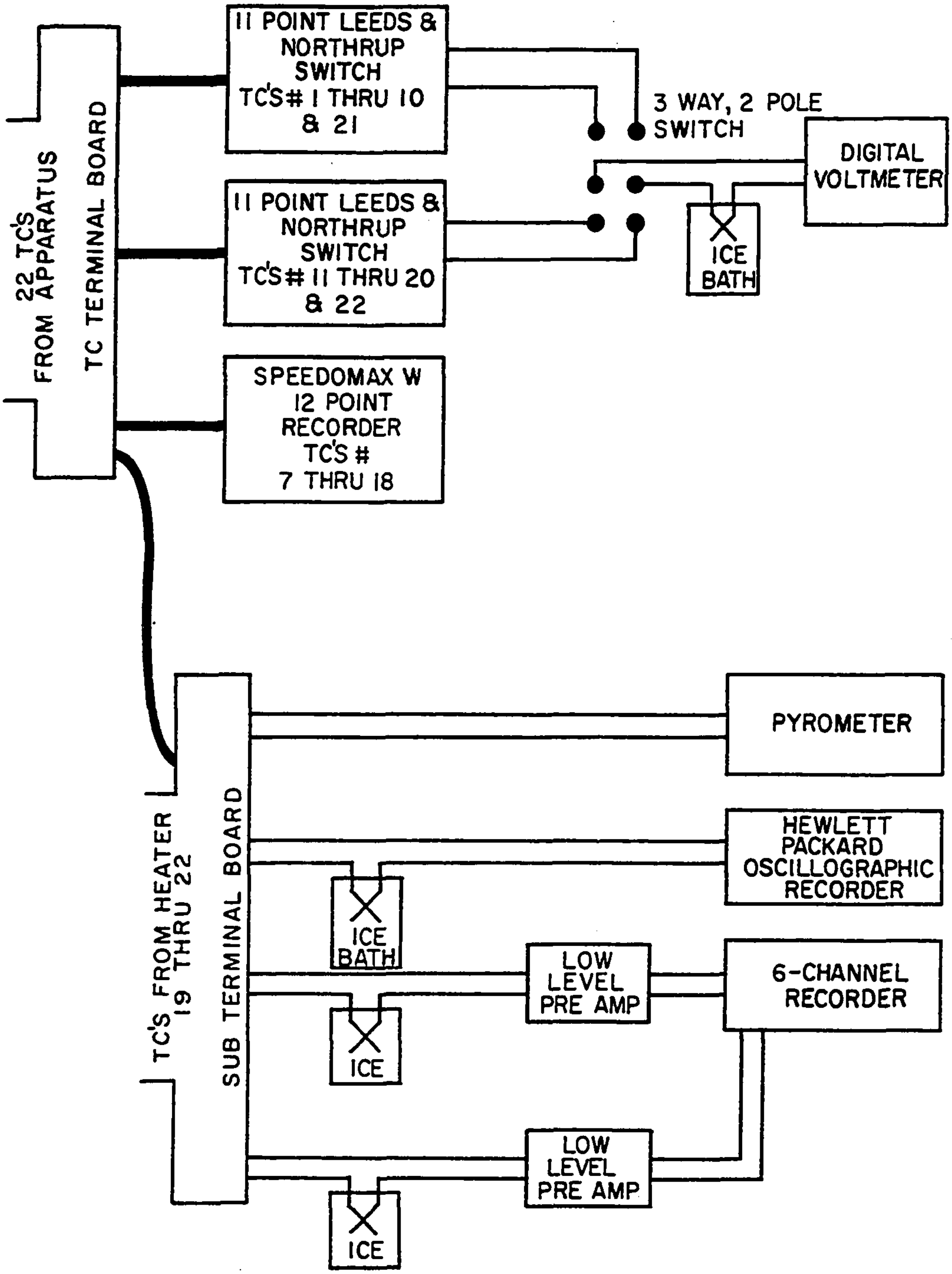


FIGURE 21. THERMOCOUPLE CIRCUITRY.

percent square wave input) gave this equipment excellent capability for recording rapid surface temperature fluctuations experienced during boiling heat transfer.

By using Sanborn low-level preamplifiers (#350-1500), additional thermocouple outputs were recorded on the Sanborn recorder (#150) which also recorded the voltage drop across the heater. The extra channels of the Sanborn recorder were not used. All recorders and the digital voltmeter are shown in Figure 2.

CHAPTER III

EXPERIMENTAL PROCEDURES

Preliminary Preparation

All instrumentation was checked for operability and calibrated where possible before incorporating it into the experimental system. The various calibrations are discussed in Appendix B.

Each piece of the equipment: boiling vessel, fill vessel, condenser, etc., was thoroughly cleaned with dichloroethylene prior to installation, to remove any oil or grease films present. After installation, the entire system was vacuum checked for leaks as previously described. In addition, the system was pressured to 200 psig and found to hold nicely at this level.

To refine the operating procedure and acquaint the operator with the system, 16 experimental runs were made with water. Though no subatmospheric runs were made, nucleate boiling runs were made at pressures up to 200 psig and heat fluxes up to 790,000 Btu/hr-ft^2. Water used for the tests was distilled and deionized. It was dumped from the system and replaced with fresh water 5 times during the

16 runs, so that dissolved impurities would be flushed from the system. The operational procedure thus developed was found to be satisfactory for boiling mercury runs and is fully discussed later in this chapter.

To prepare the system for charging mercury to it, the drain valve (#10 in Figure 1) was opened to drain water from the system and left open after the water had stopped flowing. Helium was then purged through the system to carry out additional water droplets and dry the system. When visible moisture had ceased leaving the system, the drain valve was closed and the vacuum pumps were turned on. Auxiliary heating was used to heat the system to about 500F while the vacuum pumps continued evacuating the system. Condensed moisture collected and froze in the liquid nitrogen cold trap and had to be removed twice when the trap became clogged with ice. After a few hours, no further collection of water occurred and the system was allowed to cool after being filled with helium to maintain a slight positive pressure.

Each time the system had been filled with water, a one-gallon quantity was sufficient to give a 10 inch liquid level in the boiling vessel. Since the test heater location was at the 3.5 inch level and the upper auxiliary heaters at the 5 inch level, it was decided to charge 100 lb of mercury (0.887 gallon) to the system which resulted in an 8.5 inch liquid level. The charge vessel was closed off from the rest of the system by closing appropriate valves. Eight 12.5 lb polyethylene bottles of mercury were then poured into the fill vessel. After replacing the fill plug, the charge vessel was evacuated and repressurized with helium.

Mercury was transferred to the boiling vessel by evacuating it and opening the Hoke valve. When gurgling and bumping in the transfer line evidenced complete transfer of the mercury, the Hoke valve was closed. Pressure fluctuations shown by the manometer also gave a good indication of complete transfer of the liquid. Transferral could also have been achieved by pressurizing the fill vessel sufficiently to force mercury into the boiling vessel.

Reverse transfer from the boiling vessel to the charge vessel was likewise accomplished by evacuating the charge vessel and opening the Hoke valve. This procedure was only required when it was desired to change heaters or change the liquid level. The mercury remained in the boiling vessel between runs except when one of the above changes was made.

Experimental Procedure

To begin a run, the auxiliary heaters were turned on to begin heating the pool. They were initially turned to about 70 volts which corresponded to 670 watts total input to the pool. At this setting, the flux level in each heater was 19,000 Btu/hr-ft^2. During mercury runs, the auxiliary heaters were never operated above this level to prevent burning them out since the sheaths were not treated to be wetted by mercury. As the pool temperature approached saturation, voltage on the auxiliary heaters was gradually decreased to about 50 volts which corresponded to a flux level slightly above 10,000 Btu/hr-ft^2.

While the pool was heating up, the water control valves were adjusted to allow a slow but steady flow of cooling water through the condenser coils. A thermos bottle used for immersing reference junction thermocouples was filled with crushed ice and water. All instrumentation was turned on to allow warm-up before taking readings. Barometric pressure and ambient temperature were recorded during this time.

System pressure was always initially set above the operating pressure to allow the pool temperature to exceed the desired saturation value. The pressure was then dropped to the desired level with the resulting boil-off assuring saturated conditions. At this point, the liquid level was determined by taking thermocouple readings along the entire depth of the boiling vessel and condenser. For an estimate of the liquid level, the readout of the 12-point recorder was quite convenient for detecting which thermocouple was the first to deviate from the high temperature present in the pool. For a more accurate determination, individual readings could be plotted as in Figure 22. For mercury boiling at high fluxes, such precise plots were not obtained since considerable superheating existed in the vicinity of the test heater (see Chapter IV).

Once all preliminary thermocouple readings were made, the system pressure was again checked (and adjusted if needed, as it was after each power increase) before turning on the rectifier. Power to the test heater was increased incrementally with the following information being recorded: overall voltage drop, test heater voltage, amperage, heater thermocouple readings, and liquid thermocouple readings. At low flux levels, very short times were required for the system to reach steady state after a power increase; at high levels, longer times were required as shown by the continuous heater thermocouple traces. In each case, sufficient time for steady state was allowed before taking the above readings. At intermediate flux levels, the pool temperature was again recorded along its entire depth.

An overall voltage drop was recorded from the voltmeter on the rectifier. Heater voltage was measured across the taps located on the heater sheath and molybdenum rod. Bulk liquid temperature was obtained from the topmost thermocouple in the liquid.

To obtain maximum information from each run, and to detect any "aging" of the surface during high flux

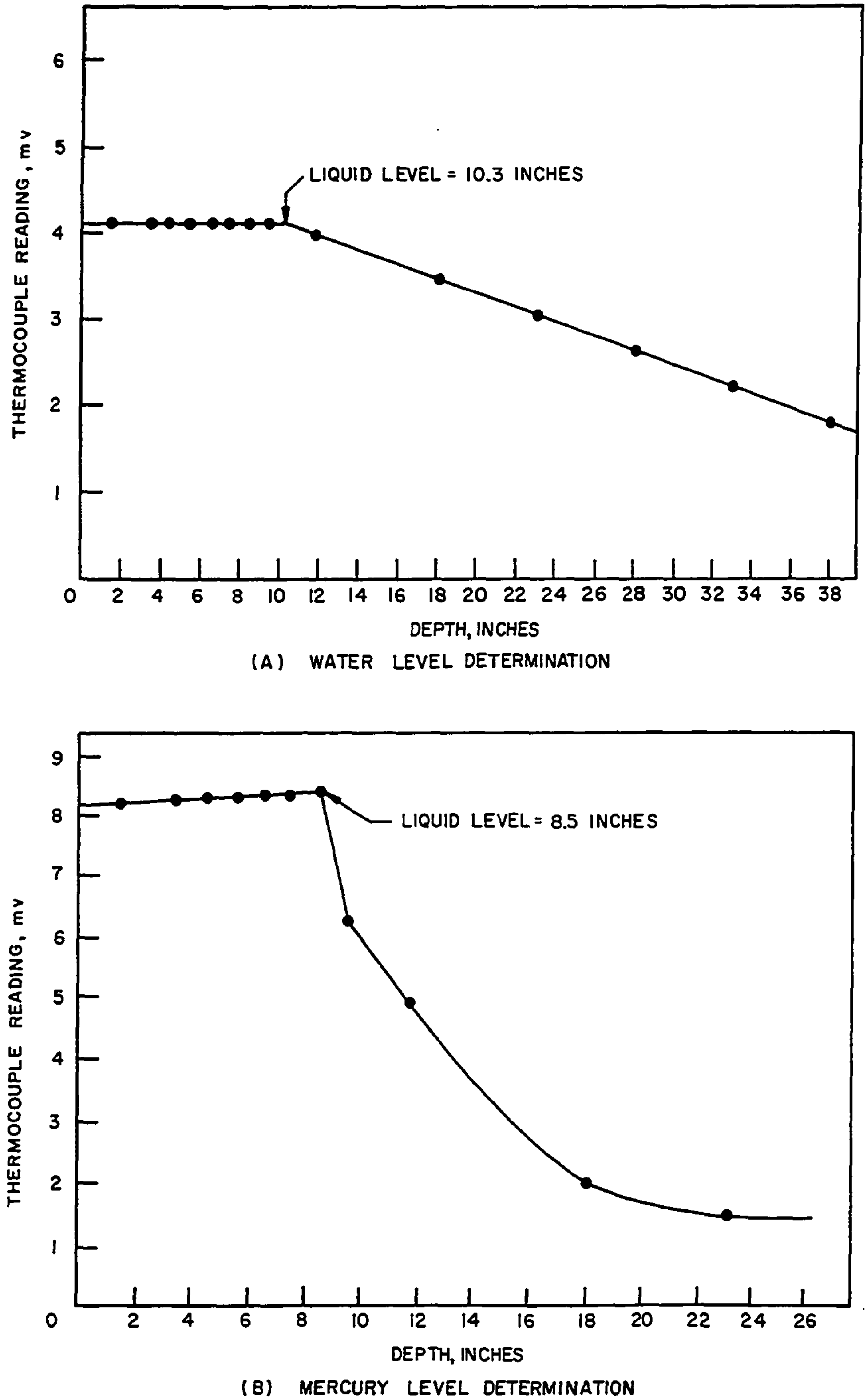


Figure 22. Pool Depth Determinations.

operation, the power level was adjusted stepwise upward until it was felt that burnout was imminent or until the temperature exceeded the pyrometer set-point which would turn off the rectifier automatically. The power was then adjusted stepwise downward with pertinent information being recorded at each level. In case of pyrometer cut-off, the rectifier powerstat was turned down slightly and the rectifier was reactivated to accomplish the downward cycle.

With the peculiar behavior observed for boiling mercury, a clearly defined burnout point was not observed. However, a change in nucleate boiling behavior was easily detectable in the heater thermocouple traces (see Chapter IV).

Though only constant pressure boiling curve determinations were made for mercury, the "decreasing pressure" method of burnout determination used by Noyes (95) and Colver (33) was employed successfully to obtain 5 burnout values for water at various pressures. In addition, 15 burnout determinations were made for water at 6 different pressures using the increasing flux approach.

A computer program was written for the IBM 360 model 40 computer facility at the University. Data reduction was accomplished rapidly and accurately with this program. Details of the data reduction are given in Appendix C.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The experimental procedures described in the preceding chapter were used to obtain nucleate boiling water data, water burnout data, and mercury boiling curves. Plots and tables of the data are presented in Appendix D. Since the test heater assembling procedure was continuously revised and refined throughout the experimental program, the data are grouped in tables according to the test heaters and pool depths which were utilized. Test Heaters A and B were used only for boiling water, while Test Heaters 1 and 2 were used solely for obtaining mercury data.

Tabular information in Appendix D includes the following measurements: system pressure, pool depth above the heater, heat flux, measured heater temperatures, extrapolated surface temperatures, bulk temperature, and the driving-force temperature difference, ΔT. The bulk temperature was taken to be the temperature measured by the topmost thermocouple located in the boiling pool, i.e., very nearly the free surface temperature. Errors involved in the bulk temperature measurement will be fully discussed later in this chapter. Estimates of possible errors involved in the rest of the above measurements are presented in Appendix E along with a discussion of heat losses and their effect on the data.

Water Data

A preliminary study of water was performed to improve and finalize the test heater design as presented in Chapter II. The water study was also carried out for the purpose of relating results from the present experimental system to existing data. Various problems arose which had to be solved before the primary study of boiling mercury could be undertaken. Interfacial thermal resistance between the copper cylinder and stainless steel sheath was encountered. This resistance was eliminated by soldering the thermocouples in place and filling the interfacial cavity with low-melting solder or liquid-metal alloy. Electrical contact resistance between the molybdenum plunger rod and the graphite heating element was alleviated by plating the molybdenum.

Nucleate Boiling

Runs made with Test Heaters A and B which gave obviously erroneous surface temperature measurements, are not reported in Appendix D. Test Heater B was dismantled and reassembled three separate times in efforts to obtain representative data. Upon proper refinement of the heater assembling procedure, Runs 7, 8, and 9 were made. As shown in Figure 23, these runs compared favorably with other investigations using tube heaters and horizontal plate heaters.

It should be noted that the second transition region (marked by a change in slope of the boiling curve) observed by Gaertner (48) was not observed in the present water study. However, the maximum nucleate boiling fluxes (burnout) obtained at atmospheric pressure were in the flux range that Gaertner found the transition to occur, i.e., near 200,000 Btu/hr-ft^2, as shown in Figure 23. Gaertner stated that this behavior is to be expected for boiling on wires, small tubes, and thin strips.

In each water run made, it was observed that D-C current passing through metal in contact with the heater thermocouples created an induced EMF in the thermocouple signals. Such induced EMF's were measured according to the procedure described in Appendix E, and the necessary corrections in thermocouple readings were made.

With the sensitive recording equipment used for this study, the rapid temperature fluctuations which accompany nucleate boiling could be observed. Typical examples of these fluctuations at various flux levels are shown in Figures 24a, 24b, and 24c.

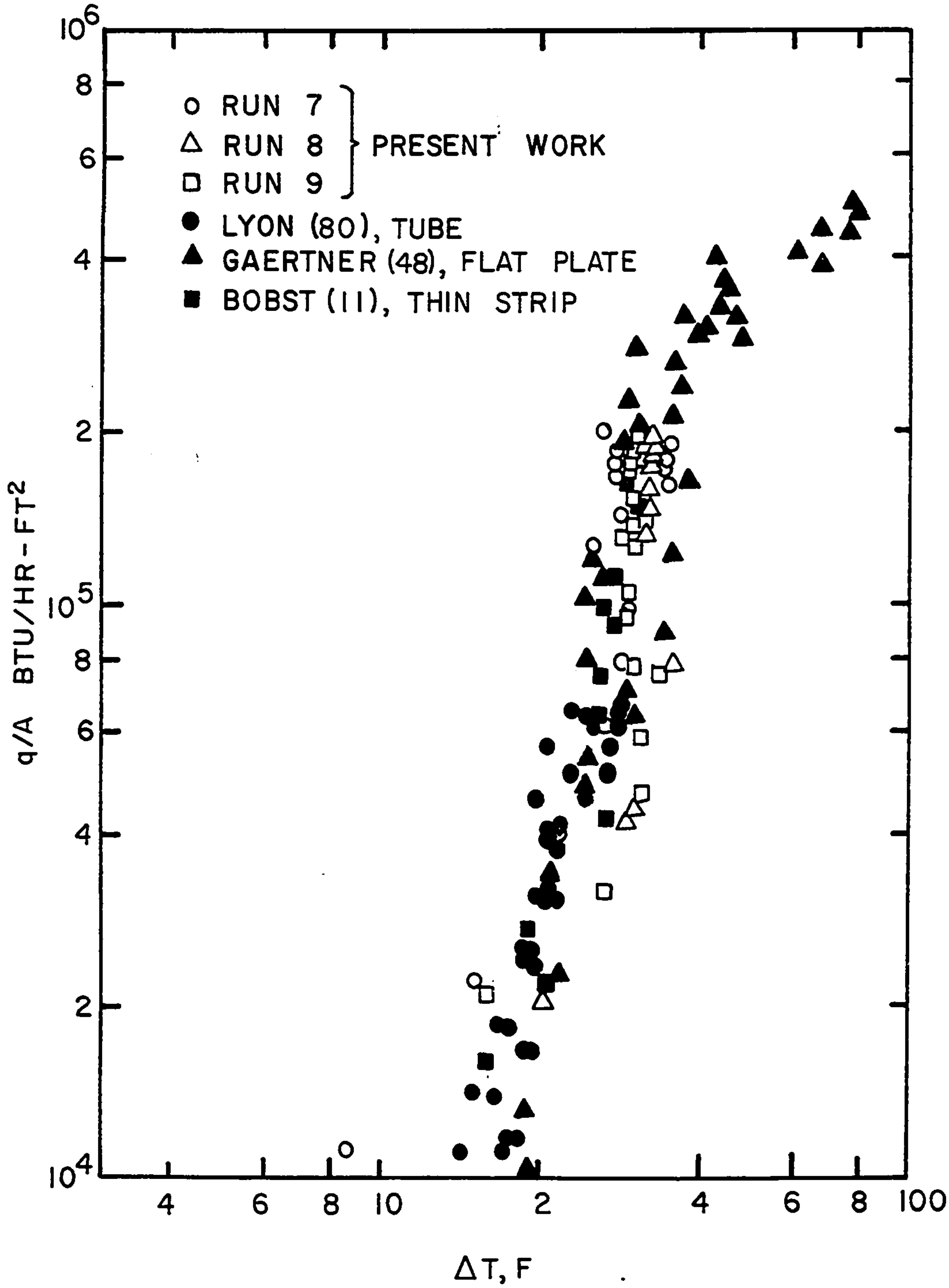


FIGURE 23. ATMOSPHERIC NUCLEATE BOILING WATER DATA COMPARED TO PREVIOUS STUDIES.

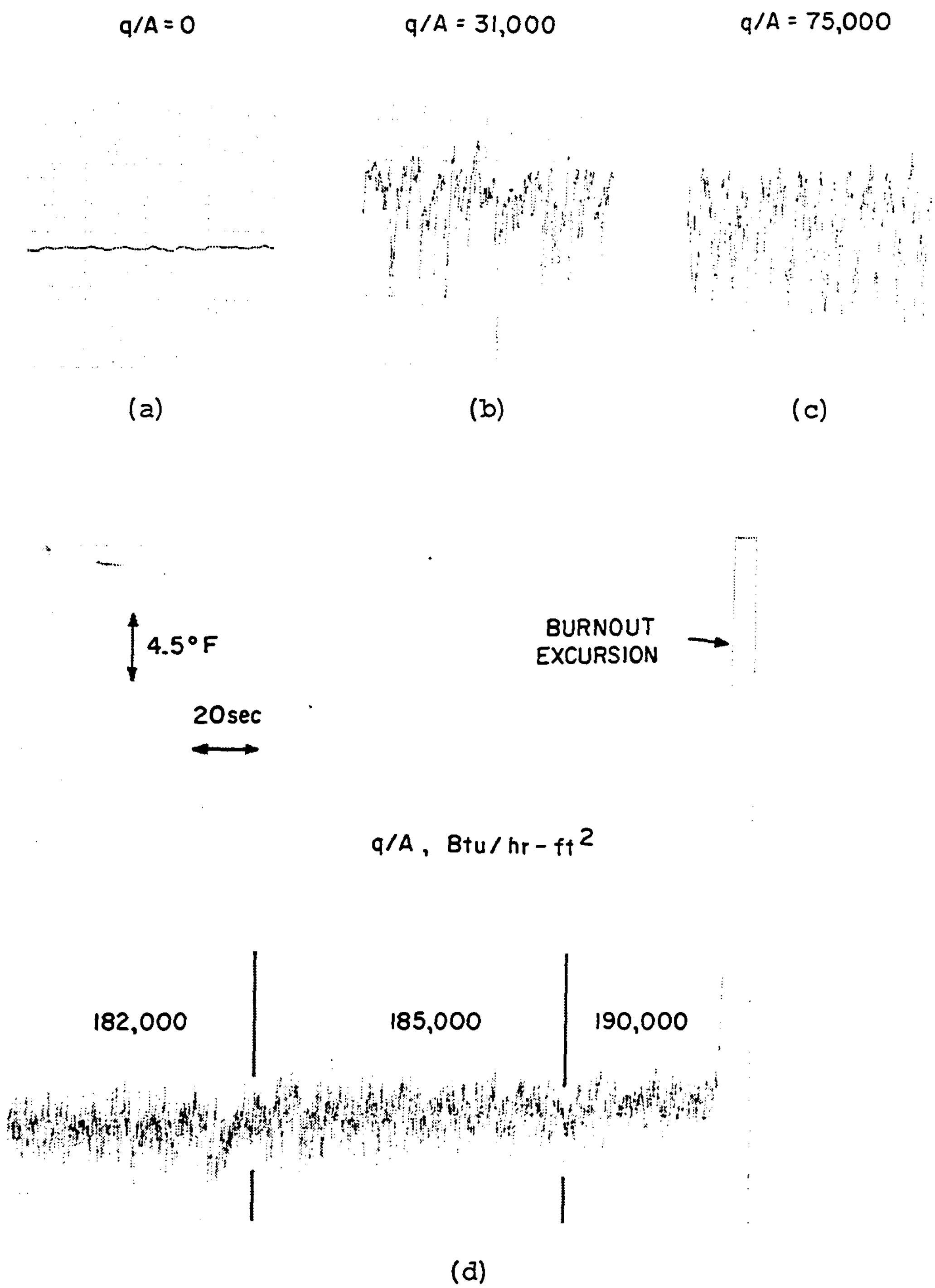


Figure 24. Test Heater Temperature Fluctuations and a Burnout Excursion for Pool Boiling Water.

Burnout

In each nucleate boiling run, the flux level was increased incrementally until a large instantaneous temperature rise in the heater indicated burnout. A typical thermocouple trace showing such a large temperature excursion is shown in Figure 24d.

Two runs were conducted with Test Heater A before installing the pyrometer cut-off in the system. Power to the heater was turned off manually at the termination of the first run before the heater was damaged. The rapid temperature rise at burnout during the second run caused the heater to fail. Before power to the heater could be turned off, the copper cylinder in the heater became molten and metal flowed around the graphite heating element causing a short circuit. To prevent reoccurrence of the above failure, no runs were made with Test Heater B until the pyrometer had been installed.

Although erroneous surface temperature readings were obtained in many of the nucleate boiling water runs, this did not affect the validity of recorded burnout values. In addition to the burnout determinations made during each nucleate boiling run, 5 burnouts were obtained by setting a constant flux and gradually decreasing the system pressure until burnout ensued. For these determinations, the pyrometer cut off the rectifier at the onset of burnout. Thus, the operator's attention could be directed to regulating the decrease in system pressure and recording the pressure level at which burnout occurred. No heater temperatures were recorded during these determinations.

Water burnout data ranged from about 200,000 Btu/hr-ft^2 at atmospheric pressure to 790,000 Btu/hr-ft^2 at 200 psig. All water burnout data are shown in Figure 25, along with the water data of Howell and Bell (58), Bobst (11), and Caswell and Balzhiser (26). Howell and Bell obtained their data from a thin strip heater, as did Bobst. Caswell and Balzhiser used a horizontal cylindrical heater similar to that used in this study. Included in Figure 25 are the correlations of Zuber and Tribus (129) and Rohsenow and Griffith (104).

Note how well the data of Howell and Bell agree with the present study. Although Caswell's data are at much higher fluxes for atmospheric pressure, it can be seen in Figure 25 that his data more nearly agree with the present study for higher pressures since a steeper slope is exhibited by the data of the present study.

It should be noted that significant electrical contact resistance existed at the ends of the graphite heating element during some runs. This resistance at times ranged as high as 20 percent of that calculated for the graphite, but it was felt that the copper cylinder in the heater dissipated the heat generation so that local fluxes at the heater ends did not exceed the average flux by an excessive

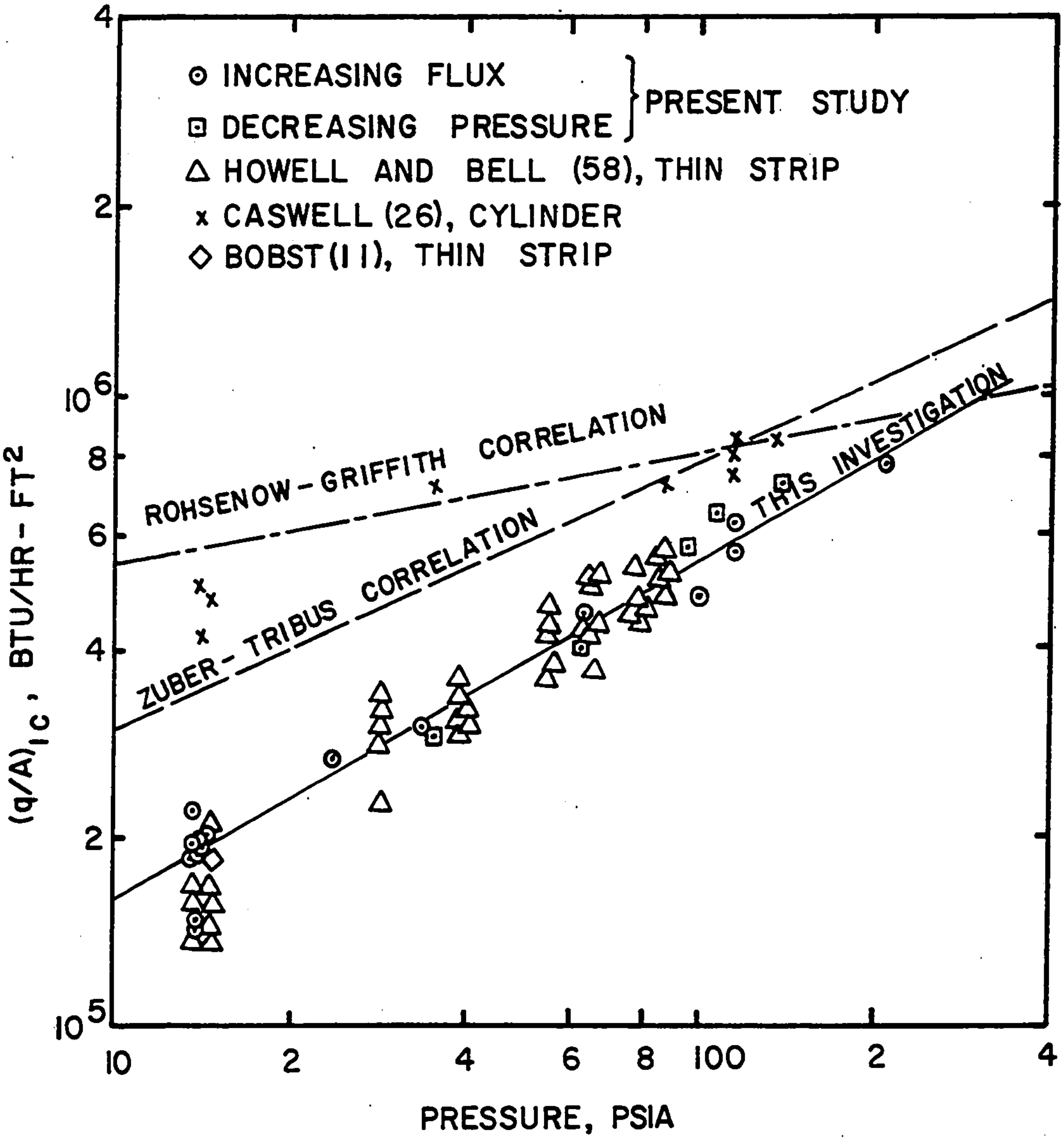


Figure 25. Water Burnout Data Compared to Previous Studies.

amount. The consistent trend of burnout flux versus pressure shown in Figure 25 suggests that burnout determinations were not appreciably affected.

On removing Test Heater B from the system, the boiling surface was discolored at the end near the Swagelok fitting. This further indicated a disproportionate amount of heat generation at the molybdenum-graphite interface. Before installing Test Heater 1 for the mercury study, the molybdenum was plated as discussed in Chapter II. No further difficulty of this type was encountered.

Mercury Data

Test Heaters 1 and 2 were assembled according to procedures developed during the water investigation and described in Chapter II. Test Heater 1 was used to make 33 runs and obtain boiling curves at system pressures ranging from 1 to 1,143 mm mercury (45 inches mercury). Fourteen additional runs were made with Test Heater 2 over a comparable pressure range. As previously mentioned, plots and tables of the data from all individual runs are included in Appendix D and will be referred to from time to time. Flux levels extended to 1,100,000 Btu/hr-ft^2 when operating with the greatest liquid pool depth (8.5 inches above the heater) at a system pressure of 5 mm mercury.

Nucleate Boiling

Runs 1 through 6, shown in Figures D-1 through D-6 of Appendix D, exhibited considerable hysteresis and lacked the consistency observed in subsequent runs. Specific behavior encountered in these runs will be discussed later in this chapter, as undoubtedly, the surface of Test Heater 1 was not yet fully conditioned to boiling mercury. The present discussion will then be restricted to runs which gave representative data for a conditioned surface.

Runs 7 through 27, made with Test Heater 1, are summarized in Figure 26. These runs were made with an 8.5 inch liquid depth in the boiling vessel. Since the test heater was located 3.5 inches from the bottom of the pool, this corresponded to a 5 inch liquid level above the heater.

Runs 28 through 33 were made with the liquid level 2 inches above the heater. Boiling curves for these runs are summarized in Figure 27.

Figure 28 shows the results of Runs 34 through 41 made with a 5 inch liquid level above Test Heater 2.

After adding 47 pounds of mercury to the 100 pounds previously charged to the system, Runs 42 through 47 were made with an 8.5 inch liquid level above the heater. These runs are shown in Figure 29.

In each of the Figures 26, 27, 28, and 29, smooth curves are presented to best reflect the average trend of each boiling curve. That is, for normal runs, the boiling

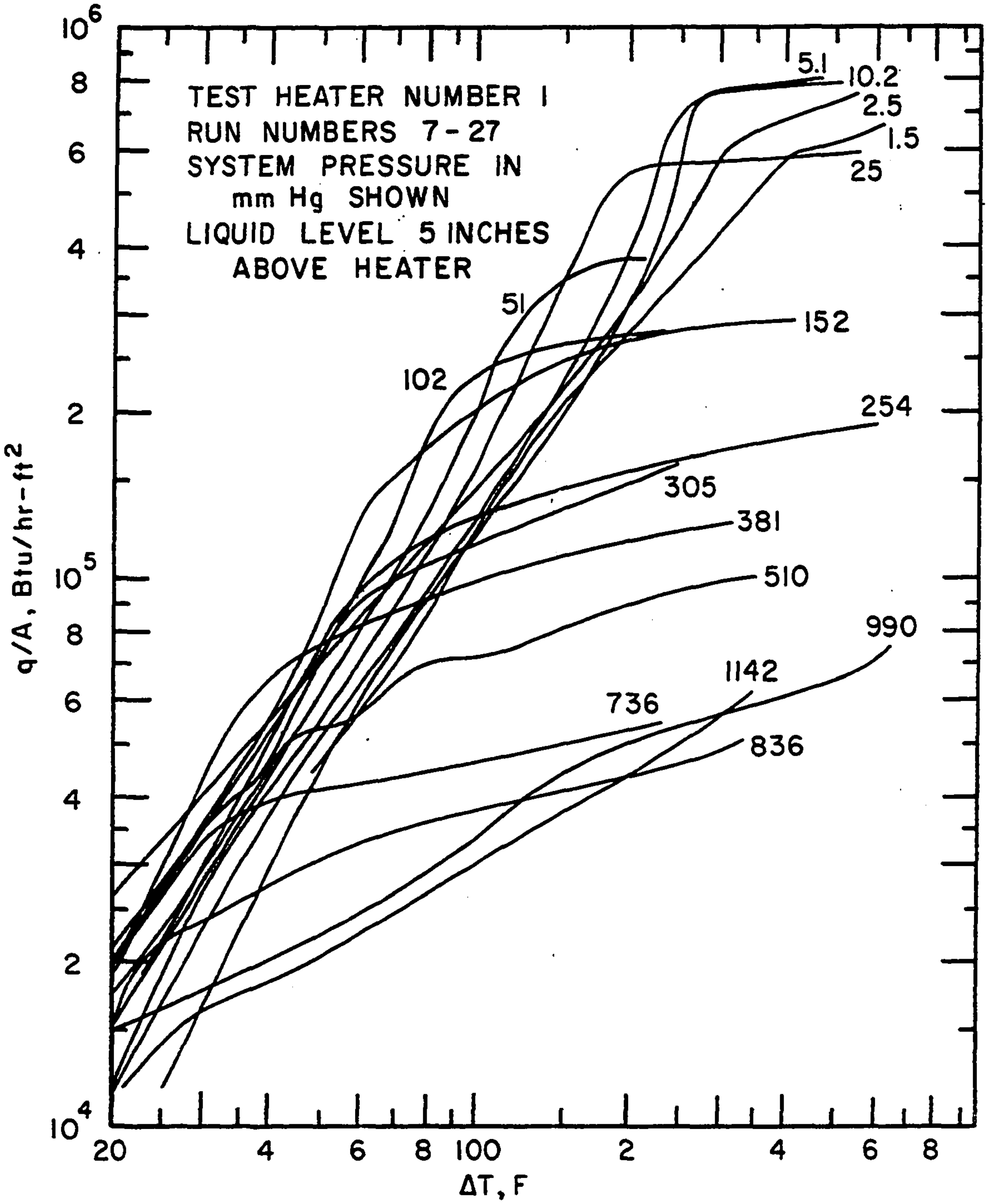


Figure 26. Plot of Mercury Results for a 5 Inch Liquid Depth Above Test Heater 1.

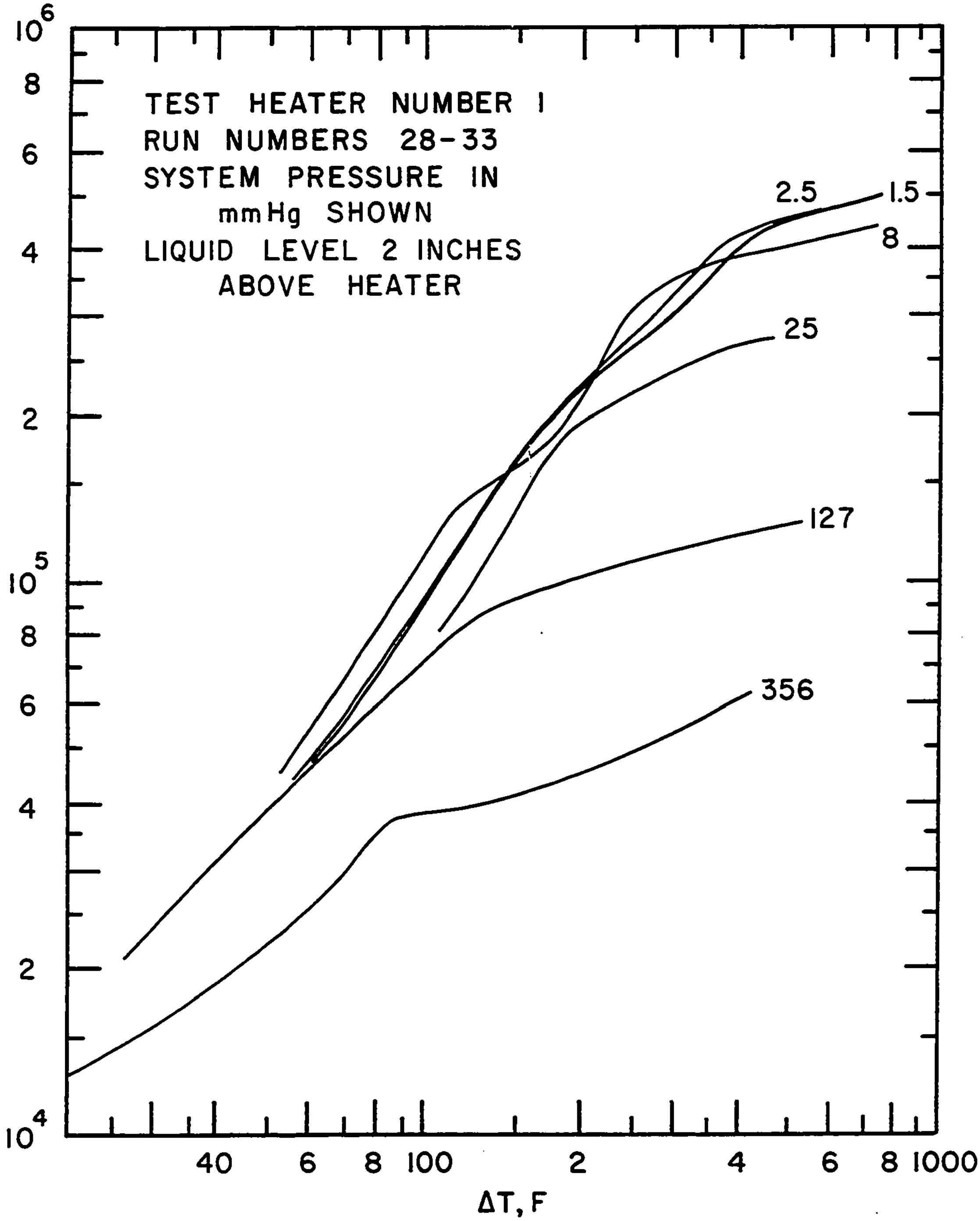


Figure 27. Plot of Mercury Results for a 2 Inch Liquid Depth Above Test Heater 1.

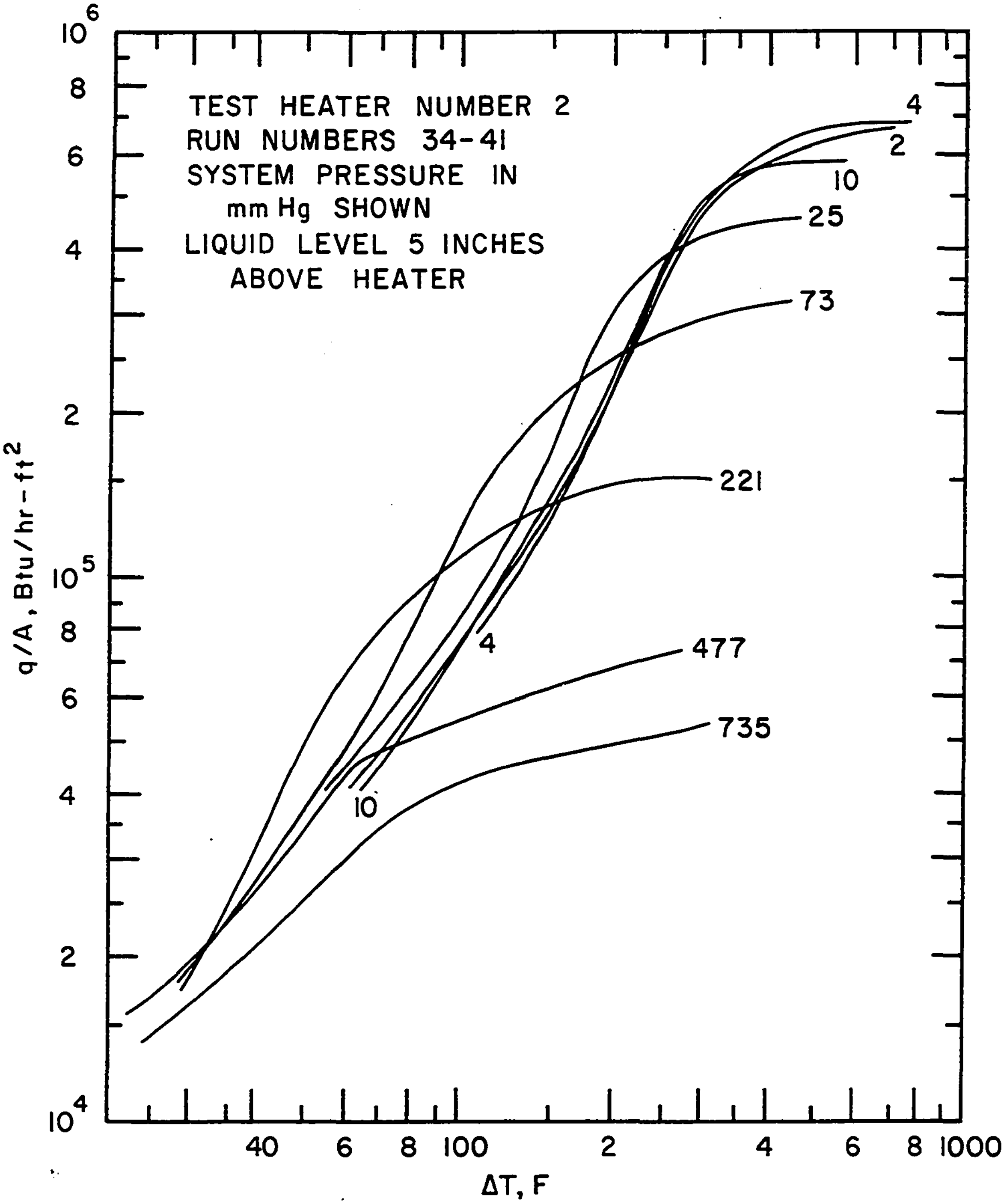


Figure 28. Plot of Mercury Results for a 5 Inch Liquid Depth Above Test Heater 2.

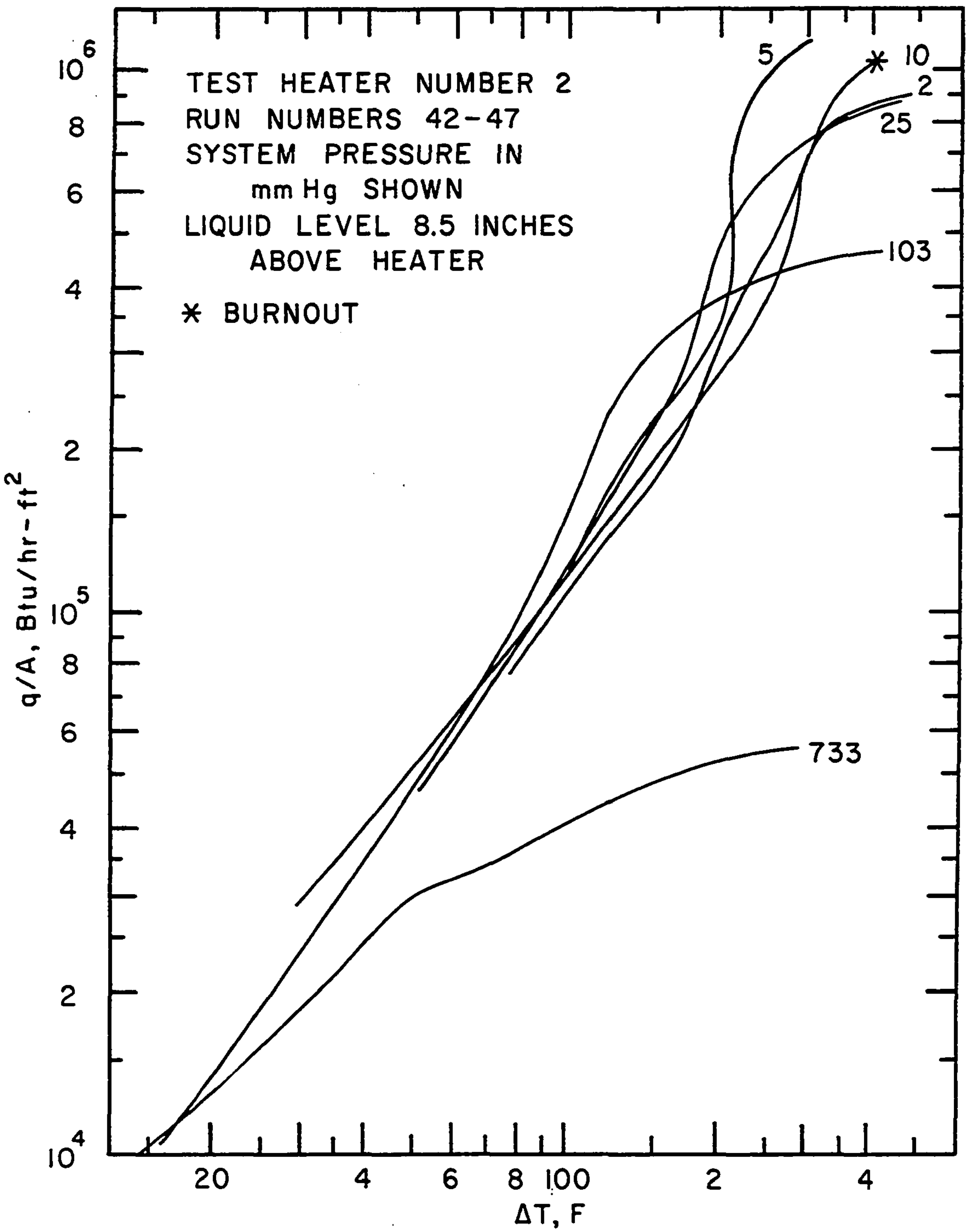


Figure 29. Plot of Mercury Results for an 8.5 Inch Liquid Depth Above Test Heater 2.

curves obtained in the upward and downward cycles were averaged. A normal run consisted of an upward cycle of incremental changes in heat flux until limiting ΔT's were reached, followed by decremental changes in flux to give a boiling curve for the downward cycle.

Note that each set of runs in Figures 26, 27, 28, and 29 forms a homologous group of curves. Moreover, it is readily seen in the figures that in each run, a flux level was reached where the slope of the boiling curve decreased markedly. This point of transition or departure, herein termed "departure flux," is of particular interest and will be discussed in a later section.

Reproducibility.--Considering the scatter usually observed in liquid metal boiling studies, it was felt that exceptional reproducibility was attained in this study. Composite plots of the data shown in Figures 26, 27, 28, and 29 give an initial indication of the consistency and, therefore, reproducibility of the data. For additional comparison, Runs 10, 17, and 38 are shown in Figure 30. Recall that Runs 10 and 17 were made with Test Heater 1 and Run 38 with Test Heater 2. Figure 30 shows that exceptional reproducibility was obtained for Test Heater 1. Note that observed ΔT's in Runs 10 and 17 were very close while the surface had aged slightly more to give a higher departure flux in Run 17.

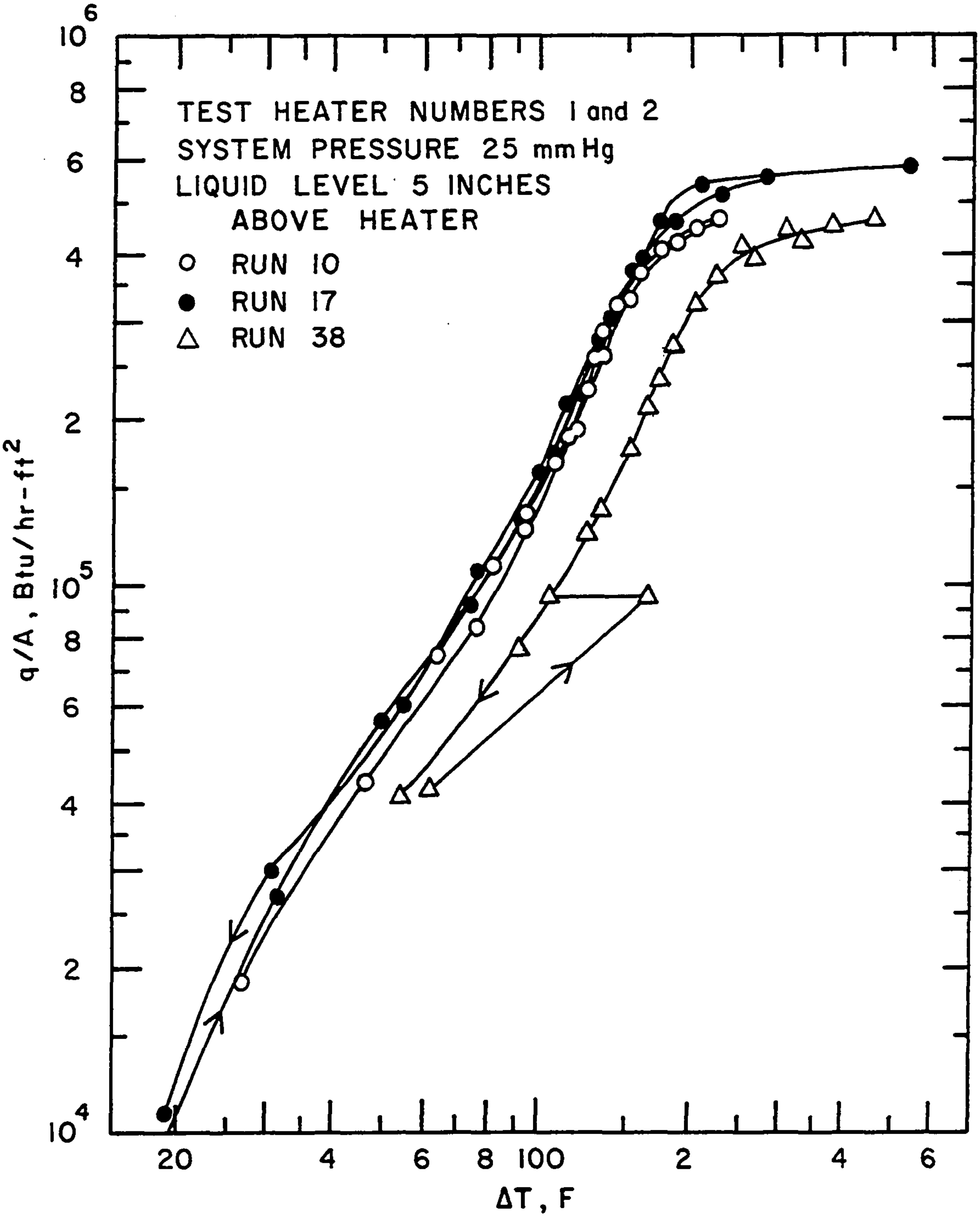


Figure 30. Reproducibility of Mercury Results.

Considering the difference in treatment of the two heater surfaces, Run 38 shows very good agreement with the runs made with Test Heater 1.

It can also be seen in Figure 30 that very close agreement was shown for the increasing and decreasing flux cycles. This will be further discussed in a later section concerning hysteresis.

Induced EMF.--Initially, small induced EMF's were observed in the heater thermocouple signals. These were measured and the necessary corrections made as discussed in Appendix E. After a few runs, no induced EMF was observed. This was taken to mean that the free end of the heater achieved good electrical contact with the mercury pool so that the pool carried a major portion of the current. Comparing the overall voltage drop and heater voltages observed in both the water and mercury studies, it was concluded that negligible power dissipation occurred in the mercury pool.

Effects of surface aging.--The heater surface became conditioned to boiling mercury during Runs 1 through 6. In Run 4, the ΔT increased to about 400 degrees F and suddenly dropped to less than 70 degrees at a constant flux level as shown in Figure 31. This marked decrease in ΔT was a definite sign that nucleation had begun. The same behavior was observed during Run 5, shown in Figure D-5 of Appendix D, but this drastic temperature drop was not observed in

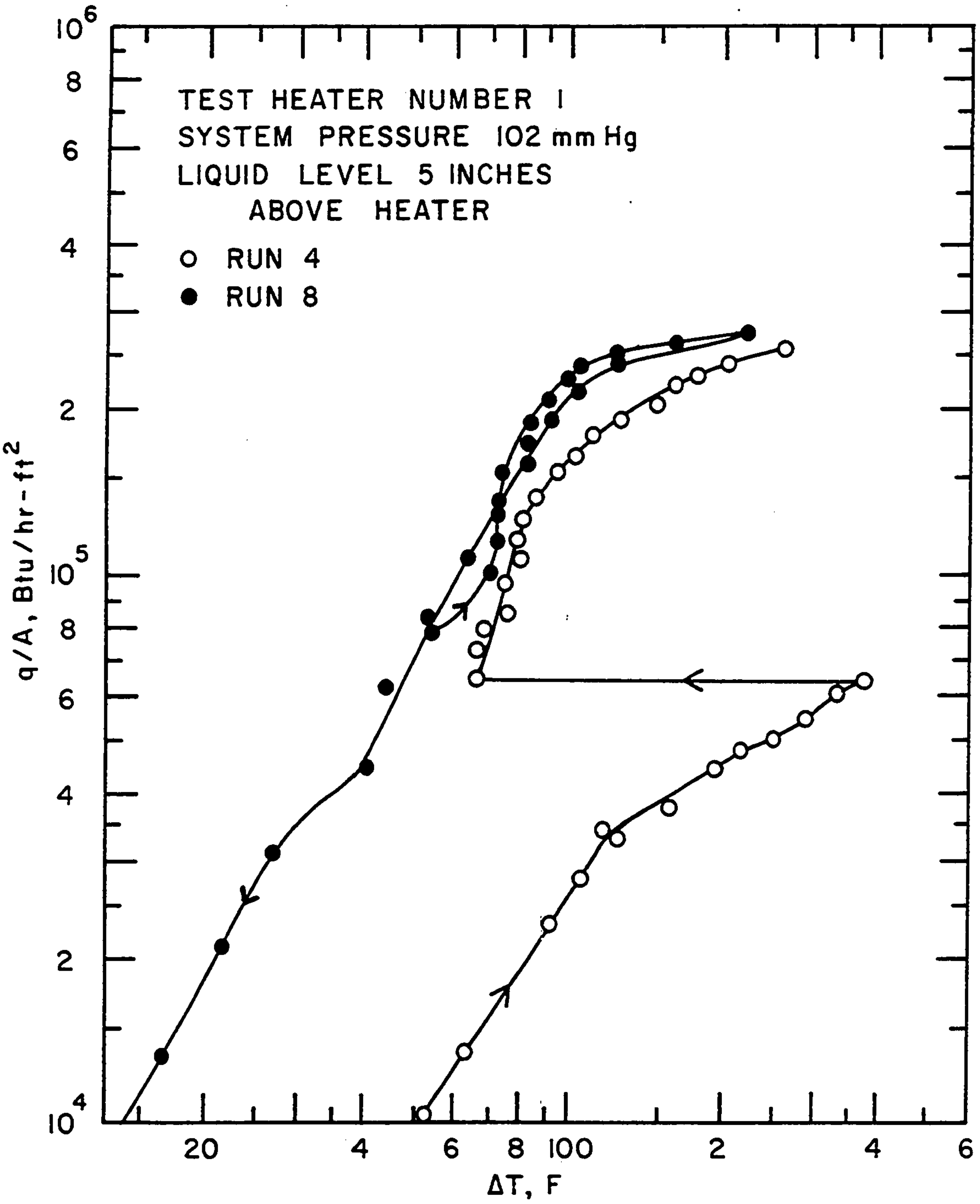


Figure 31. Effects of Aging on Test Heater 1.

subsequent runs with Test Heater 1. In fact, succeeding runs exhibited much lower ΔT's for the lower (and what appeared to be totally convective) portion of the boiling curve. Run 8, also shown in Figure 31, was made at the same pressure and pool depth as Run 4. These runs agreed closely but it was apparent that the surface had further aged resulting in a shift of the curve to lower ΔT's. Note that the departure flux is more well defined in Run 8 than in Run 4.

In later runs with Test Heater 1, it appeared that the surface had aged sufficiently so that the transition from apparent convective heat transfer to nucleate boiling occurred more easily. This was felt to be an indication that stable nucleation sites had been established. During Run 25, shown in Figure D-24 of Appendix D, the heat flux was by chance set at a flux level where periodic changes from convection to nucleate boiling and back could be observed in the temperature trace. Figure 32 shows that the surface temperature gradually rose indicating destabilization of nucleation. The temperature would rise about 50 or 60 degrees F, then suddenly fall to its original level and repeat the cycle. This occurred at a flux level of 212,000 Btu/hr-ft^2 and was the last point in the downward cycle during Run 25. Referring again to Figure D-24, it can be seen that there is an inflection in the boiling curve at about 200,000 Btu/hr-ft^2 which further indicates a change

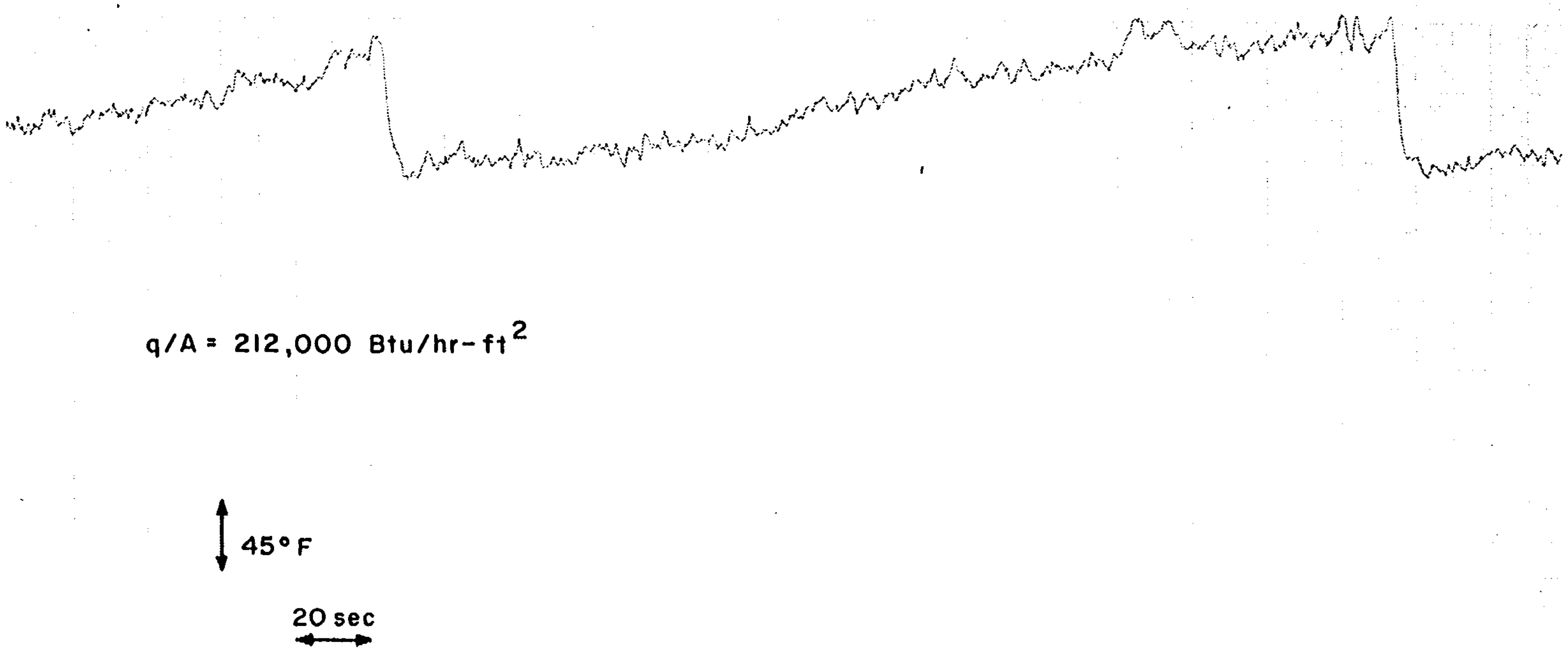


Figure 32. Destabilization and Re-establishment of Nucleate Boiling During Run 25.

in boiling behavior such as transition from convection to nucleate boiling.

When Test Heater 1 was removed from the system, the surface had a frosty grey appearance as shown in Figure 33. The heater was immersed part way in a beaker of clean mercury and showed complete nonwettability. In Figure 33, it can be seen that the portion of the Swagelok fitting which had been in contact with boiling mercury was still silvered by mercury as the entire surface had been when the heater was installed in the system.

Silver-plated Test Heater 2, shown in Figure 34, also exhibited aging, but in a different manner than Test Heater 1. Run 34 was the initial run with Test Heater 2 and is shown in Figure D-33 of Appendix D. During Run 34, the system was allowed to run for an extended period at a flux of about 55,000 Btu/hr-ft^2. Heater temperatures rose about 200 degrees F while operating at this flux, indicating that perhaps the silver plating had dissolved away from the surface.

Test Heater 2 never gave as smooth a change from convective to nucleate boiling as Test Heater 1 had shown. Individual plots of Runs 34 through 47, shown in Figures D-33 through D-46 of Appendix D, show that most of the boiling curves obtained with Test Heater 2 exhibited a discontinuity at intermediate flux levels. The apparent absence of active nucleation sites resulted in high ΔT's,

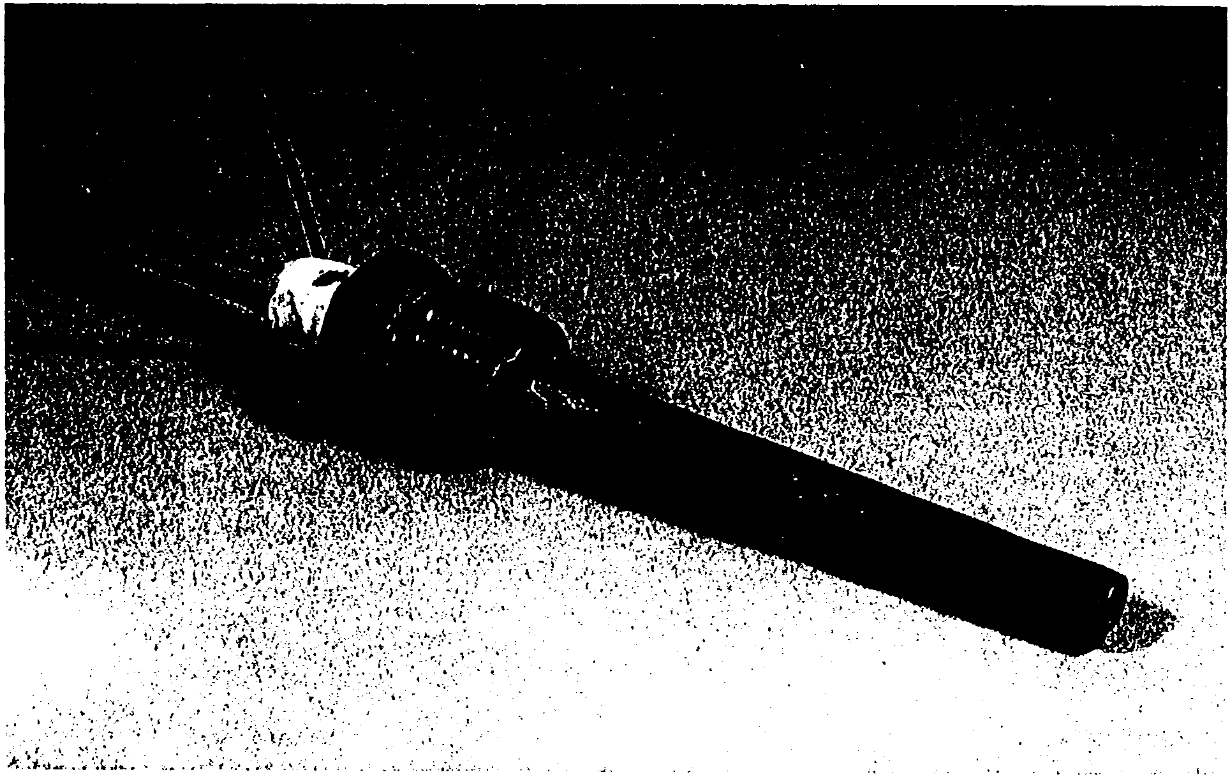


Figure 33. Test Heater 1 after Removal from Boiling Vessel.

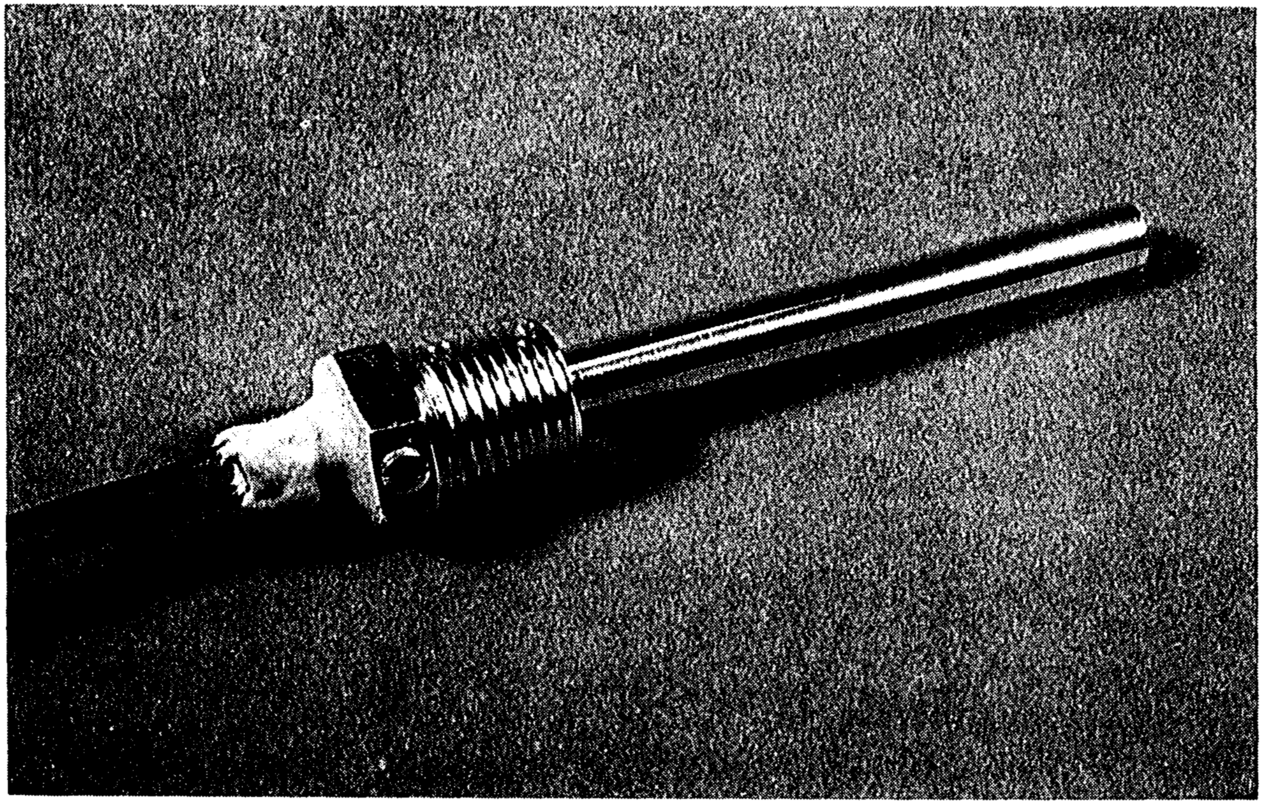


Figure 34. Test Heater 2 prior to Installation in Boiling Vessel.

but upon reaching an adequate flux level, sufficient superheat was achieved at the heater surface to activate sites and provide the sudden establishment of nucleate boiling. This caused the ΔT to immediately drop to a substantially lower value. Actual deviations to higher ΔT's were more pronounced than that shown in plots of the data, since the heater temperature usually rose considerably when the flux level was increased above the last point of apparent convective heat transfer. Figure 35 shows this behavior as observed in Run 39. When the flux was increased, the temperature rose rapidly and then fell to a stable level indicating that the surface was supporting nucleation. It can be seen in Figure 35 that the surface temperature had risen about 200 degrees F above the level corresponding to nucleate boiling. Notice also in Figure 35 that occasional spikes (temperature increases of about 40 degrees F) still occurred after nucleation began. However, when the flux was further increased, more stable boiling was achieved. This behavior is very similar to that observed by Colver (33) for boiling potassium.

It was felt that the different behavior of the two test heaters during transition from convective to nucleate boiling heat transfer indicated that after it was fully conditioned the smoother surface of Test Heater 1 must have provided nucleation sites which were more easily activated than those on Test Heater 2.

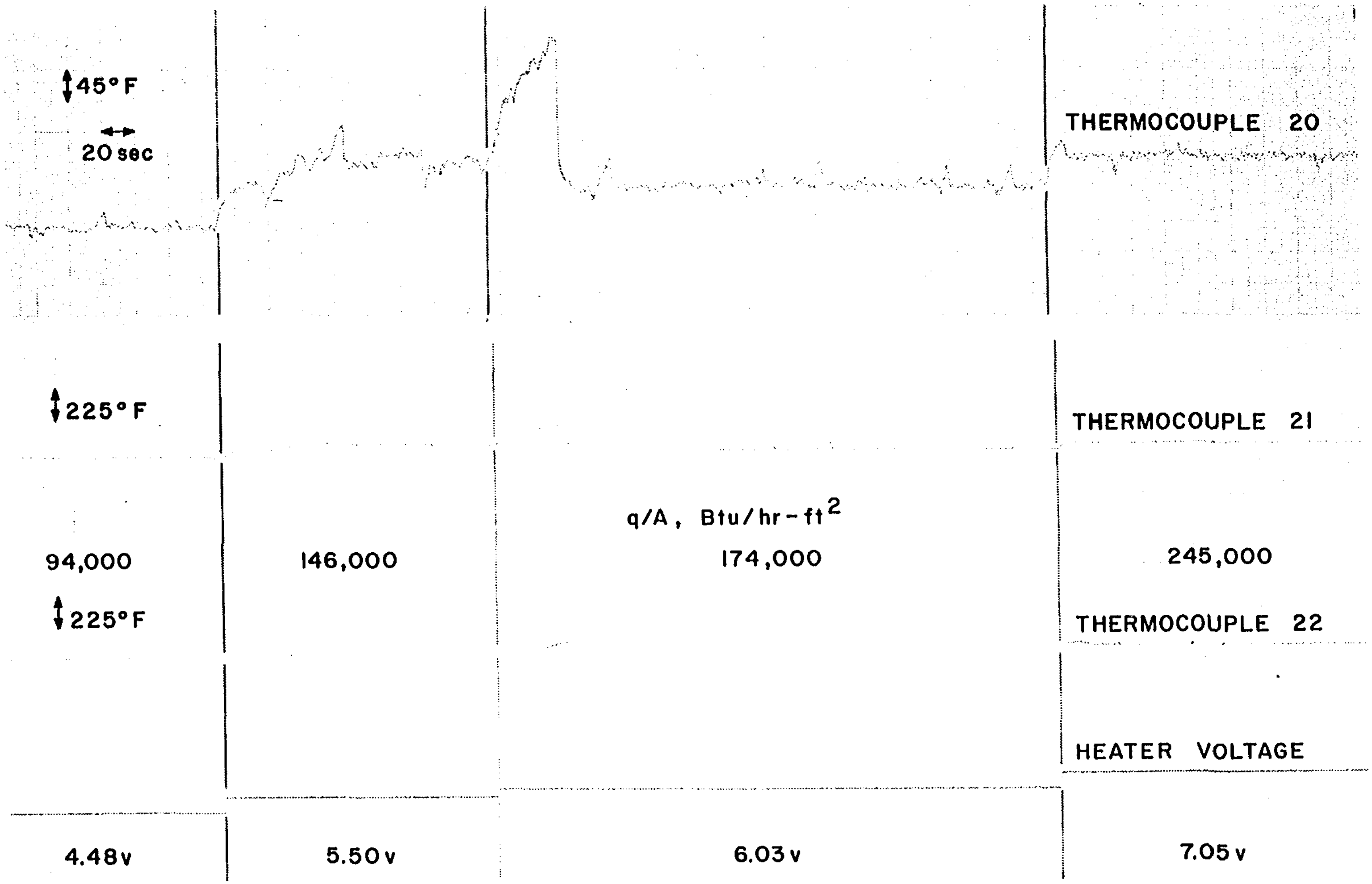


Figure 35. Activation of Nucleation Sites During Run 39.

Noise and vibration.--Although noise from the vacuum pumps and the cooling fan on the rectifier made it difficult to characterize low level noises, a distinguishable rumbling sound emanated from the enclosure once nucleate boiling was established. This sound was accompanied by discernible vibration of the outer enclosure. As the heat flux was further increased, the vibration became more pronounced.

Temperature fluctuations.--Figure 35 shows the type of temperature fluctuations observed before and after nucleate boiling was achieved during a run. When the departure flux was surpassed, much larger fluctuations occurred as shown in Figure 36. These fluctuations were also accompanied by occasional large temperature excursions (more than 200 degrees F) as shown in Figure 37.

Pool temperature gradients.--Pool temperature gradients have been reported in previous liquid metal studies by Colver (33) and Madsen and Bonilla (82). It was found that such gradients existed in this study also.

From Table 1 in Chapter II, it can be seen that thermocouple number 6 is the only thermocouple positioned to measure temperatures directly above the test heater. Using readings obtained from this thermocouple, the liquid thermocouple nearest the free surface, and heater surface temperatures, Figure 38 was prepared.

Pool thermocouples other than number 6 indicated that sufficient mixing was present so that most of the pool

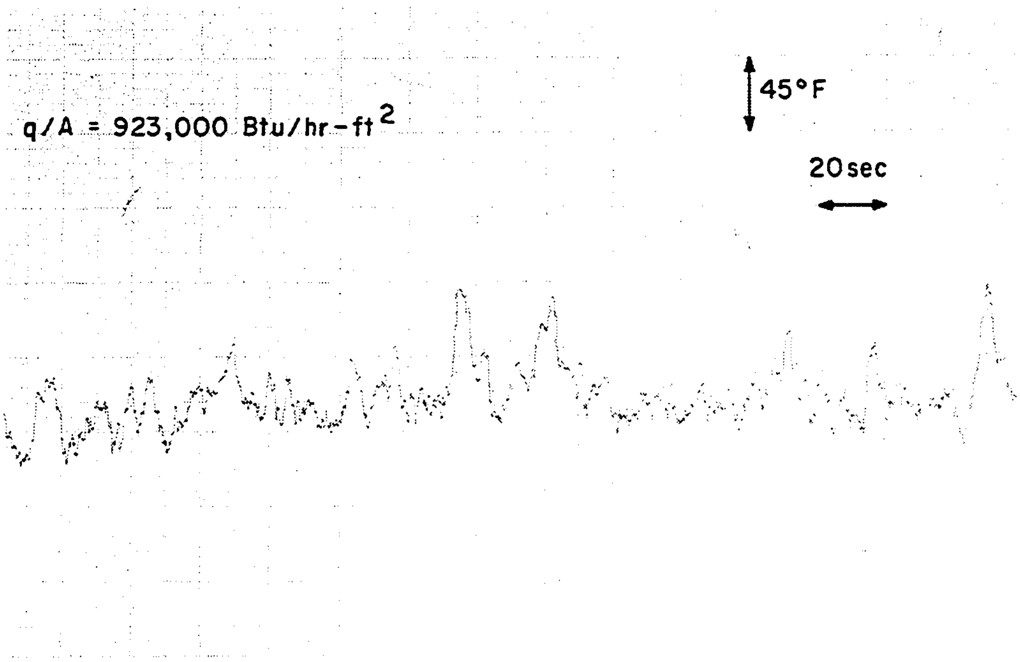


Figure 36. Test Heater Temperature Fluctuations above the Departure Flux.

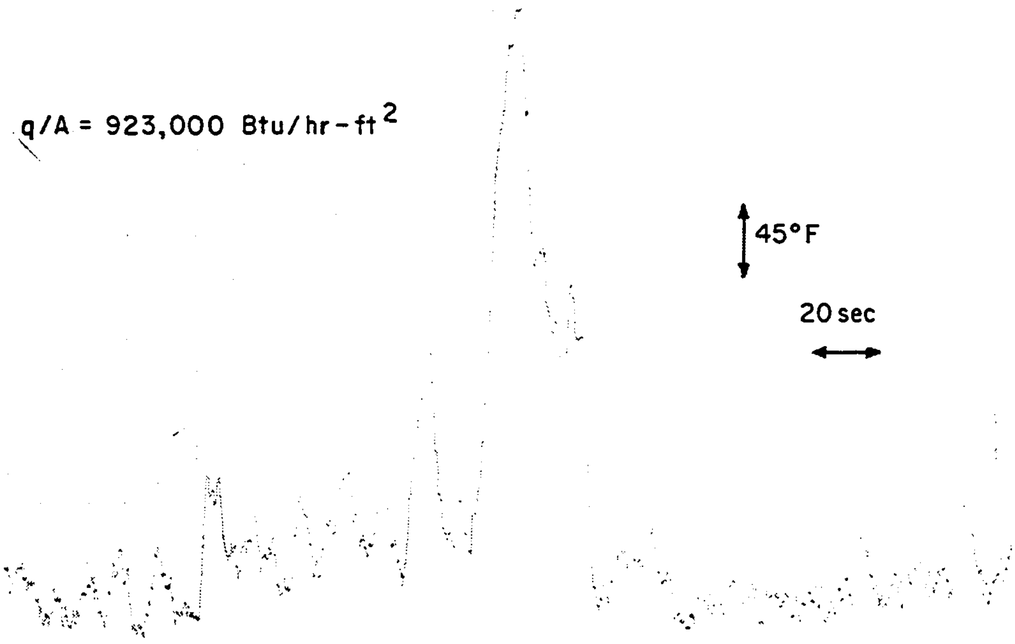


Figure 37. Test Heater Temperature Excursion above the Departure Flux.

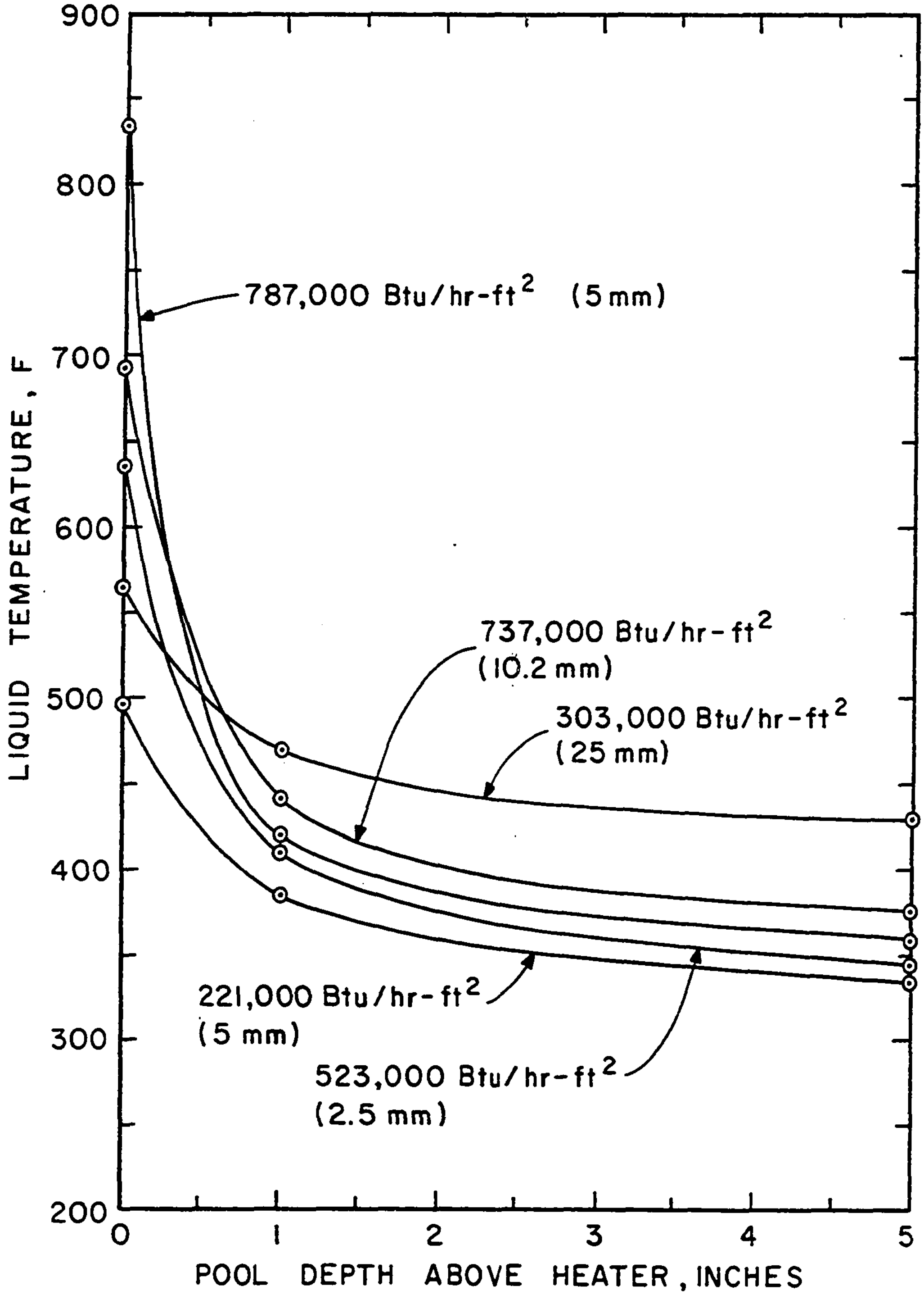


Figure 38. Pool Temperature Gradients.

was at a fairly uniform temperature for system pressures near atmospheric and was only 10 to 20 degrees F hotter than the pool free surface for low system pressures. None of the pool thermocouples indicated temperatures as high as those measured by thermocouple number 6 located 1 inch directly above the test heater.

Because of mercury's extremely high density of almost 800 lb/ft^3, static pool pressures at the test heater were substantially larger than low system pressures used in this study. Thus, it is perhaps of some interest to consider hypothetical stagnant pool temperature gradients necessary for the establishment of equilibrium saturation conditions in the pool, taking into account the pressure due to static head. Considering this, it was found that, for low system pressure, such gradients were quite steep and were nearly linear. A simple calculation showed that to establish the gradient required in a stagnant pool for a 2 mm mercury system pressure, a uniform conductive heat flux of about 3,300 $Btu/hr\text{-}ft^2$ over the boiling vessel cross-section would be required. Ratioing areas for the vessel cross-section and test heater showed that a flux of 10^6 $Btu/hr\text{-}ft^2$ at the heater corresponded to a flux of 136,000 $Btu/hr\text{-}ft^2$ spread over the vessel cross-section. Since this amounted to 41 times the flux required to establish the aforementioned equilibrium gradient in a stagnant pool, it can be seen that convection and latent heat transfer prevented such a gradient from being established. Thus when comparing observed pool gradients to the hypothetical ones discussed, it is seen that apparent local subcooling is a result of high liquid density and good mixing in the pool rather than insufficient addition of heat to the pool.

Pool surface temperature.--It was found that the pool surface exhibited an apparent superheat for high fluxes at low system pressure. This could have been due, in part, to inexact pool depth determination. Figure 22 in Chapter III shows that the liquid thermocouple nearest the free surface could be as much as 1 inch below the liquid surface. Pool temperature gradients shown in Figure 38 would not be affected but free surface temperatures would be slightly in error. Extending the observed gradients in Figure 38 to a pool depth of 6 inches shows that the correction in all cases would be less than 10 degrees F.

Comparison to previous mercury studies.--Fluxes in previous studies have extended to less than 150,000 Btu/hr-ft^2 for pure pool boiling mercury and only to 200,000 Btu/hr-ft^2 for pool boiling mercury with additives. This compares to fluxes achieved in this study in excess of 1,000,000 Btu/hr-ft^2.

A synopsis of the work by Bonilla, et al. (13), Korneev (68), Lyon (80), and Farmer (100), is shown in Figure 39. Although their nucleate boiling flux levels are not comparable to those achieved in this study, it can be

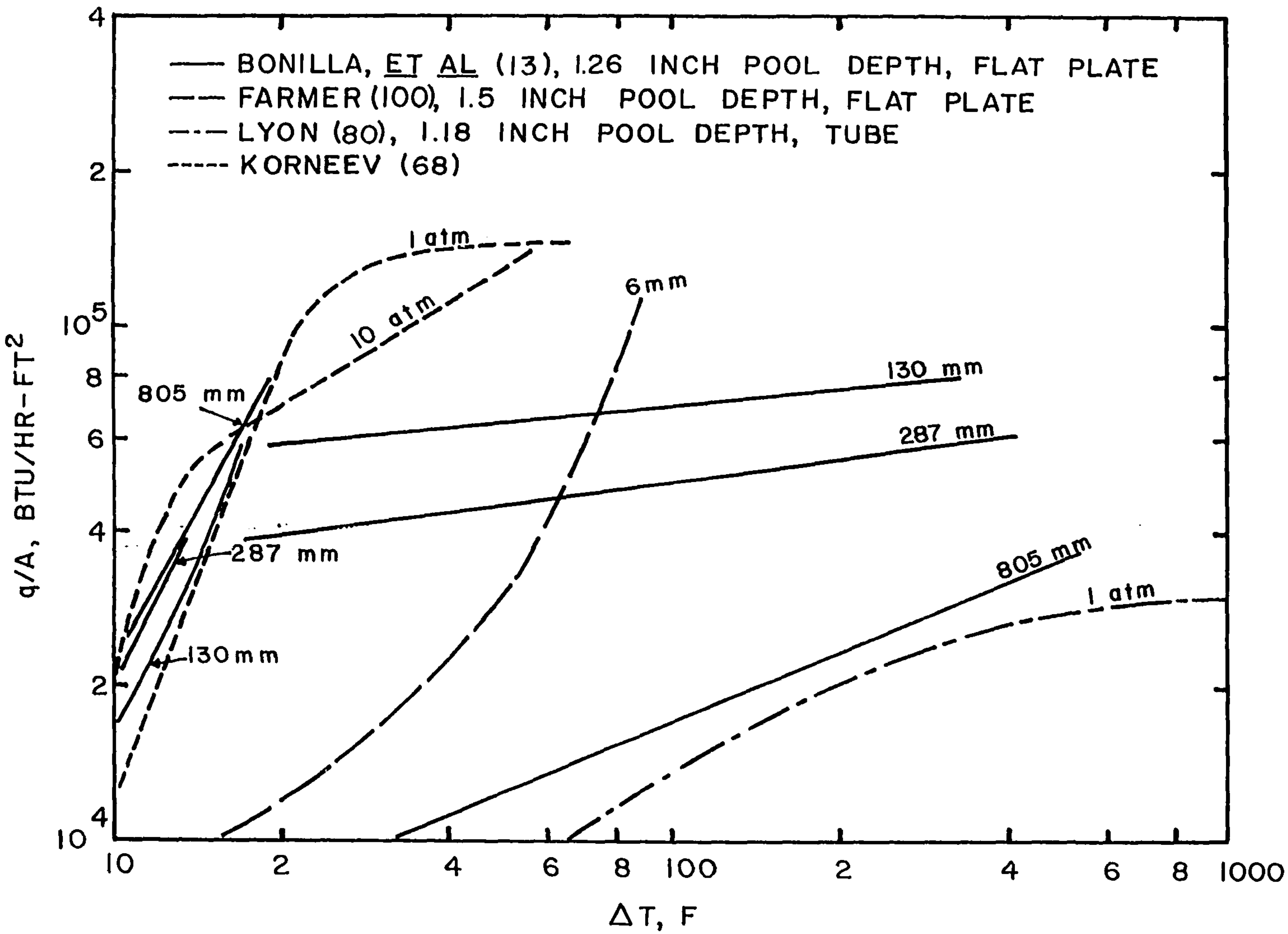


FIGURE 39. MERCURY RESULTS FROM PREVIOUS STUDIES.

seen that the slopes of nucleate boiling curves in this study (Figures 26, 27, 28, and 29) are much the same as those observed by Bonilla, *et al*., Korneev, and Farmer. Bonilla, *et al*. stated that the slope ranged from 2 to 3 for nucleate boiling in their work. Except for the near-vertical portion of the boiling curves in Runs 46 and 47, the same range of slope was observed in this study for nucleate boiling. Though the present work has not been presented in Figure 38 to prevent crowding, let it suffice to say that the curve of Farmer most closely approximates the position of data obtained in the present study for low flux levels.

The more horizontal curves of Bonilla, *et al*., and Lyon shown in Figure 38 also closely agree in slope with data obtained in this study for fluxes above the departure flux. However, flux levels achieved in this region for comparable system pressures were well above the data of Bonilla, *et al*., and Lyon.

Notice in Figure 38 that Korneev observed a higher departure flux for a 1 atmosphere pressure than for a 10 atmosphere pressure. This trend is in complete agreement with observations made in this study. It also appears that the data of Bonilla and co-workers would have exhibited the departure flux as observed in the present study and in Korneev's work, if they had joined the two portions of their boiling curves for system pressures of 130 and 287 mm mercury. Other aspects of this interesting feature of pool boiling mercury will be discussed in a later section devoted to the departure flux.

Comparison to correlations.--Eckert's (41) equation for free convection (Equation 6), as modified by Hyman, et al. (62), satisfactorily predicted the slope of experimental data in the convective region; however, predicted ΔT's were about an order of magnitude higher than the present data, obtained from a fully conditioned surface. The convective portion of boiling curves obtained in Runs 4 and 5, in which Test Heater 1 was not fully conditioned, more nearly agreed with ΔT's predicted by Eckert's equation. Changing the constant in Equation 6 from 0.54 to 5.7 brings the predicted behavior into much better agreement with data obtained for a conditioned surface.

Predicted nucleate boiling curves for the correlations by Forster and Grief (41) and Forster and Zuber (45) are much the same so only the latter one is shown in Figure 40. On comparing the predicted behavior with composite plots of the experimental data shown in Figures 26, 27, 28, and 29, it can be seen that the data do not exhibit as large a shift in ΔT with pressure as predicted by the correlation. It may be observed, however, that the correlation effectively "brackets" a large portion of the data below a flux level of 100,000 Btu/hr-ft^2. Above this flux

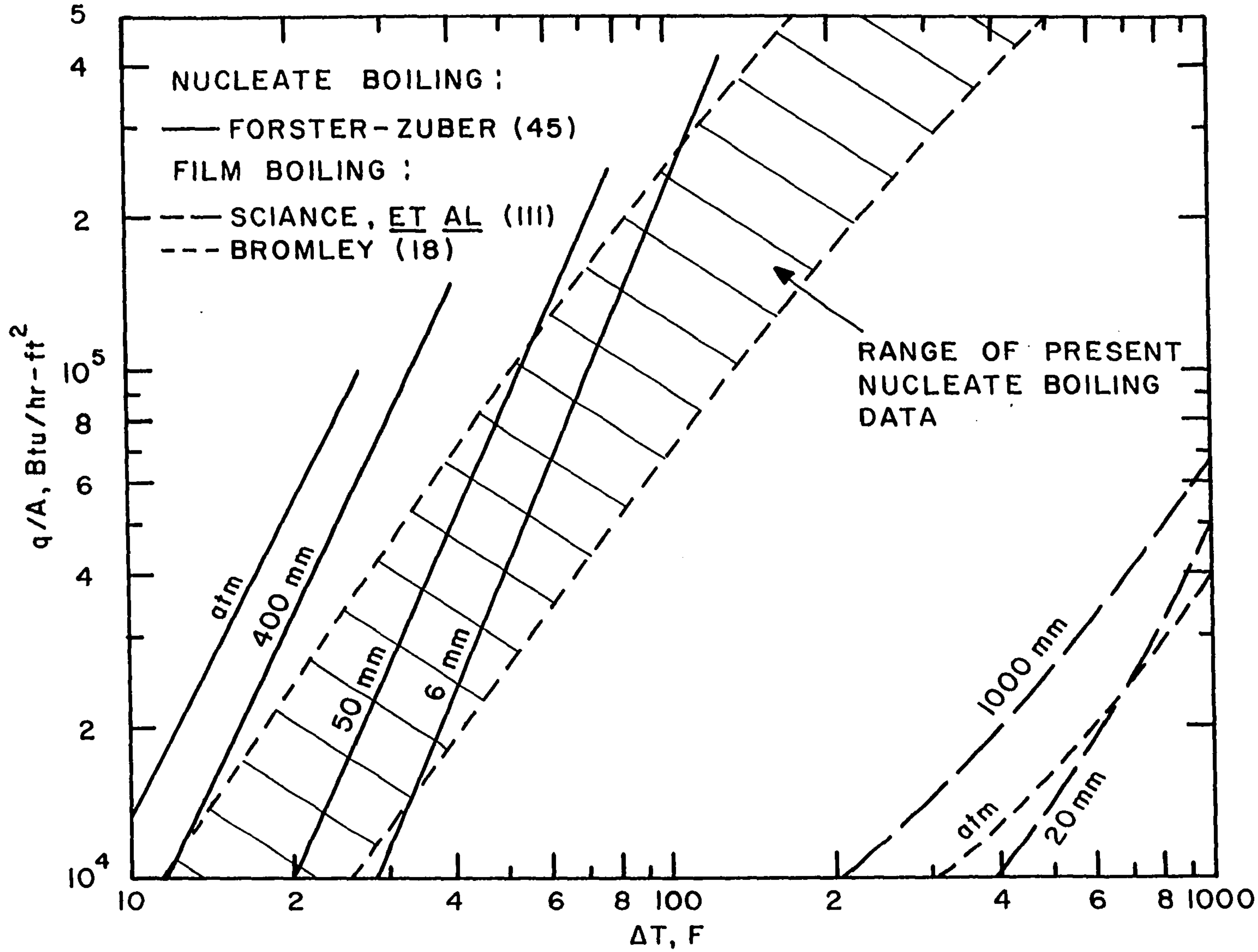


Figure 40. Boiling Correlations Applied to Mercury.

level, observed ΔT's were higher than predicted ones (especially for a 2 inch pool depth above the heater).

Film boiling correlations by Bromley (18) and Sciance, et al. (111) are also shown in Figure 40. It is readily apparent that neither correlation shows any similarity to the slope and placement of data obtained above the departure flux in each run. This is not to say that the correlations do not predict film boiling behavior for mercury but rather to help substantiate the belief that fully developed film boiling was not observed in this study for low system pressures.

Departure Flux

As previously noted, the flux at which the slope of the boiling curve decreased markedly, was designated the "departure flux," $(q/A)_D$. After reaching the departure flux, further small increases in flux caused large increases in ΔT. Temperature fluctuations in the region above the departure flux were much more pronounced as previously discussed and shown in Figure 36.

Figure 41 shows that plotting the departure flux versus system pressure gives an envelope for each liquid level studied, with high fluxes being achieved at lower system pressures and higher liquid levels. Notice, however, that the envelope for a 5 inch level with Test Heater 2 lies slightly below the envelope for the corresponding level with Test Heater 1. Observed ΔT's at the same pressure, liquid

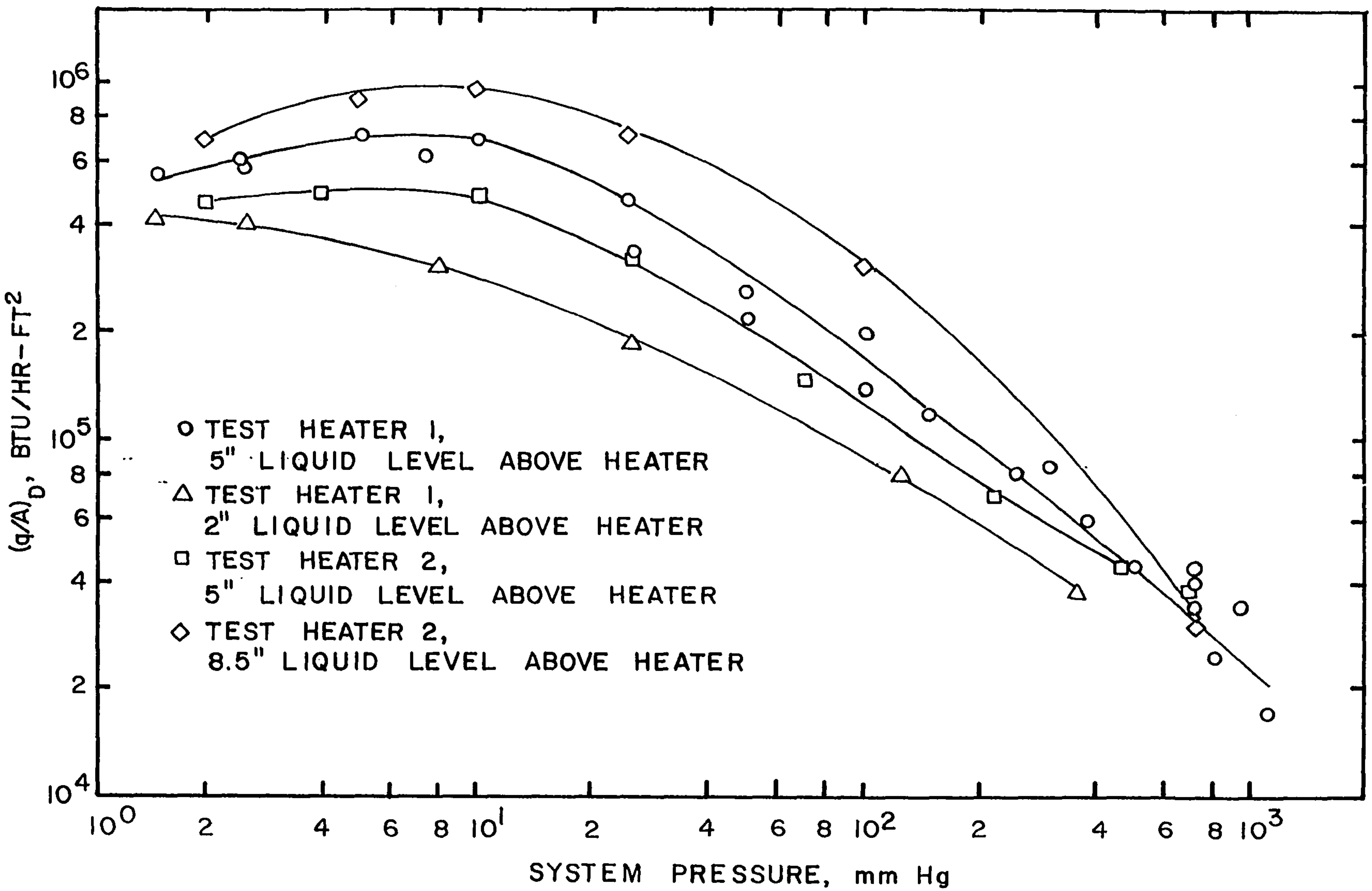


FIGURE 41. DEPARTURE FLUX AS A FUNCTION OF SYSTEM PRESSURE AND POOL DEPTH.

level, and flux level were higher for Test Heater 2 than for Test Heater 1. It is felt that this was a result of Test Heater 2 not being fully conditioned or aged in the interval between installation of Test Heater 2 and the time the runs were carried out. Since the entire 100 lbs of mercury was charged to the boiling vessel in each case, a difference in pool depth was not the cause of this behavior.

It can be seen in Figure 39 that each envelope exhibits a maximum in the low pressure range. These maxima vary from slightly over 400,000 Btu/hr-ft^2 for a 2 inch liquid level above the heater to almost 1,000,000 Btu/hr-ft^2 for an 8.5 inch level. Run 46 extended to a flux of 1,100,000 Btu/hr-ft^2 although the departure flux was reached at about 900,000 Btu/hr-ft^2.

Burnout.--The boiling behavior observed for the system operating near the flux levels and system pressures corresponding to the maxima of the departure flux envelopes, more closely resembled expected behavior for a system near the burnout flux. During Run 45, shown in Figure D-44 of Appendix D, a very large temperature excursion was observed (recorder stylus went offscale after a 400 degree F rise) which might be justifiably called a burnout. This temperature excursion, shown in Figure 42, occurred at a flux level of 1,018,000 Btu/hr-ft^2. The observation of this burnout and indications in other low pressure runs that burnout was imminent led this investigator to feel that for low pressure,

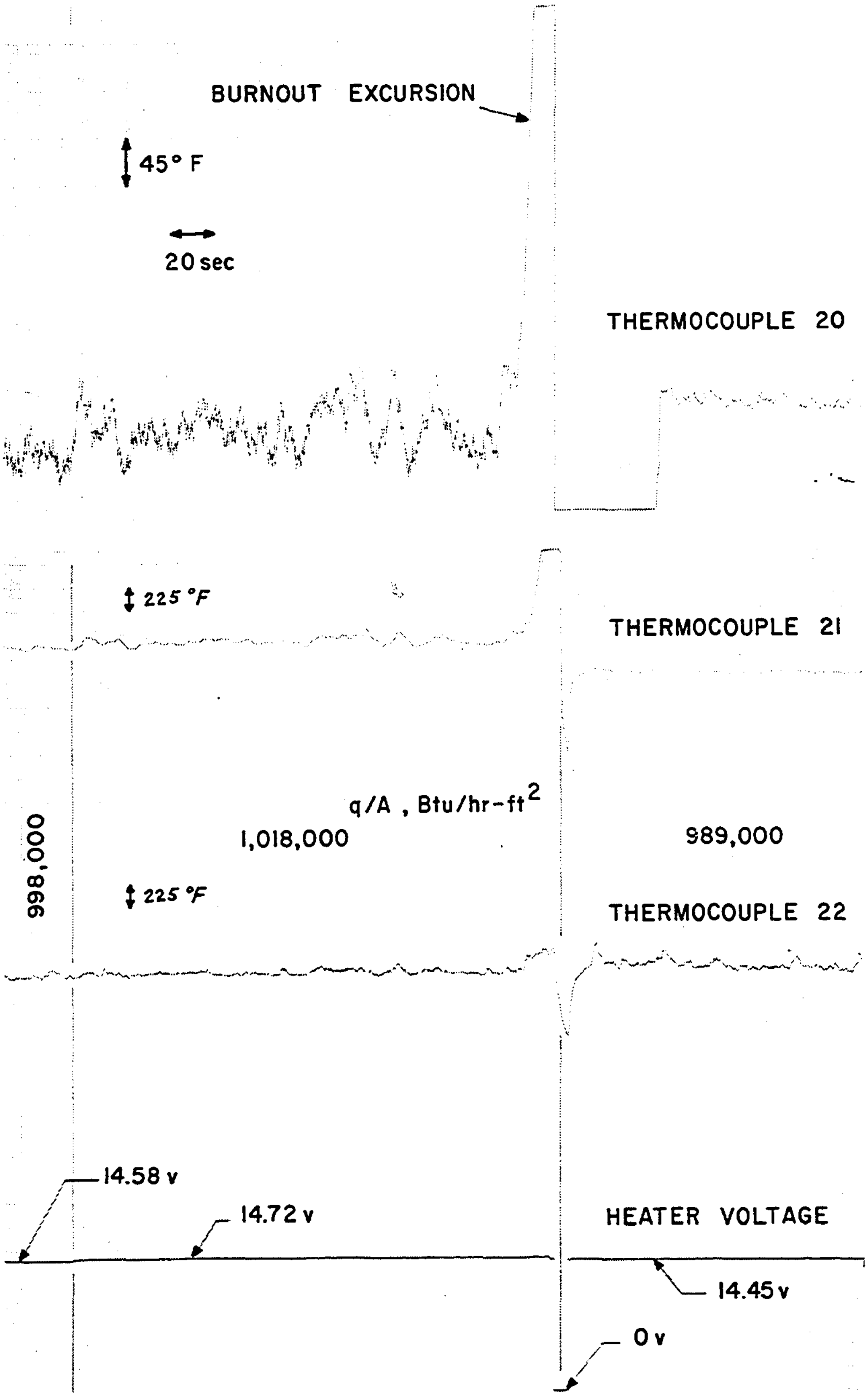


Figure 42. Test Heater Temperature Excursion at Burnout During Run 45.

the system was demonstrating behavior normally expected for a boiling system. For this reason, the observed departure fluxes were plotted versus total pressure, i.e., system pressure plus static head above the heater. Figure 43 shows that plotting the departure flux in this manner effectively separates the maxima exhibited for each liquid level and shows a consistent variation of the maxima with total pressure.

Burnout correlations of Addoms (2) and Noyes (78, 95) are included in Figure 43. Notice that these correlations very nearly predict the observed variation of the maximum departure flux. Other correlations by Rohsenow and Griffith (104), Zuber and Tribus (129), and Caswell and Balzhiser (26) fell below those shown in Figure 43. Physical properties for saturated conditions at the heater were used in evaluating the correlations.

The favorable comparison of the maximum departure flux with burnout correlations further suggests that at low pressure the system exhibited behavior normally expected for a boiling system.

Considering the effect of pool depth on the maximum departure flux, extrapolation of the line in Figure 43 would suggest that for a pool depth of 4 feet, a maximum departure flux of about 2.5 (10^6) Btu/hr-ft^2 would be possible. This depth (4 feet) corresponds to the height of liquid above the test section used by Romie, _et al_. (108) in their thermal

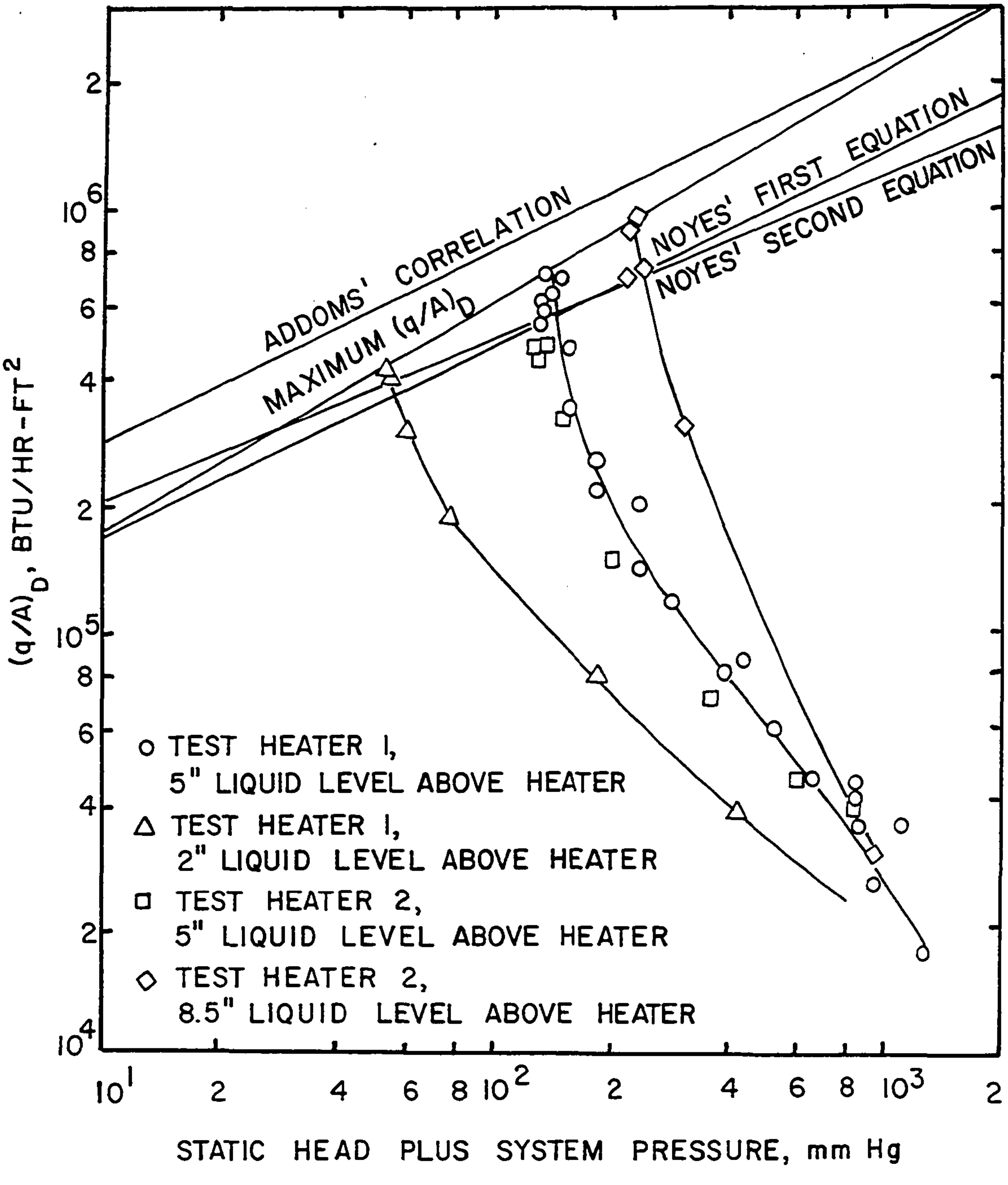


FIGURE 43. DEPARTURE FLUX AS A FUNCTION OF TOTAL PRESSURE AND POOL DEPTH.

syphon loop. Recall that they operated at fluxes up to 600,000 Btu/hr-ft^2 with no indication that burnout had been approached.

Pressure effect on departure flux.--It has previously been noted that increasing the pool depth shifted the boiling curves to lower ΔT's. Figure 41 displays the fact that increased departure fluxes were obtained with higher liquid levels. Each of these results would be expected as manifestations of pressure effects on boiling as discussed in Chapter I. However, one would not expect the departure flux to increase with decreasing system pressure as was observed. To explain this, it was necessary to find some property or feature of boiling mercury which varied in such a manner with system pressure that such behavior could have resulted.

Possible reasons for pressure effect on departure flux.--While endeavoring to understand why the departure flux increased with decreasing system pressure, many explanations were considered and discarded. It is felt that the previously discussed pool temperature gradients can perhaps most satisfactorily account for increased departure fluxes with decreases in system pressure. As previously mentioned, for low system pressures, very steep hypothetical temperature gradients must exist in the pool for equilibrium saturated conditions to be present at all levels of the pool. In addition, it was shown in Figure 38 that mixing in the pool resulted in fairly uniform pool temperatures (except near the heater) corresponding closely to saturated conditions for the system pressure. This had a net effect of producing a kind of subcooling in the pool which increased with increasing pool depth and decreasing system pressure. It is well known that subcooling enhances the nucleate boiling regime and that the enhancement is greater at lower pressures (49, 130).

Subcooling in comparison to the hypothetical equilibrium gradient accounting for static head may well have allowed the high fluxes obtained in this study, but this occurrence is a peculiarity of mercury itself and is no fault of the experimental apparatus.

Such subcooling may also have accounted for the noise and vibration observed (noted earlier) which could have resulted from the hammer effect as discussed by Bonilla, et al. (13).

It is felt that the preceding paragraphs give perhaps the most feasible explanation of the variation of departure flux with system pressure, but other explanations may be equally as good. An additional possibility is that the contact angle of boiling mercury on the heater surface was a strong function of temperature. In studying this possibility, observed values of the departure flux were plotted as a function of heater surface temperature as shown in Figure 44. Although no definitive pattern was shown, it

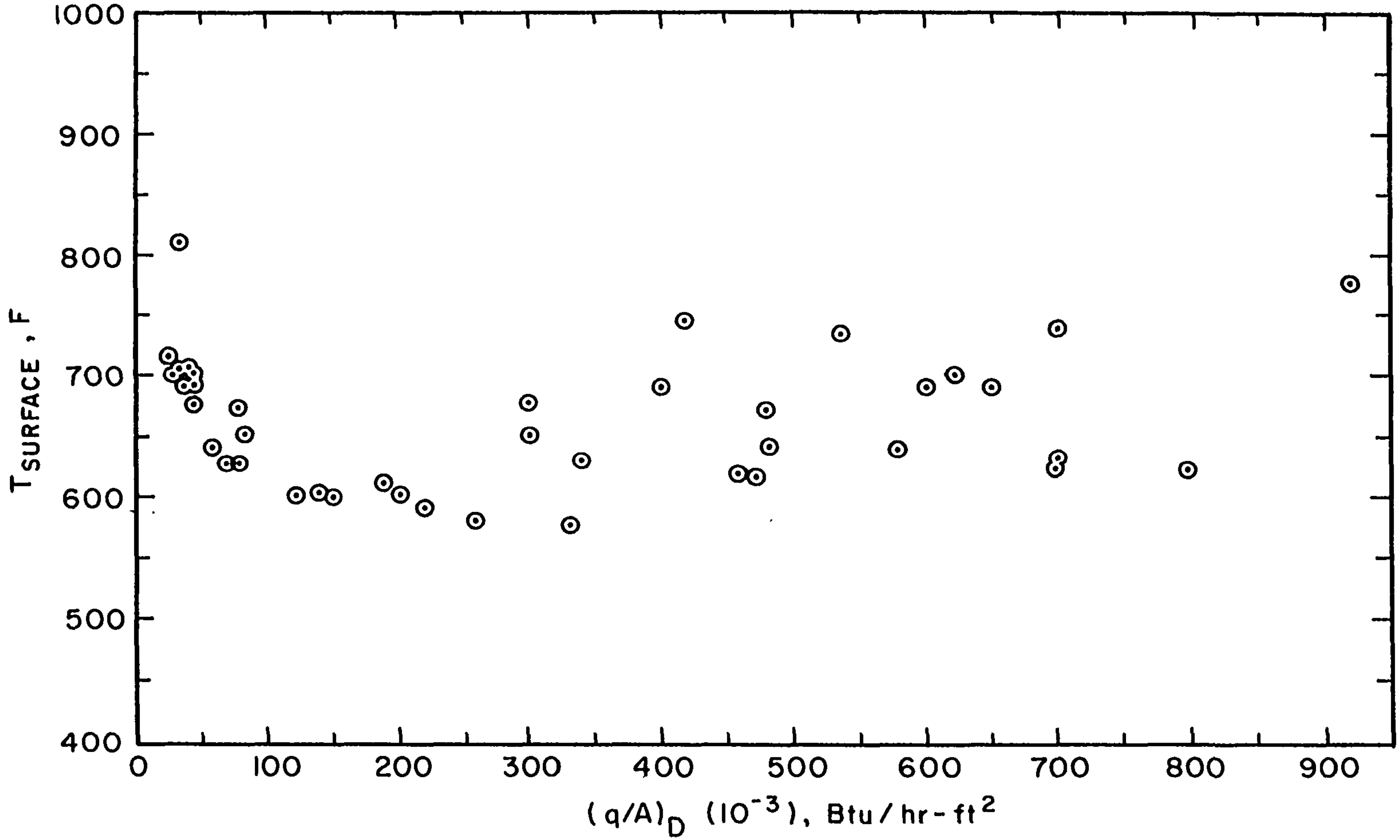


Figure 44. Departure Flux Versus Test Heater Surface Temperature.

appears that for pressures between 50 mm mercury to just under atmospheric pressure (departure fluxes from 100,000 to about 300,000 Btu/hr-ft^2), the departure flux occurred when the surface temperature reached about 600 degrees F. For system pressures below 100 mm mercury (fluxes greater than 300,000 Btu/hr-ft^2), much less regularity was observed. This would be expected since it has previously been explained that normally expected boiling behavior was observed at low system pressures. Near atmospheric pressure, it appears that the departure flux occurred whenever the surface became hot enough to vaporize the contacting liquid. This indicated that the contact angle was greater than 90 degrees so that the first vapor bubbles formed simply spread over a portion of the surface causing localized film boiling. If it so happened that the contact angle increased with temperature between 300 and 600 degrees F, and a value of 90 degrees occurred at about 600 degrees F, nucleate boiling would be possible up to this point at which time vapor patches would begin to form. In Appendix A, it is shown that the contact angle for a liquid metal can be a strong function of temperature. This then could perhaps explain the behavior of the departure flux since for low system pressures, a wider range of heat fluxes would be possible as heater surface temperatures could vary from saturation to initial nucleation and from there to 600 degrees F where bubbles would begin spreading over the surface.

Although for low system pressure, the departure flux was very near the burnout flux, it is not felt that the departure flux behavior is in any way related to the burnout flux envelope for normal systems over a pressure range up to the critical pressure. As discussed in Chapter I, it has been found that water and hydrocarbons exhibit a maximum burnout flux at a reduced pressure of about 0.333. All data taken in this mercury study were obtained at reduced pressures, P_r, between 10^{-6} and 10^{-3}. An estimated critical pressure, P_c = 15,350 psia, reported by Weatherford (117) was used to evaluate the reduced pressures.

Possible boiling mechanism above the departure flux.--To better understand the departure flux, and to formulate some idea of the type of boiling occurring above this level, the data were carefully scrutinized and the literature was carefully surveyed. Previous mercury investigators (13, 68, 80, 81) have observed instances when the slope of the boiling curve was very small; and they attributed this to film boiling due to nonwetting of the surface. Observations made in this study indicated that the small slope may have indeed been a manifestation of nonwetting, but it is doubtful that fully developed film boiling was present. It is felt that the observed phenomenon can best be compared to the second transition region hypothesized by Gaertner (48) for boiling water. Recall that the second transition is the point where a change in slope for the water boiling curve was observed at a high flux level, as shown in Figure 23. Gaertner observed that the transition occurred when vapor mushroom stems became unstable and collapsed. Considering this and the large temperature fluctuations observed above the departure flux as shown in Figures 36 and 37, it is suggested that this region is likewise characterized by formation and collapse of vapor patches on the surface. This explanation for the small slope of the boiling curve is quite plausible since additional heat would generate more vapor patches which in turn would decrease the heat transfer coefficient. This analysis is further substantiated by the observed occurrence of large temperature excursions above the departure flux. No such excursion would occur during stable film boiling. It is suggested that the large static head and substantial mass of cooler liquid surrounding the superheated layer adjacent to the heater prevented a stable film from being easily formed even though the surface was apparently nonwetted.

Hysteresis

In most of the 47 experimental runs made, little or no hysteresis was exhibited. Usually, the downward cycle closely agreed with the upward cycle except where large ΔT's were observed before nucleation occurred. In a few runs, it appeared that when the departure flux was exceeded by a sufficient amount, then higher ΔT's were exhibited during the decreasing flux cycle than for the previous increasing flux cycle.

Recall that a single burnout heat flux was recorded during this study. When it occurred, the pyrometer controller cut off power to the heater. The rectifier powerstat was turned down slightly and the rectifier was immediately reactivated. Notice in Figure D-41 of Appendix D that Run 45 demonstrated considerably lower ΔT's on the downward cycle than for the upward cycle. When the pyrometer cut off power to the heater, the surface apparently recovered completely; and by maintaining all of its active nucleation sites, much better heat transfer was achieved when power was restored at a reduced level. This is consistent with the possible boiling mechanism proposed for the region above the departure flux.

Summary

High heat fluxes can be achieved in pool boiling mercury at low system pressures even in the apparent absence of complete wetting. The magnitude of attainable nucleate boiling fluxes is dependent upon the pool depth. Therefore, the attainment of high fluxes, or even nucleate boiling, cannot be considered sufficient evidence that mercury has wetted a particular heating surface. It appears that such high fluxes are possible as a result of a kind of local sub-cooling caused, not by inadequate heating, but rather by static pressure resulting from the large density of mercury which required higher saturation temperatures at the pool bottom than the extremely good mixing in the pool would allow.

Although the surface was apparently nonwetted, some degree of wetting or other change in the character of the surface did occur which allowed higher departure fluxes and lower ΔT's for a conditioned surface.

Several questions still remain concerning pool boiling mercury although this study should provide considerable enlightenment in this somewhat muddled area. As Brooks and Bonilla (19) have stated, reliable work involving liquid metals is difficult. Our space age technology has not yet evolved an experimental apparatus capable of producing answers to all our questions.

CHAPTER V

CONCLUSIONS

Several significant conclusions have been made as a result of this study. These include the following:

1. Reproducible, consistent results were obtained for pool boiling mercury even though the test heater surface was apparently unwetted.

2. Heat fluxes for boiling mercury extended to levels never before achieved on wetted or nonwetted surfaces. Fluxes up to 1,100,000 Btu/hr-ft^2 were obtained at ΔT's less than 400 degrees F.

3. At a certain nucleate boiling flux level the slope of the boiling curve decreased significantly so that subsequent increases in flux were accompanied by large increases in ΔT. The flux level at which the pronounced decrease in slope occurred, was termed the "departure flux."

4. Departure fluxes plotted versus system pressure for different pool depths above the heater, formed envelopes, which exhibited maxima at low system pressure (less than 25 mm mercury). Maximum observed departure fluxes ranged from 400,000 Btu/hr-ft^2 for a 2 inch liquid level above the

heater to 950,000 Btu/hr-ft^2 for an 8.5 inch level above the heater.

5. The maximum departure fluxes showed good agreement with burnout correlations of Addoms (2) and Noyes (78, 95) when plotted as a function of total pressure at the heater.

6. For a fully conditioned surface, low pressure convective heat transfer was stable to remarkably high levels and at much lower ΔT's than predicted by Eckert's (41) correlation as modified by Hyman, et al. (61). Changing the constant in the correlation to 5.7 brought the experimental and predicted values into agreement.

7. Heater temperature fluctuations observed were very similar to those reported by other investigators.

8. Substantially uniform temperatures existed in the boiling pool except near the test heater where high superheats were present.

CHAPTER VI

RECOMMENDATIONS

On the basis of this study, the following suggestions are made for future endeavors:

1. A comparable study should be conducted in which further attempts would be made to obtain pool boiling mercury from a completely wetted surface. Molybdenum is supposedly completely wet by mercury (79). A heating surface of this material should provide interesting and useful results.

2. Other different types of heater surfaces should be used to further establish their wettability and boiling characteristics with mercury.

3. A concerted effort should be made to determine the temperature functionality of mercury's contact angle on various surfaces and relate the results to the observed behavior in this study.

4. Data should be taken at additional pool depths to extend the range of information and see if the observed trends of departure flux continue in the same manner.

5. The equipment constructed for this study should be utilized in studies of additional high-temperature boiling liquids.

6. The method of measuring pool free surface temperatures should be revised. Perhaps the method of Wolkoff, et al. (121) could be modified for use in this system. In addition, the technique for measuring pool depth should be refined and could perhaps be incorporated in the pool free surface temperature measurement. Also more work should be done concerning pool temperature gradients near the test heater.

7. Thermocouples should be installed in the guard heaters so that they can be operated at higher flux levels with confidence that limiting temperatures could be detected and thereby avoid failure of the guard heaters.

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APPENDIX A

DISCUSSION OF CONTACT ANGLE AND SURFACE TENSIONS

The literature survey by Balzhiser, et al. (5) contains a good discussion of interface considerations and the difficulty in characterizing surface with macroscopic parameters such as contact angle. They include in their reference listing such excellent works as those by Bikerman (10) and Herring (53). With these works available, it is not intended here to present or extend surface energy theories. Rather, it is hoped to discuss the physical significance of contact angles and surface tensions so that one can better understand analyses resulting from this approach.

Surface tensions are sometimes mistakenly thought of as a property of a single phase, e.g., one may see the term, "surface tension of mercury." This is a misnomer. Surface tensions of liquids are interfacial tensions. The liquid must be in contact with another phase, e.g., another liquid, air, vacuum, a solid, or vapor of the particular liquid.

Magnitude of the surface tension can be thought of as a measure of the non-affinity of one phase for the contacting second phase. In a three-phase system, there are three surface tensions related by the well-known expression

$$\sigma_{vs} - \sigma_{\ell s} = \sigma_{v\ell} \cos \beta \tag{A-1}$$

This can be represented graphically as in Figure A-1. Thus, visualizing that the difference, $\sigma_{vs} - \sigma_{\ell s}$, is just the

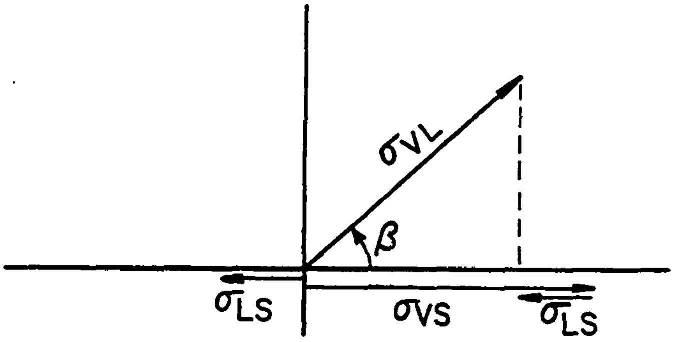

FIGURE A-1. RELATION OF SURFACE TENSIONS AND CONTACT ANGLE.

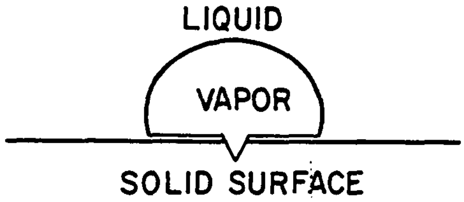

FIGURE A-2. WETTED SURFACE.

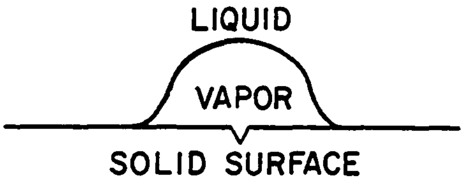

FIGURE A-3. NONWETTED SURFACE.

projection of $\sigma_{v\ell}$ on the horizontal axis, it can be seen that a change in the contact angle, β , is a measure of the variation of surface tensions involving the solid surface. That is, $\sigma_{v\ell}$ could remain constant while β varied from 0 to 180 degrees. Therefore, it seems that the contact angle should be included in correlations predicting boiling and burnout heat fluxes. The contact angle, β, is the angle subtended (in the liquid) by the liquid-solid and liquid-vapor interfaces. For a contact angle less than 90 degrees, liquid can remain under a bubble as it grows from a vapor-filled cavity (Figure A-2). For an obtuse contact angle, a bubble will sweep liquid from the surface as it grows (Figure A-3). This amounts to localized film boiling and causes propagation of such at low fluxes as has been observed by Gaertner (47) for surfaces nonwetted by water.

Since surface tensions are defined in terms of surface free energies, it is quite logical that they should be functions of temperature. However, there is no known experimental method for measuring components of the surface stress tensor (5), so vapor-solid and liquid-solid surface tensions are not known. Contact angles can be determined though, and their variation with temperature can be quite dramatic as illustrated by Figure A-4. This figure is a crossplot prepared from a figure which appeared in reference 12.

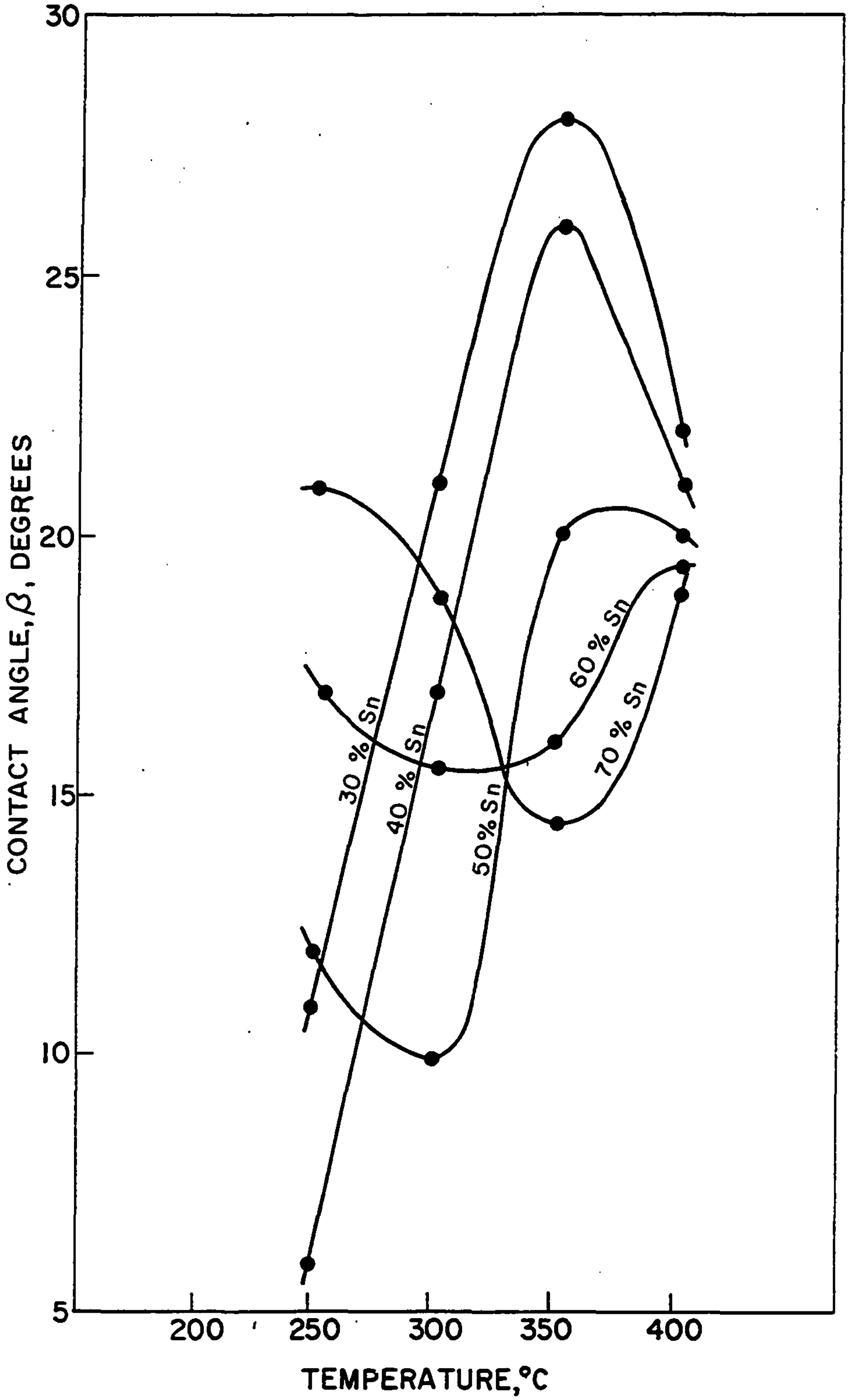

FIGURE A-4. CONTACT ANGLE VERSUS TEMPERATURE FOR Pb/Sn SOLDER ON A COPPER SURFACE.

Randall (102) observed a wide range of contact angles for mercury on Haynes alloy 25 surfaces. With angles varying from 34 to 123 degrees, he found that mercury wetting was a function of surface pretreatment and temperature as well as time. Conditioning times required for wetting to occur varied for different surface treatment.

APPENDIX B

CALIBRATIONS

Thermocouple Calibration

Thermocouple calibrations were obtained by insitu measurements and comparison to standard tables for Chromel-Alumel thermocouples. All thermocouples immersed in the boiling liquid were found to measure saturation temperatures of water within 1 degree F. Such a check was not possible for boiling mercury because of superheating in the pool. However, having previously compared thermocouple outputs for uniform water pool temperatures, it was obvious that deviations in the mercury pool were due to superheat and not erroneous readings. At low fluxes, the topmost thermocouple in the mercury pool agreed very closely with the vapor pressure curve shown in Figure B-1. The experimental points plotted in Figure B-1 correspond to the first flux level in each run so considerable superheat is reflected in the plot at low pressure since these runs began at fluxes as high as 200,000 Btu/hr-ft^2.

Whenever a new heater was installed, readings were made with power off to compare heater thermocouples with those near the heater. In each heater, only the thermocouple located near the vessel wall deviated more than 1 degree F; and it was usually not more than 5 degrees F below pool temperatures. With this check it could be fairly certain that even if absolute temperature measurements were slightly in error, temperature differences would not reflect this error.

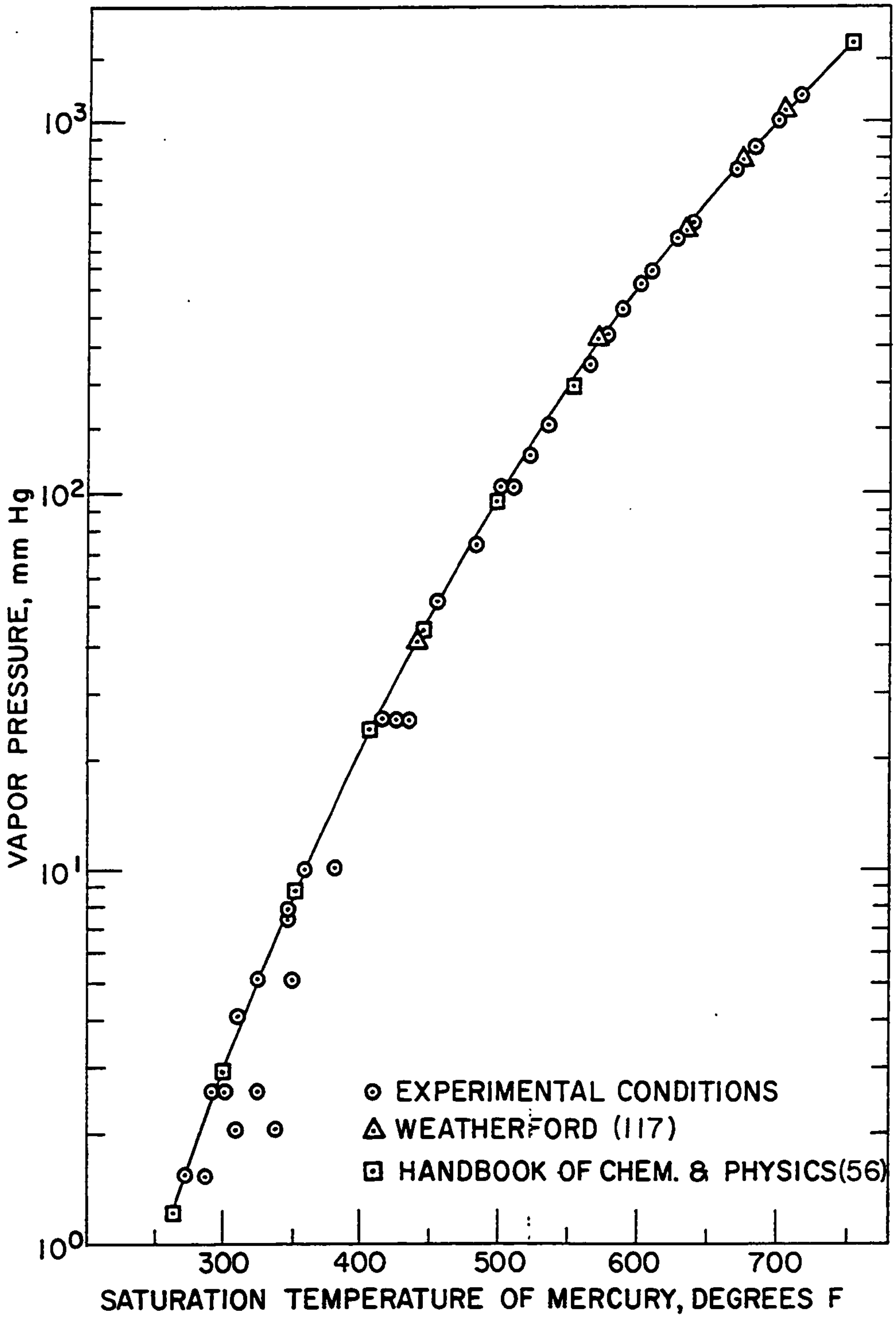

FIGURE B-1. VAPOR PRESSURE CURVE FOR MERCURY.

Pressure Measurements

All pressure measurements for mercury runs were made with a mercury manometer or a cartesian-diver vacuum gauge which was pre-calibrated by the manufacturer. In elevated pressure water runs, a 0-200 psig gauge was used. The calibration curve for this gauge is shown in Figure B-2.

Power Measurements

Heater voltage and current were measured with multi-range Simpson meters which were calibrated against a digital voltmeter. Accuracy of these meters is presented in Appendix E along with an estimate of the expected error involved in each of the foregoing measurements.

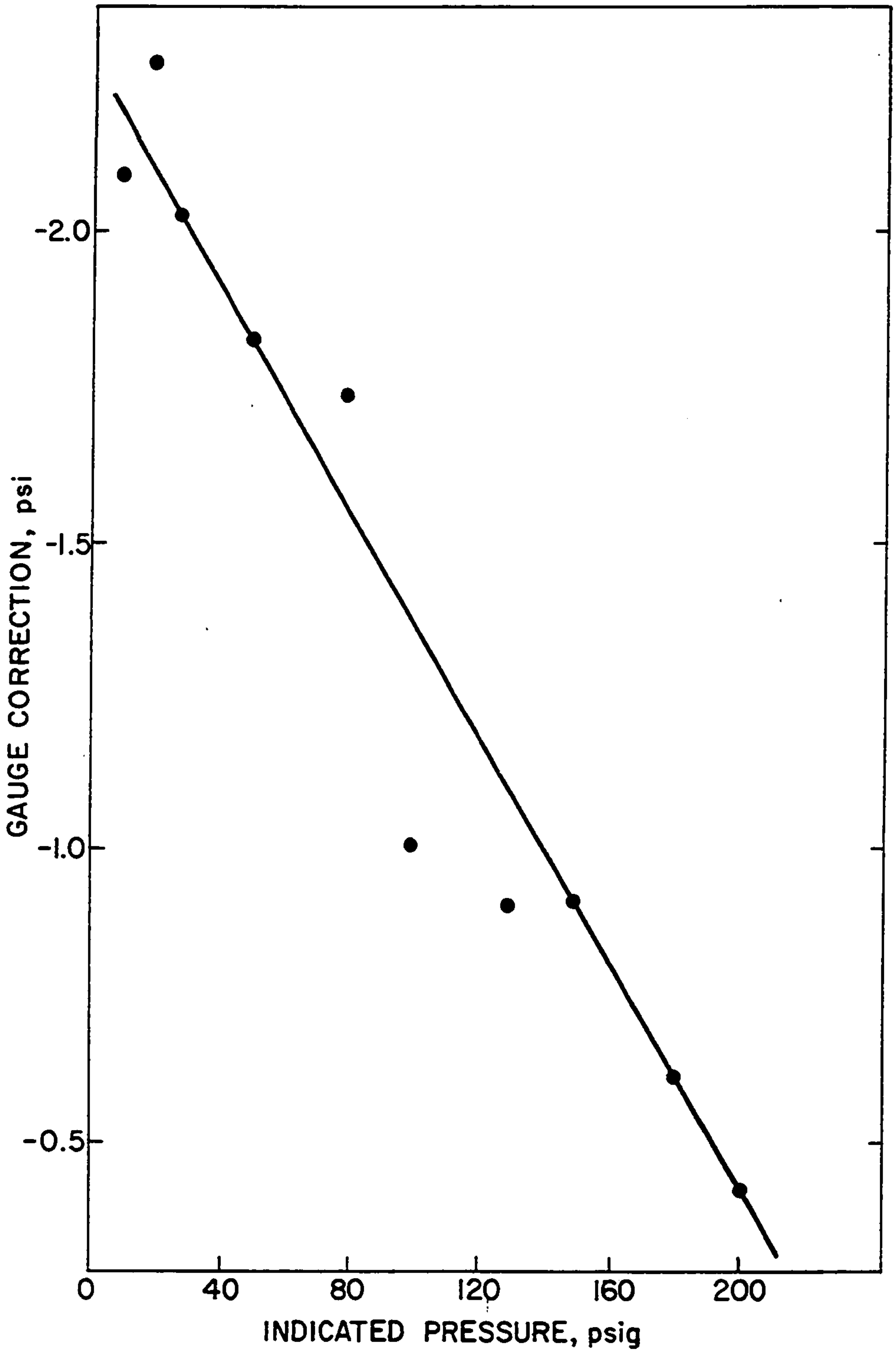

FIGURE B-2. CALIBRATION CURVE FOR PRESSURE GAUGE.

APPENDIX C

DATA REDUCTION

Heater temperature measurements were made with thermocouples imbedded 0.020 inches below the heater surface. It was necessary to extrapolate the measured temperatures to the heater surface. Flat plate extrapolation is not completely accurate for small diameter heaters such as that used in this study and it involves a trial and error procedure for materials whose thermal conductivity varies with temperature. Therefore, a computer program was written to provide accurate radial temperature extrapolations.

Beginning with Fourier's radial heat conduction equation

$$q/A = -k\ (\partial T/\partial r) \tag{C-1}$$

we can replace k by the linear expression C + DT, and A by $2\pi rL$. By separating variables and integrating from (T_1, r_1) to (T_2, r_2), the resulting equation can be solved for T_2

$$T_2 = -\gamma + \sqrt{\gamma^2 - \delta} \tag{C-2}$$

where,

$$\gamma = C/D \tag{C-3}$$

and,

$$\delta = \frac{q\ \ln\left(\frac{r_2}{r_1}\right)}{D\ \pi\ L} - 2\ \gamma\ T_1 - T_1^{\ 2} \tag{C-4}$$

From data appearing in the Metals Handbook (79), a linear expression for thermal conductivity of 304 stainless steel was determined (C=6.64632 and D=0.00425) for T in degrees R.

Letting T_1 be the temperature measured below the heater surface, and T_2 the desired surface temperature, the following program was written for computation on the IBM 360 model 40 computer facility at the University. Using the WATFOR compiling system, compilation time was less than 7 seconds and run time was about 6 seconds per run.

Rather than converting thermocouple readings manually to temperatures, a second-degree Lagrange interpolation was utilized in the computer program. Key values for interpolating Chromel-Alumel readings were obtained from the ASTM Standards (3).

```
$JOB            RS-02101,RUN=CHECK,KP=26
      DIMENSION T(32), E(32), S(4), C(3), TW(3), TDEL(3)
C     INSERT KEY VALUES FOR SECOND-DEGREE LAGRANGE INTERPOLATION
      T(1) = 50.0
      DO 1 I=2,32
    1 T(I)=T(I-1) + 50.0
      E(1)=0.3956
      E(2)=1.5163
      E(3)=2.6621
      E(4)=3.8194
      E(5)=4.9704
      E(6)=6.0904
      E(7)=7.1984
      E(8)=8.3117
      E(9)=9.4311
      E(10)=10.5650
      E(11)=11.7068
      E(12)=12.8566
      E(13)=14.0153
      E(14)=15.1793
      E(15)=16.3514
      E(16)=17.5262
      E(17)=18.7022
      E(18)=19.8979
      E(19)=21.0718
      E(20)=22.2552
      E(21)=23.4402
      E(22)=24.6261
      E(23)=25.8110
      E(24)=26.9850
      E(25)=28.1547
      E(26)=29.3231
      E(27)=30.4867
      E(28)=31.6462
```

```
      E(29)=32.7961
      E(30)=33.9350
      E(31)=35.0690
      E(32)=36.1950
C     PRINT HEADING FOR DATA IN TABULAR FORM
   19 WRITE (6,15)
   15 FORMAT(1H1,35X,9HTABLE II ,/,28X,25H POOL BOILING WATER DATA ,/,5X
     2,21HTEST HEATER--B         ,33X,12HRUN NUMBER--,/,5X,17HSYSTEM PRESS
     3URE--,6X,5H PSIA,28X,6HDATE--,/,23X,34HPOOL DEPTH ABOVE HEATER-- 6
     4 INCHES,/<
      WRITE (6,20)
   20 FORMAT(80H THERMOCOUPLE     HEAT FLUX       T MEASURED     T SURFACE
     2    T BULK       DELTA T ,/,80H    NUMBER       BTU/HR-SQ FT      DEG
     3REES F    DEGREES F    DEGREES F   DEGREES F<
C     READ DATA CARD, PERFORM INTERPOLATION, EXTRAPOLATE TEMPERATURE
C     TO HEATER SURFACE
    2 READ (5,3)VOLT,AMP,S(1),S(2),S(3),S(4)
    3 FORMAT (6F8.4<
C     BLANK CARD INSERTED BETWEEN SETS OF DATA WILL HAVE PROGRAM PRINT
C     NEW HEADING FOR NEXT SET OF DATA
      IF(AMP)19,19,4
    4 CONTINUE
      DO 10 I=1,4
      J=3
    7 IF(S(I) - E(J))9,9,8
    8 J=J + 2
      GO TO 7
    9 G1=(S(I)-E(J-1))*(S(I)-E(J))*T(J-2)/((E(J-2)-E(J-1))*(E(J-2)-E(J))
     1)
      G2=(S(I)-E(J-2))*(S(I)-E(J))*T(J-1)/((E(J-1)-E(J-2))*(E(J-1)-E(J))
     1)
      G3=(S(I)-E(J-2))*(S(I)-E(J-1))*T(J)/((E(J)-E(J-2))*(E(J)-E(J-1)))
   10 S(I)=G1 + G2 + G3
      FLUX=139.1163*AMP*VOLT
```

```
            DO 13 I=1,3
            ALPHA = 1563.84
            S(I)=S(I)+459.69
            BETA = 115.2992*AMP*VOLT-3127.68*S(I)-S(I)**2
            S(I)=S(I)-459.69
         13 TW(I) = -ALPHA+ SQRT(ALPHA**2-BETA)-459.69
            I=3
            J=20
            TDEL(I)=TW(I)-S(4)
         14 WRITE (6,16) J,FLUX,S(I),TW(I),S(4),TDEL(I)
         16 FORMAT(6X,I2,9X,F3.0,8X,F7.2,6X,F7.2,6X,F7.2,5X,F7.2<
      C     PROGRAM WILL SKIP A LINE AFTER PRINTING INFORMATION FROM EACH
      C     DATA CARD
            WRITE (6,18)
         18 FORMAT(1H <
            GO TO 2
         17 CONTINUE
            STOP
            END
```

APPENDIX D

PLOTS AND TABLES OF EXPERIMENTAL DATA

The following plots and tables present the experimental data obtained during the course of this study. In order to have the computer prepare tabular data, it was decided to present the data in final form rather than include raw measurements.

Most headings in the tables are self-explanatory, but the following comments might be helpful to the reader. T MEASURED denotes the temperature measured 0.020 inches below the heater surface. T SURFACE is the temperature obtained by extrapolating to the surface by the method described in Appendix C. T BULK is the temperature measured by the topmost thermocouple in the boiling liquid (very close to saturation temperature at low fluxes, see Appendix B). DELTA T is the difference between T SURFACE and T BULK.

All plots were prepared using data from thermocouple number 20. Other thermocouples demonstrated similar trends and fluctuations (see Chapter IV) but their inclusion on the plots would have caused crowding with resultant reduction in clarity.

TABLE II
POOL BOILING WATER DATA

TEST HEATER--B
SYSTEM PRESSURE--14.25 PSIA

RUN NUMBER--7
DATE--10/11/67

POOL DEPTH ABOVE HEATER-- 6 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	8113.	217.37	215.87	211.30	4.57
20	11452.	222.15	220.03	211.30	8.74
20	21689.	230.40	226.41	211.30	15.11
20	39904.	240.84	233.52	211.30	22.23
20	60864.	249.11	237.99	211.30	26.69
20	79018.	253.54	239.11	211.30	27.81
20	99096.	258.43	240.36	211.30	29.06
20	121240.	258.43	236.30	211.30	25.00
20	146373.	266.44	239.80	211.30	28.50
20	165208.	269.11	239.05	211.30	27.76
20	175325.	270.90	239.01	211.30	27.71
20	185443.	272.68	238.97	211.30	27.67
20	200328.	273.57	237.15	211.30	25.85
20	160741.	275.81	246.65	211.30	35.36

TABLE II
POOL BOILING WATER DATA

TEST HEATER--B
SYSTEM PRESSURE-- 14.25 PSIA
POOL DEPTH ABOVE HEATER-- 6 INCHES
RUN NUMBER-- 7 Cont'd
DATE-- 10/11/67

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	173618.	276.25	244.75	211.30	33.46
20	177332.	278.04	245.89	211.30	34.59
20	184580.	279.83	246.38	211.30	35.08

TABLE II
POOL BOILING WATER DATA

TEST HEATER--B
RUN NUMBER---8
SYSTEM PRESSURE--14.30 PSIA
DATE--10/16/67
POOL DEPTH ABOVE HEATER-- 6 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	44581.	248.68	240.53	210.43	30.10
20	43466.	247.80	239.86	210.43	29.43
20	79413.	260.65	246.20	210.43	35.77
20	132167.	265.99	241.95	210.43	31.52
20	149578.	270.90	243.72	210.43	33.29
20	155985.	272.24	243.90	210.43	33.48
20	169172.	274.02	243.30	210.43	32.87
20	173117.	275.36	243.94	210.43	33.51
20	176820.	276.25	244.17	210.43	33.74
20	180273.	275.81	243.08	210.43	32.65
20	183175.	276.25	243.01	210.43	32.58

TABLE II
POOL BOILING WATER DATA

TEST HEATER--8 RUN NUMBER--9
SYSTEM PRESSURE--14.35 PSIA DATE--10/18/67
POOL DEPTH ABOVE HEATER-- 6 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	20908.	235.62	231.78	211.08	20.70
20	31131.	244.32	238.63	211.08	27.55
20	46126.	252.20	243.79	211.08	32.71
20	59491.	253.98	243.13	211.08	32.05
20	74725.	258.43	244.81	211.08	33.74
20	141298.	267.33	241.63	211.08	30.55
20	99256.	258.43	240.33	211.08	29.25
20	79581.	255.76	241.24	211.08	30.16
20	106495.	260.21	240.80	211.08	29.72
20	106271.	260.21	240.84	211.08	29.76
20	129034.	264.66	241.17	211.08	30.09
20	139485.	266.44	241.06	211.08	29.98
20	151849.	269.11	241.50	211.08	30.42
20	163056.	270.01	240.35	211.08	29.27

TABLE II
POOL BOILING WATER DATA

TEST HEATER--B
SYSTEM PRESSURE-- 14.35 PSIA
RUN NUMBER--9 Cont'd
DATE--10/18/67
POOL DEPTH ABOVE HEATER-- 6 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	169732.	271.34	240.49	211.08	29.41
20	171844.	272.24	241.00	211.08	29.92
20	175533.	273.57	241.69	211.08	30.61
20	162106.	270.90	241.43	211.08	30.35
20	170435.	272.68	241.71	211.08	30.63
20	173116.	273.57	242.13	211.08	31.05
20	176391.	274.91	242.89	211.08	31.81
20	179406.	275.81	243.24	211.08	32.16
20	181867.	275.36	242.34	211.08	31.26
20	185368.	276.25	242.61	211.08	31.53
20	189790.	277.15	242.70	211.08	31.62

TABLE 3

WATER BURNOUT DATA

Heater	Run Number	System Pressure Psia	Determination Method	Burnout Heat Flux Btu/hr-ft^2	Date
A	1	14.10	IFCP[a]	191,000	3/6/67
A	2	13.45	IFCP	224,000	3/13/67
B	3	13.57	IFCP	193,000	7/24/67
B	4	23.5	IFCP	269,000	7/24/67
B	5	33.5	IFCP	299,000	7/24/67
B	6	14.20	IFCP	198,000	9/26/67
B	6	14.20	IFCP	188,000	9/26/67
B	7	14.28	IFCP	200,000	10/11/67
B	7	14.28	IFCP	185,000	10/11/67
B	8	14.32	IFCP	183,000	10/16/67
B	9	14.40	IFCP	190,000	10/18/67
B	10	64.2	DPCF[b]	405,000	10/19/67
B	11	114.2	IFCP	565,000	10/19/67
B	11	114.2	IFCP	622,000	10/19/67
B	12	64.3	IFCP	451,000	11/17/67
B	13	14.15	IFCP	147,000	11/21/67
B	13	14.15	IFCP	145,000	11/21/67
B	14	100.0	IFCP	481,000	11/21/67
B	15	35.2	DPCF	289,000	11/30/67
B	16	214.0	IFCP	790,000	11/30/67
B	16	133.0	DPCF	730,000	11/30/67
B	16	109.0	DPCF	656,000	11/30/67
B	16	95.0	DPCF	581,000	11/30/67

[a]IFCP = Increasing Flux at Constant Pressure

[b]DPCF = Decreasing Pressure at Constant Flux

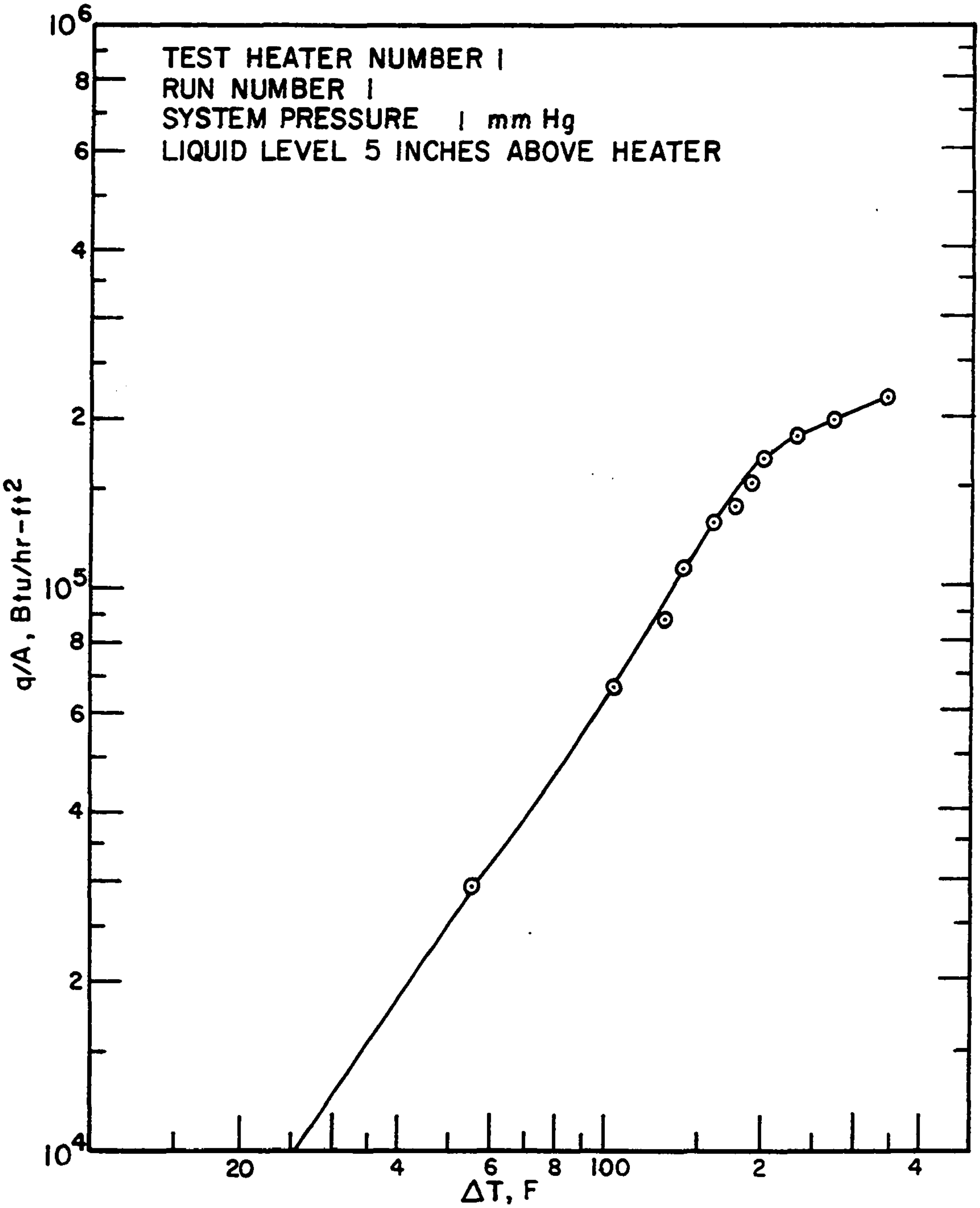

FIGURE D-1. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER---1 RUN NUMBER--- 1

SYSTEM PRESSURE--- 1 MM HG DATE-- 3/28/68

POOL DEPTH ABOVE HEATER--- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	1273.	291.46	291.23	284.30	6.93
21	1273.	286.54	286.31	284.30	2.01
20	8543.	307.62	306.10	282.51	23.59
21	8543.	286.98	285.45	282.51	2.94
20	29284.	342.37	337.23	282.51	54.72
21	29284.	302.23	297.00	282.51	14.49
20	66324.	406.19	394.85	290.57	104.29
21	66324.	346.90	335.27	290.57	44.71
20	87143.	448.61	433.96	311.67	122.30
21	87143.	381.54	366.48	311.67	54.81
20	109450.	478.21	460.02	320.68	139.34
21	109450.	390.51	371.65	320.68	50.97
20	122726.	497.14	476.88	320.68	156.21
21	122726.	394.99	373.87	320.68	53.20
20	137726.	519.09	496.54	325.64	170.91
21	137726.	412.90	389.36	325.64	63.73
20	151025.	534.41	509.83	329.70	180.13
21	151025.	421.84	396.11	329.70	66.41

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 1 Cont'd
SYSTEM PRESSURE--1 MM HG DATE--3/28/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	165521.	558.43	531.72	331.96	199.76
21	165521.	435.24	407.18	331.96	75.22
20	184341.	593.21	563.65	338.29	225.56
21	184341.	453.05	422.01	338.29	83.72
20	198947.	636.43	605.25	343.27	261.98
21	198947.	479.54	446.38	343.27	103.11
20	222270.	709.44	675.53	343.27	332.26
21	222270.	505.93	469.25	343.27	125.98

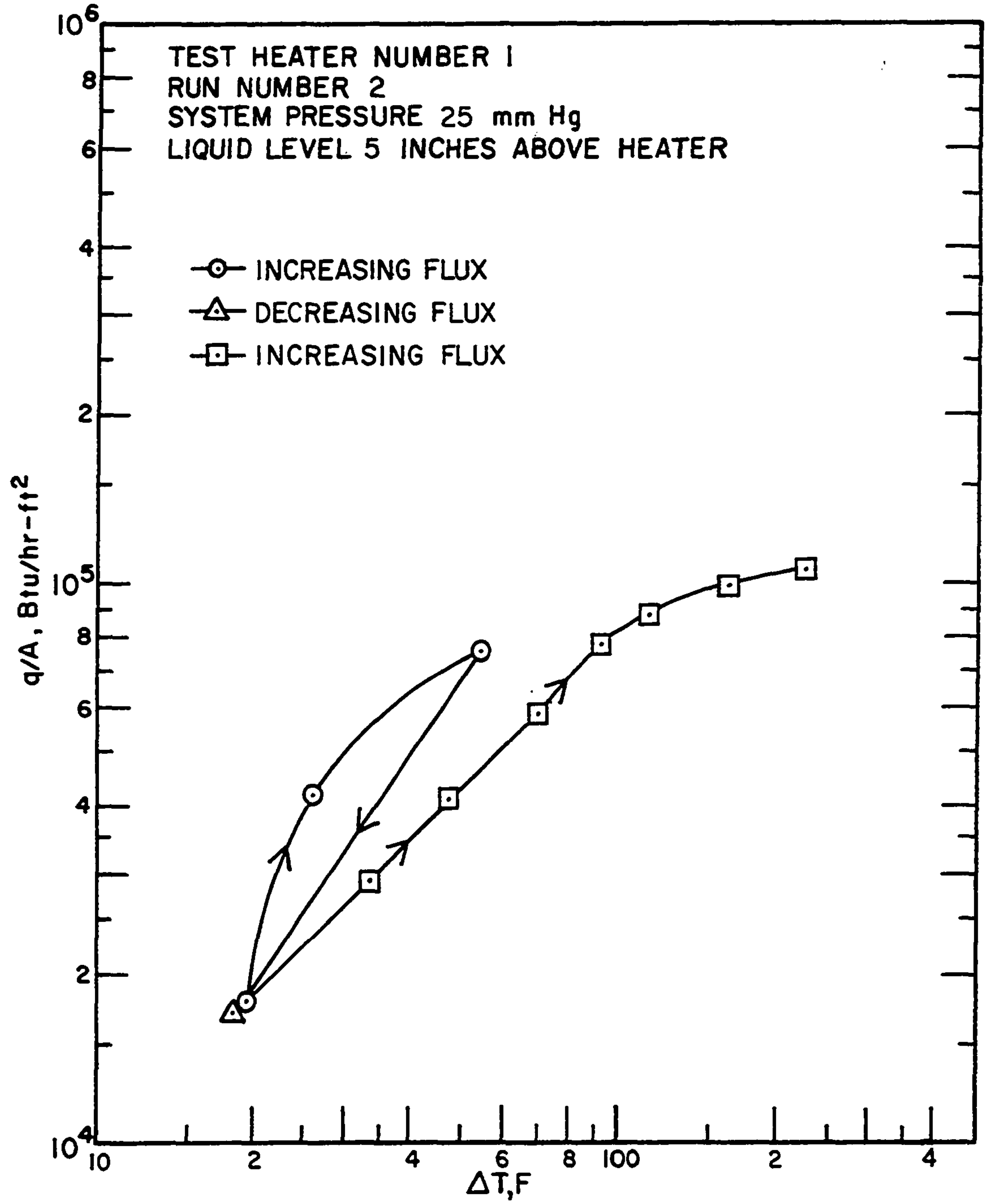

FIGURE D-2. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 2
SYSTEM PRESSURE-- 25.4 MM HG DATE-- 3/28/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	17718.	455.26	452.29	433.01	19.29
21	17718.	446.39	443.41	433.01	10.40
20	42292.	468.51	461.47	435.24	26.23
21	42292.	486.14	479.15	435.24	43.91
20	75301.	503.73	491.36	437.47	53.89
21	75301.	523.47	511.19	437.47	73.72
20	2938.	435.24	434.74	429.44	5.31
21	2938.	427.65	427.15	429.44	-2.28
20	17629.	454.82	451.87	433.01	18.86
21	17629.	445.05	442.09	433.01	9.08
20	28607.	475.13	470.38	437.47	32.91
21	28607.	459.68	454.90	437.47	17.43
20	40326.	490.55	483.89	436.58	47.31
21	40326.	472.92	466.22	436.58	29.64
20	57930.	514.71	505.23	436.58	68.65
21	57930.	490.55	480.98	436.58	44.40
20	77009.	540.97	528.49	437.47	91.03
21	77009.	508.12	495.49	437.47	58.02

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 | RUN NUMBER--2 Cont'd
SYSTEM PRESSURE-- 25.4 MM HG | DATE--3/28/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	85889.	562.79	548.99	436.13	112.86
21	85889.	514.71	500.64	436.13	64.51
20	85889.	584.53	570.85	439.70	131.15
21	85889.	527.85	513.86	439.70	74.16
20	98161.	612.70	597.22	437.47	159.75
21	98161.	534.41	518.46	437.47	80.99
20	107162.	670.86	654.33	437.47	216.86
21	107162.	554.07	536.78	437.47	99.31

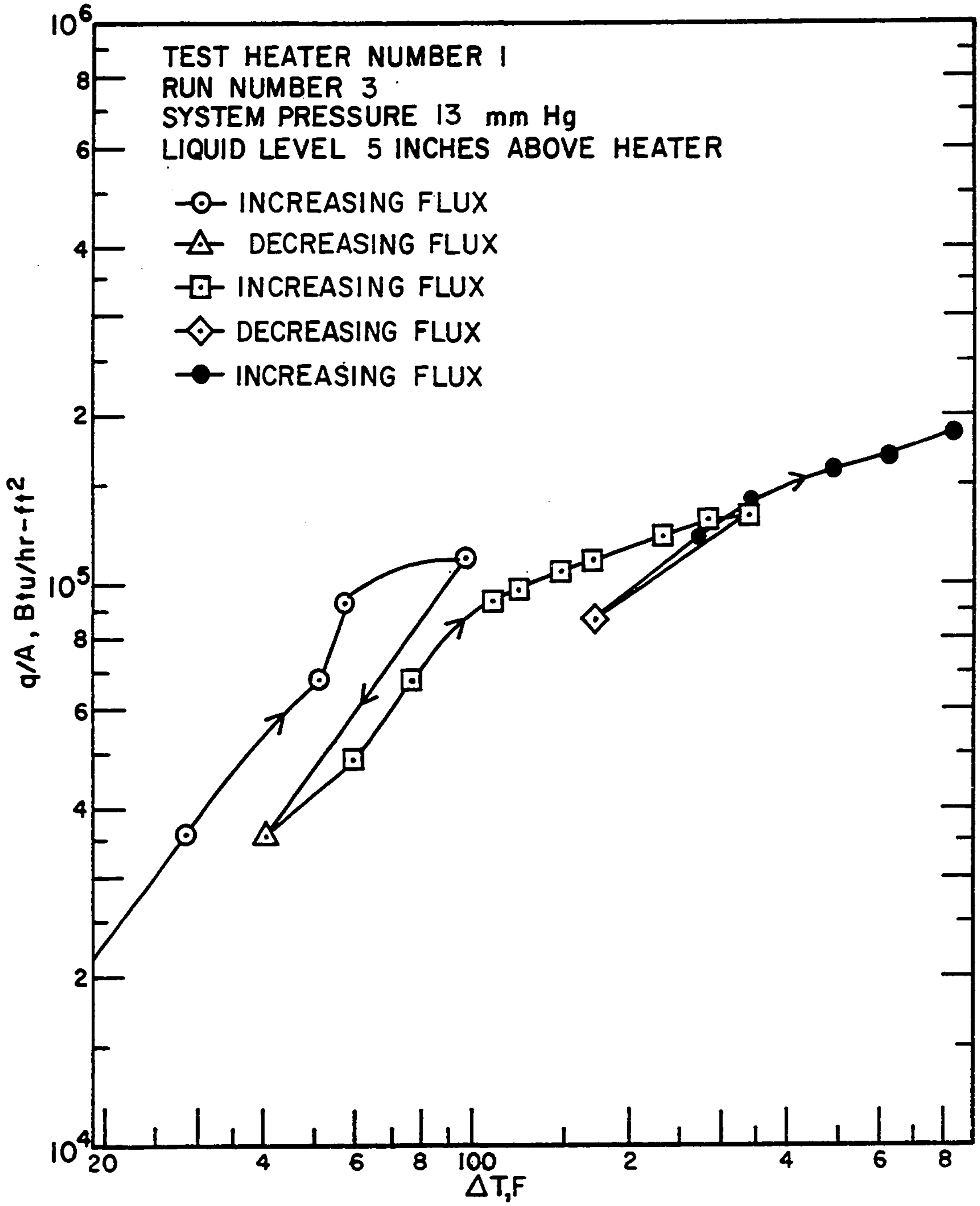

FIGURE D-3. MERCURY RESULTS

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER---1
SYSTEM PRESSURE--- 12.7 MM HG
POOL DEPTH ABOVE HEATER--- 5 INCHES

RUN NUMBER--- 3
DATE--- 4/2/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	15282.	343.72	341.05	327.44	13.60
21	15282.	337.39	334.70	327.44	7.26
20	35786.	374.81	368.61	340.55	28.06
21	35786.	367.17	360.96	340.55	20.40
20	68043.	421.84	410.29	359.07	51.21
21	68043.	403.51	391.86	359.07	32.79
20	92301.	460.56	445.12	387.82	57.29
21	92301.	454.82	439.33	387.82	51.51
20	113380.	514.71	496.13	399.48	96.65
21	113380.	487.02	468.24	399.48	68.76
20	35698.	438.81	432.79	392.75	40.04
21	35698.	426.31	420.26	392.75	27.51
20	49915.	457.47	449.12	390.51	58.60
21	49915.	437.47	429.05	390.51	38.54
20	69447.	481.74	470.23	394.55	75.68
21	69447.	449.51	437.84	394.55	43.29
20	90548.	521.28	506.49	397.24	109.26
21	90548.	471.60	456.52	397.24	59.28

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 12.7 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER--3 Cont'd
DATE-- 4/2/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	97799.	534.41	518.52	399.48	119.04
21	97799.	479.10	462.85	399.48	63.37
20	106875.	562.79	545.60	397.24	148.37
21	106875.	488.35	470.65	397.24	73.41
20	114725.	578.02	559.68	397.24	162.44
21	114725.	488.35	469.35	397.24	72.11
20	126834.	645.04	625.27	397.24	228.04
21	126834.	514.71	493.91	397.24	96.68
20	134095.	696.60	676.10	397.24	278.86
21	134095.	543.15	521.41	397.24	124.18
20	141934.	752.07	730.80	397.24	333.56
21	141934.	562.79	539.94	397.24	142.71
20	87504.	575.84	561.86	397.24	164.62
21	87504.	488.35	473.87	397.24	76.63
20	87916.	571.49	557.42	397.24	160.18
21	87916.	487.02	472.47	397.24	75.23
20	119925.	683.74	665.32	397.24	268.09
21	119925.	516.90	497.26	397.24	100.02

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 12.7 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER-- 3 Cont'd
DATE-- 4/2/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	134387.	764.84	744.80	399.48	345.32
21	134387.	562.79	541.16	399.48	141.69
20	151401.	904.73	883.23	397.24	485.99
21	151401.	580.19	555.98	397.24	158.74
20	164035.	1031.43	1009.10	398.13	610.97
21	164035.	636.43	610.75	398.13	212.62
20	180115.	1243.38	1220.45	399.48	820.97
21	180115.	675.16	647.36	399.48	247.88

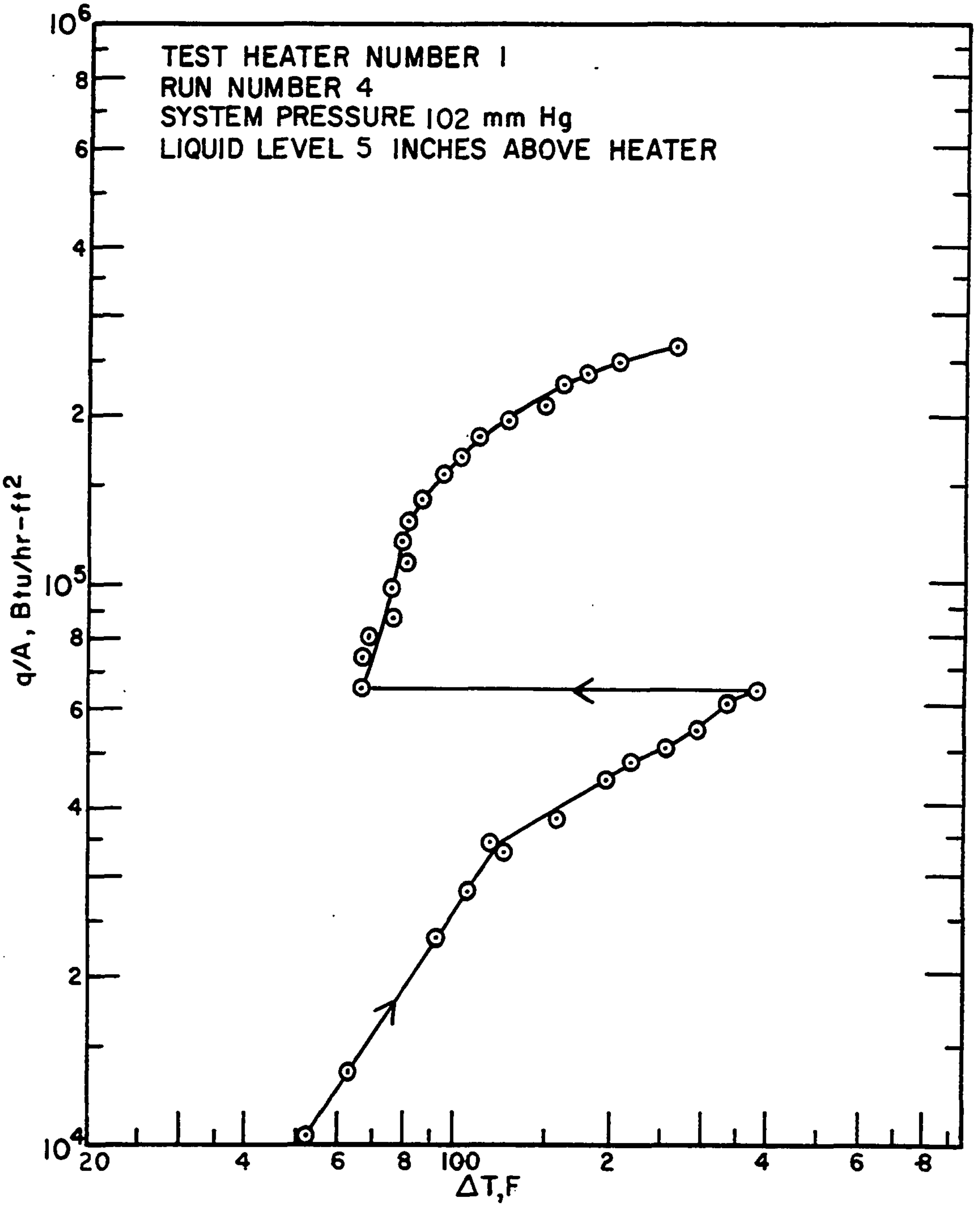

FIGURE D-4. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER---1 RUN NUMBER---4
SYSTEM PRESSURE--- 102 MM HG DATE---4/16/68
POOL DEPTH ABOVE HEATER--- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	18844.	558.43	555.40	512.51	42.89
21	18844.	545.77	542.73	512.51	30.22
20	40657.	632.12	625.77	513.39	112.38
21	40657.	584.53	578.07	513.39	64.68
20	38730.	593.21	587.07	513.39	73.68
21	38730.	620.47	614.40	513.39	101.01
20	27764.	578.02	573.59	512.95	60.64
21	27764.	594.08	589.68	512.95	76.73
20	10387.	564.96	563.30	512.07	51.23
21	10387.	548.39	546.72	512.07	34.65
20	14223.	576.71	574.44	512.51	61.93
21	14223.	560.61	558.32	512.51	45.81
20	23243.	607.07	603.41	512.51	90.90
21	23243.	584.53	580.84	512.51	68.32
20	27877.	623.50	619.13	512.51	106.62
21	27877.	596.68	592.27	512.51	79.75
20	33108.	640.74	635.58	513.39	122.19
21	33108.	610.53	605.32	513.39	91.93

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--4 Cont'd
SYSTEM PRESSURE--102 MM HG DATE--4/16/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	32809.	640.74	635.63	512.51	123.12
21	32809.	611.83	606.67	512.51	94.15
20	38997.	675.16	669.16	511.64	157.53
21	38997.	635.14	629.05	511.64	117.42
20	45141.	711.58	704.73	512.51	192.22
21	45141.	657.96	650.97	512.51	138.46
20	49192.	739.31	731.92	512.51	219.40
21	49192.	676.45	668.89	512.51	156.37
20	51729.	773.35	765.68	512.51	253.17
21	51729.	700.89	693.00	512.51	180.49
20	54061.	808.24	800.32	512.51	287.81
21	54061.	739.31	731.18	512.51	218.67
20	61187.	854.12	845.30	513.39	331.91
21	61187.	771.23	762.14	513.39	248.75
20	65886.	904.73	895.39	512.95	382.44
21	65886.	805.27	795.60	512.95	282.65
20	66656.	588.87	578.28	512.51	65.77
21	66656.	577.58	566.94	512.51	54.43

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 | RUN NUMBER--4 Cont'd
SYSTEM PRESSURE-- 102 MM HG | DATE--4/16/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	73788.	590.18	578.45	512.95	65.50
21	73788.	580.19	568.42	512.95	55.47
20	78938.	594.08	581.55	513.83	67.72
21	78938.	589.74	577.19	513.83	63.37
20	88391.	601.88	587.89	512.95	74.94
21	88391.	595.38	581.36	512.95	68.40
20	99719.	606.21	590.45	513.39	77.06
21	99719.	597.55	581.73	513.39	68.34
20	108678.	610.53	593.38	512.95	80.43
21	108678.	601.88	584.67	512.95	71.72
20	118210.	610.53	591.87	512.51	79.36
21	118210.	604.04	585.33	512.51	72.82
20	128705.	614.86	594.56	512.51	82.05
21	128705.	605.78	585.41	512.51	72.90
20	138531.	621.34	599.54	512.95	86.59
21	138531.	610.53	588.65	512.95	75.70
20	153585.	632.12	608.05	513.83	94.22
21	153585.	621.34	597.16	513.83	83.33

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--4 Cont'd
SYSTEM PRESSURE-- 102 MM HG DATE-- 4/16/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	166384.	640.74	614.73	512.95	101.78
21	166384.	627.81	601.68	512.95	88.73
20	180075.	649.34	621.28	512.51	108.76
21	180075.	629.97	601.69	512.51	89.18
20	190367.	670.86	641.42	512.51	128.91
21	190367.	635.14	605.30	512.51	92.79
20	206561.	694.46	662.78	513.39	149.39
21	206561.	629.54	597.07	513.39	83.68
20	225191.	707.30	672.91	513.39	159.52
21	225191.	634.28	598.93	513.39	85.54
20	232520.	725.24	689.96	513.39	176.57
21	232520.	638.59	602.14	513.39	88.75
20	248019.	764.84	727.73	513.39	214.34
21	248019.	645.04	606.24	513.39	92.85
20	262235.	820.15	781.68	513.83	267.85
21	262235.	670.86	630.22	513.83	116.39

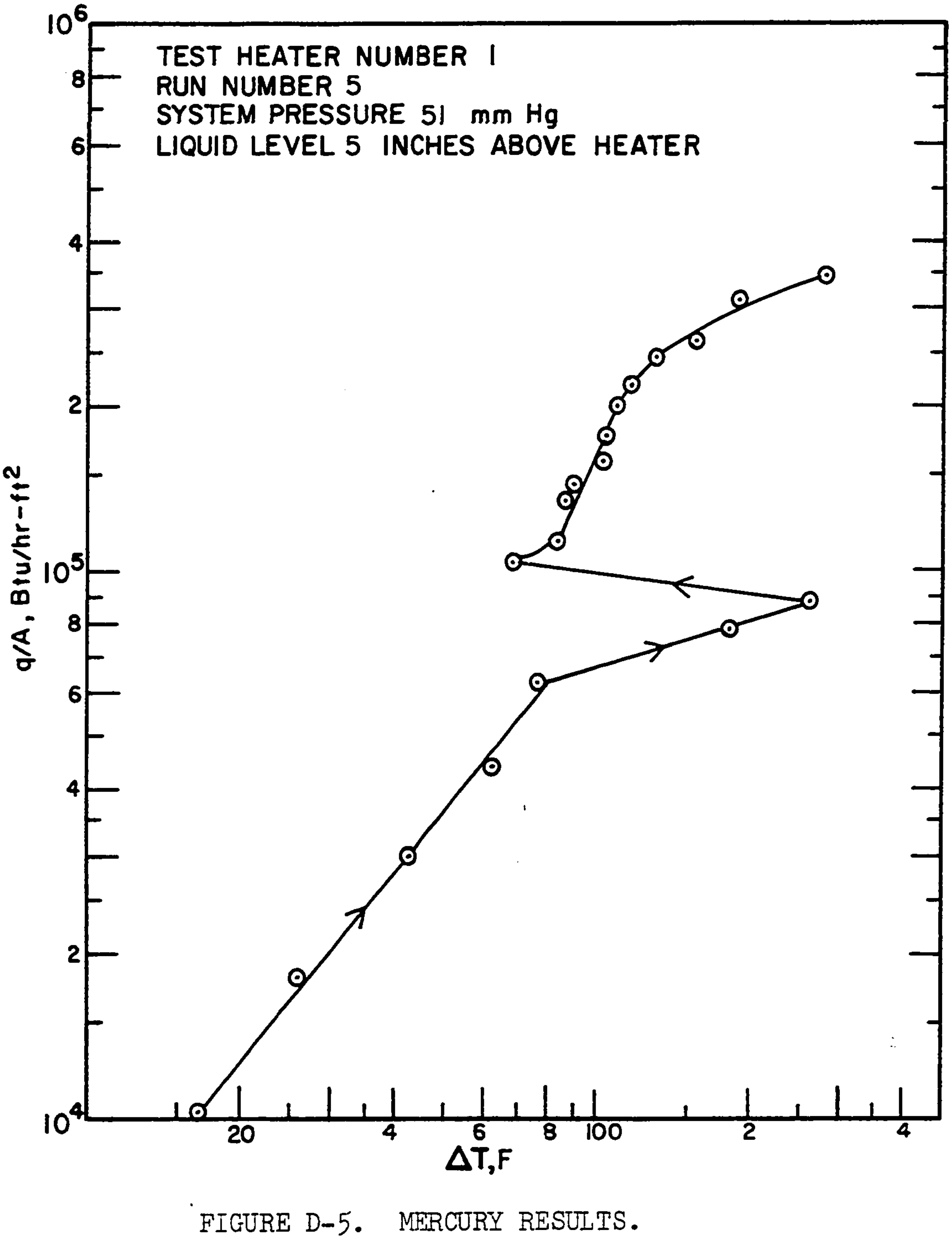

FIGURE D-5. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--5
SYSTEM PRESSURE--51 MM HG DATE--4/16/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	10319.	487.02	485.32	468.51	16.81
21	10319.	477.33	475.62	468.51	7.11
20	18390.	497.14	494.12	467.63	26.49
21	18390.	484.82	481.78	467.63	14.15
20	29916.	514.71	509.82	467.19	42.63
21	29916.	501.54	496.62	467.19	29.43
20	44562.	536.60	529.38	467.63	61.75
21	44562.	514.71	507.42	467.63	39.79
20	62102.	554.94	544.94	468.95	75.99
21	62102.	534.41	524.33	468.95	55.38
20	78490.	662.26	650.12	468.51	181.61
21	78490.	597.55	585.11	468.51	116.60
20	88867.	739.31	725.94	469.39	256.55
21	88867.	666.56	652.84	469.39	183.44
20	104037.	556.25	539.48	469.84	69.65
21	104037.	555.38	538.60	469.84	68.77
20	114616.	573.67	555.32	470.72	84.60
21	114616.	571.49	553.13	470.72	82.41

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 51 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER-- 5 Cont'd
DATE--4/16/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	130035.	580.19	559.41	470.28	89.13
21	130035.	574.97	554.15	470.28	83.88
20	141031.	582.36	559.84	469.84	90.00
21	141031.	580.19	557.65	469.84	87.81
20	155710.	597.55	572.81	469.39	103.42
21	155710.	585.84	560.99	469.39	91.59
20	175137.	601.88	574.09	469.39	104.69
21	175137.	591.04	563.14	469.39	93.74
20	200059.	614.86	583.25	470.72	112.53
21	200059.	600.58	568.79	470.72	98.08
20	219359.	623.50	588.93	470.72	118.21
21	219359.	603.18	568.34	470.72	97.62
20	244491.	642.89	604.62	470.28	134.34
21	244491.	608.37	569.59	470.28	99.31
20	267004.	668.71	627.30	471.16	156.14
21	267004.	623.50	581.36	471.16	110.20
20	303831.	705.16	658.63	471.16	187.47
21	303831.	635.14	587.35	471.16	116.19

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--5 Cont'd
SYSTEM PRESSURE-- 51 MM HG DATE--4/16/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	343300.	798.88	748.02	471.60	276.42
21	343300.	653.65	599.97	471.60	128.37

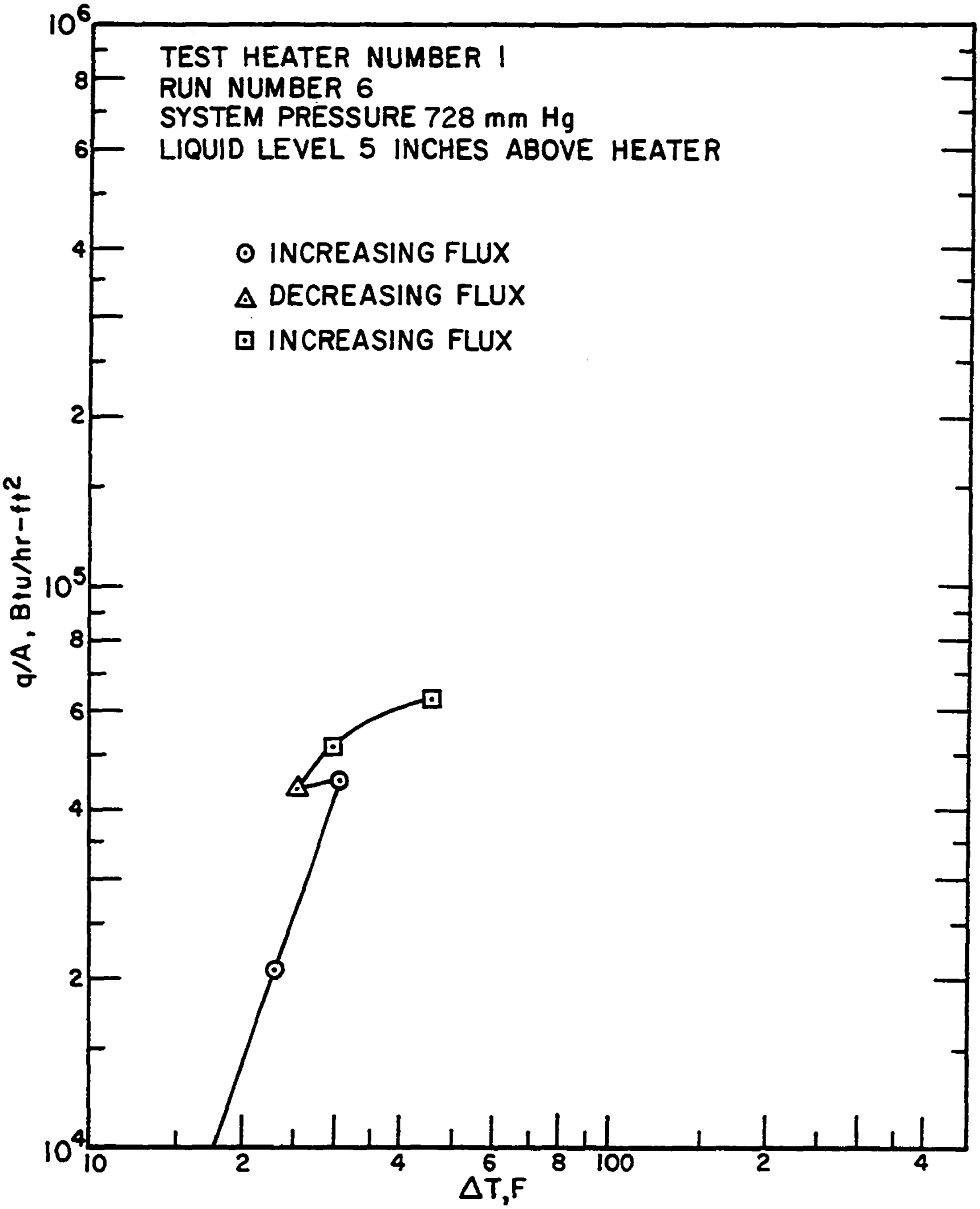

FIGURE D-6. MERCURY RESULTS

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--6
SYSTEM PRESSURE--728 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	5234.	678.59	677.79	672.15	5.64
21	5234.	678.59	677.79	672.15	5.64
20	21235.	696.60	693.37	670.00	23.36
21	21235.	683.74	680.49	670.00	10.49
20	45442.	708.16	701.26	670.86	30.39
21	45442.	703.03	696.11	670.86	25.25
20	44429.	704.31	697.55	672.15	25.40
21	44429.	700.89	694.12	672.15	21.97
20	51000.	709.01	701.27	672.15	29.12
21	51000.	707.30	699.55	672.15	27.40
20	64639.	726.52	716.76	672.15	44.61
21	64639.	739.31	729.59	672.15	57.44

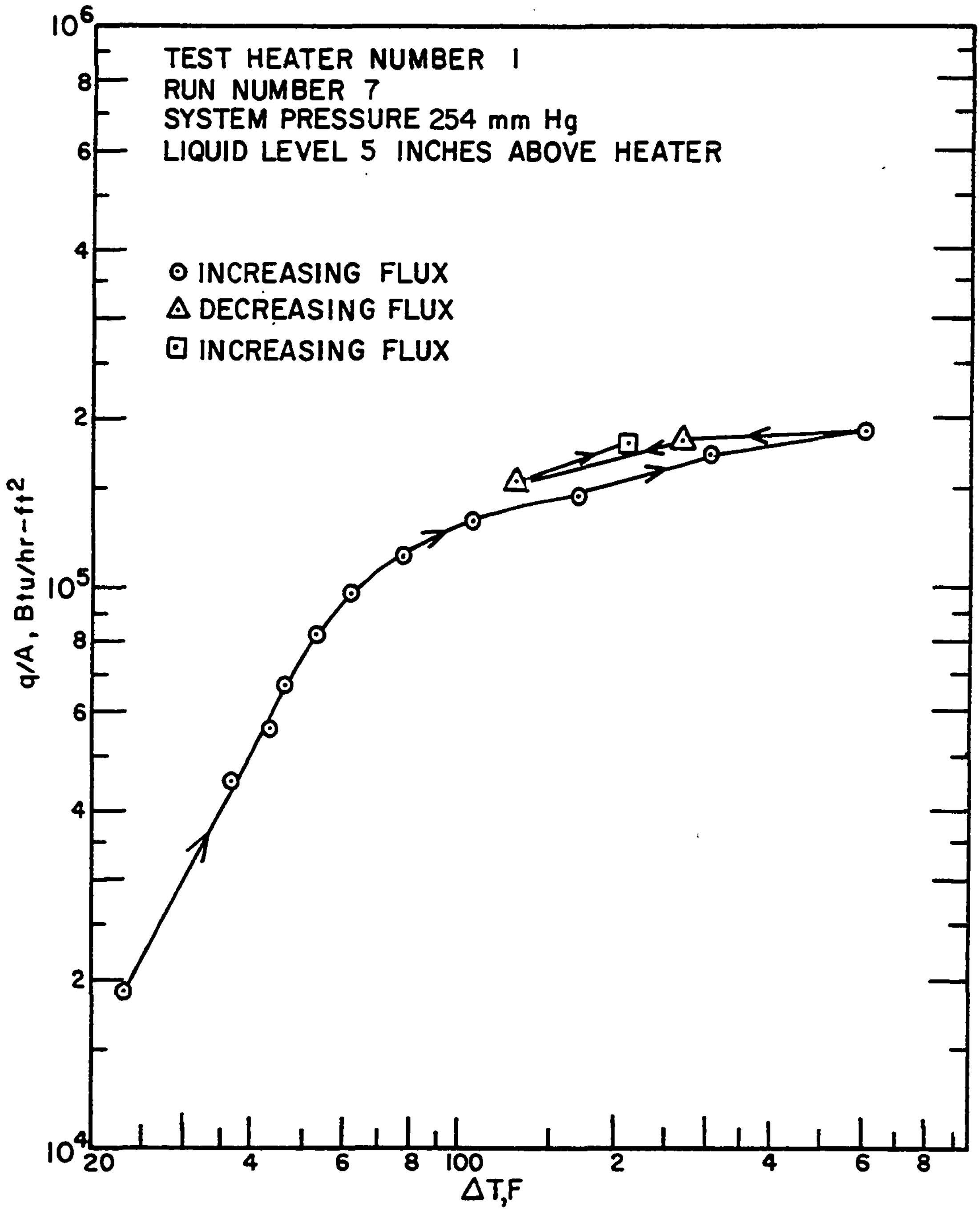

FIGURE D-7. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--7
SYSTEM PRESSURE--254 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	19165.	604.04	601.02	578.45	22.57
21	19165.	594.51	591.48	578.45	13.03
20	45196.	622.63	615.55	578.02	37.53
21	45196.	624.36	617.28	578.02	39.26
20	56168.	630.40	621.61	578.45	43.16
21	56168.	630.83	622.05	578.45	43.59
20	67665.	636.00	625.44	578.45	46.98
21	67665.	635.57	625.00	578.45	46.55
20	81734.	642.46	629.72	577.15	52.58
21	81734.	640.74	627.99	577.15	50.85
20	98556.	655.80	640.52	578.02	62.50
21	98556.	649.34	634.02	578.02	56.00
20	115923.	673.01	655.14	577.15	77.99
21	115923.	658.82	640.85	577.15	63.70
20	133338.	706.88	686.56	578.02	108.55
21	133338.	670.86	650.28	578.02	72.26
20	148168.	764.84	742.73	578.02	164.72
21	148168.	670.86	647.98	578.02	69.96

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 254 MM HG
RUN NUMBER-- 7 Cont'd
DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	171648.	904.73	880.34	577.15	303.19
21	171648.	747.81	722.03	577.15	144.88
20	180896.	1200.64	1177.30	577.15	600.16
21	180896.	832.91	806.54	577.15	229.39
20	179512.	869.72	843.89	577.58	266.31
21	179512.	741.43	714.40	577.58	136.81
20	150803.	726.95	704.13	576.71	127.42
21	150803.	683.74	660.56	576.71	83.85
20	175081.	811.65	785.94	577.15	208.79
21	175081.	713.72	687.08	577.15	109.93

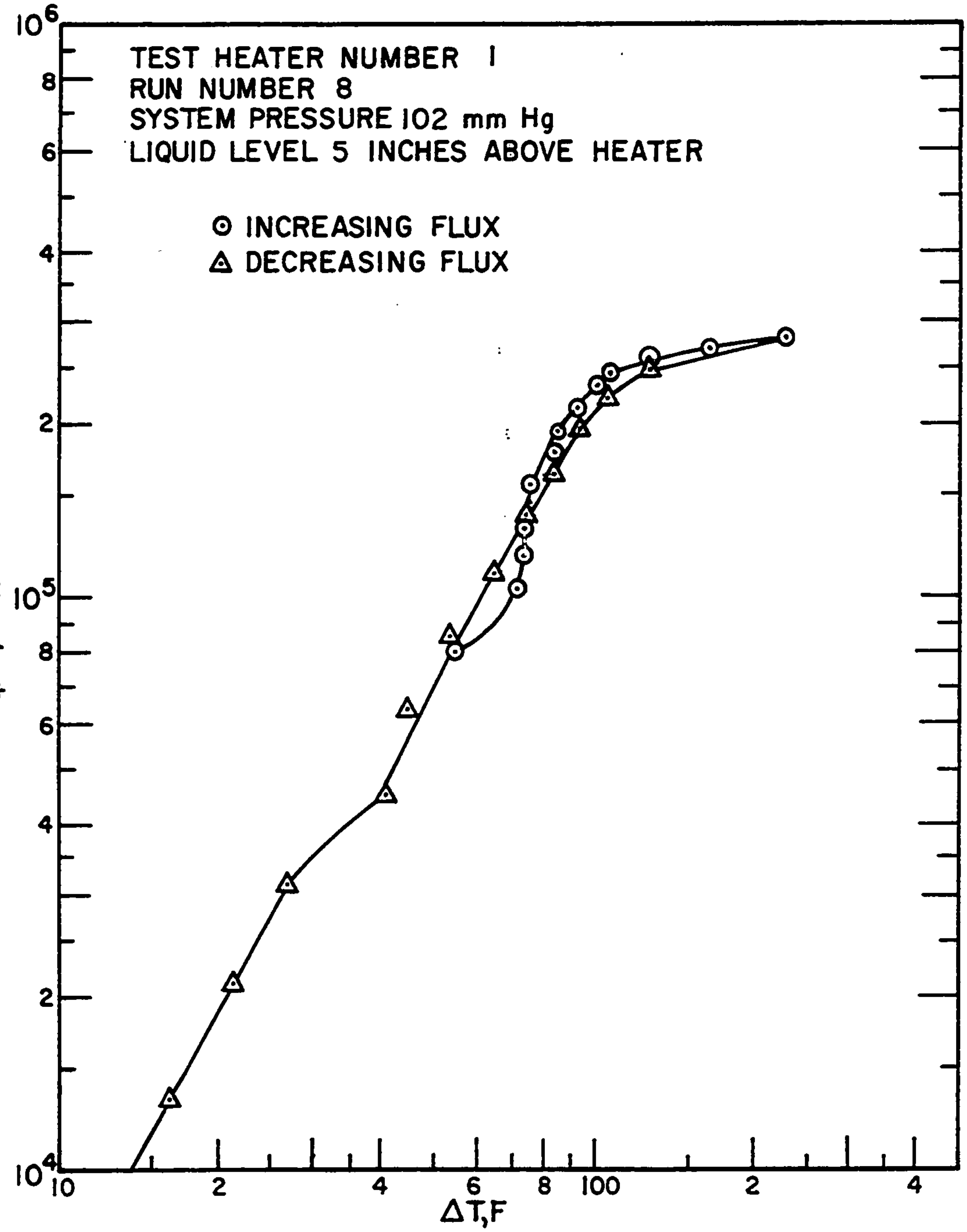

FIGURE D-8. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 8
SYSTEM PRESSURE--102 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	80131.	575.84	563.04	508.12	54.91
21	80131.	571.49	558.67	508.12	50.54
20	102167.	594.95	578.73	508.12	70.60
21	102167.	584.53	568.25	508.12	60.12
20	115730.	599.71	581.37	508.56	72.80
21	115730.	588.87	570.45	508.56	61.89
20	128499.	601.88	581.52	508.56	72.95
21	128499.	569.32	548.70	508.56	40.13
20	154912.	610.53	586.05	509.44	76.61
21	154912.	599.71	575.13	509.44	65.69
20	173384.	621.34	594.03	510.32	83.71
21	173384.	606.21	578.74	510.32	68.42
20	187596.	625.65	596.15	509.88	86.27
21	187596.	614.86	585.23	509.88	75.35
20	205110.	633.42	601.23	509.88	91.35
21	205110.	623.50	591.19	509.88	81.31
20	223015.	645.04	610.18	509.88	100.30
21	223015.	627.81	592.72	509.88	82.84

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--8 Cont'd
SYSTEM PRESSURE-- 102 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	235135.	657.96	621.37	509.44	111.93
21	235135.	636.43	599.54	509.44	90.10
20	253916.	675.16	635.88	509.88	126.00
21	253916.	645.04	605.32	509.88	95.44
20	267144.	713.72	672.97	509.88	163.09
21	267144.	657.96	616.35	509.88	106.47
20	285468.	777.61	735.06	509.88	225.18
21	285468.	673.01	628.78	509.88	118.90
20	248290.	673.01	634.58	509.88	124.70
21	248290.	645.04	606.20	509.88	96.32
20	216021.	649.34	615.64	510.32	105.32
21	216021.	627.81	593.83	510.32	83.51
20	189154.	629.97	600.26	509.44	90.82
21	189154.	617.02	587.16	509.44	77.72
20	162043.	617.02	591.46	509.44	82.02
21	162043.	602.75	577.05	509.44	67.61
20	131731.	604.04	583.19	509.88	73.31
21	131731.	588.87	567.89	509.88	58.01

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--8 Cont'd
SYSTEM PRESSURE--102 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	107977.	595.38	578.24	512.51	65.73
21	107977.	580.19	562.95	512.51	50.43
20	83096.	580.19	566.93	512.51	54.42
21	83096.	571.49	558.19	512.51	45.68
20	62155.	567.14	557.18	511.20	45.98
21	62155.	560.61	550.62	511.20	39.42
20	45886.	558.43	551.05	509.44	41.61
21	45886.	547.52	540.11	509.44	30.67
20	32366.	543.15	537.92	511.20	26.73
21	32366.	538.78	533.54	511.20	22.35
20	21335.	535.72	532.27	511.20	21.07
21	21335.	528.73	525.26	511.20	14.06
20	12854.	527.85	525.76	508.56	17.20
21	12854.	522.16	520.06	508.56	11.50
20	6121.	521.28	520.28	509.88	10.40
21	6121.	514.71	513.71	509.88	3.83

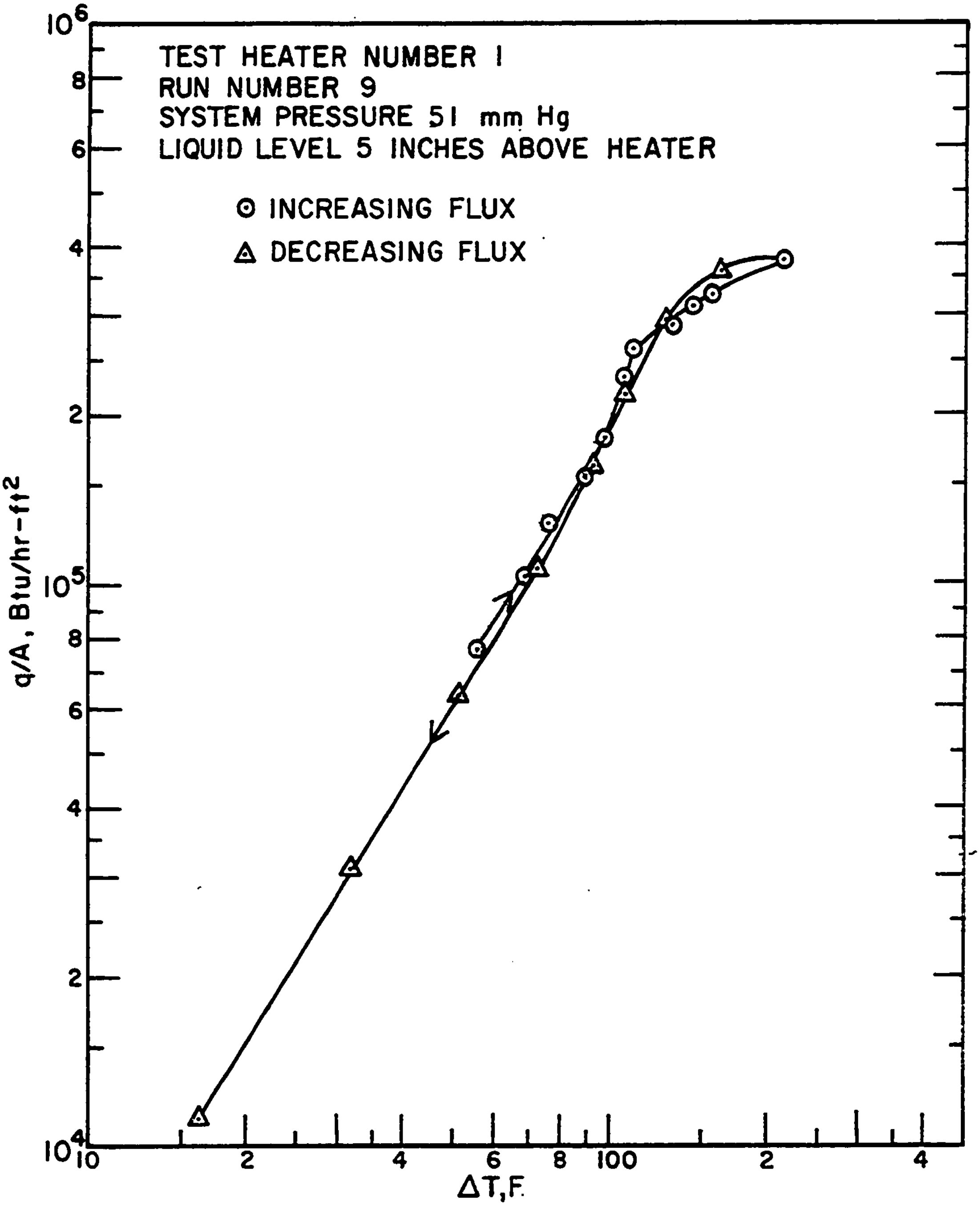

FIGURE D-9. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 51 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER-- 9
DATE-- 4/22/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	78351.	536.60	523.88	467.19	56.70
21	78351.	523.47	510.69	467.19	43.50
20	101615.	554.07	537.68	468.51	69.17
21	101615.	540.97	524.50	468.51	55.98
20	125259.	564.96	544.83	468.51	76.32
21	125259.	551.89	531.65	468.51	63.14
20	158696.	582.36	557.00	467.63	89.37
21	158696.	564.96	539.43	467.63	71.80
20	184045.	591.04	561.71	466.30	95.40
21	184045.	573.67	544.14	466.30	77.83
20	221607.	606.21	571.05	465.42	105.63
21	221607.	586.70	551.28	465.42	85.86
20	253856.	619.18	579.07	465.42	113.65
21	253856.	601.88	561.50	465.42	96.08
20	283630.	636.43	591.87	464.98	126.89
21	283630.	613.99	569.05	464.98	104.07
20	311644.	651.50	602.77	465.42	137.35
21	311644.	627.81	578.65	465.42	113.22

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--9 Cont'd
SYSTEM PRESSURE-- 51 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	335687.	670.86	618.73	466.30	152.42
21	335687.	640.74	588.00	466.30	121.70
20	373278.	735.05	678.39	465.42	212.97
21	373278.	657.96	599.64	465.42	134.21
20	349751.	681.60	627.48	466.30	161.17
21	349751.	642.89	587.97	466.30	121.66
20	289701.	640.74	595.29	466.75	128.54
21	289701.	619.18	573.35	466.75	106.61
20	216071.	606.21	571.94	466.30	105.63
21	216071.	586.70	552.17	466.30	85.87
20	158743.	582.36	556.99	466.30	90.69
21	158743.	564.96	539.42	466.30	73.12
20	103809.	556.25	539.52	465.42	74.10
21	103809.	547.52	530.73	465.42	65.31
20	62952.	527.85	517.60	466.30	51.30
21	62952.	519.09	508.81	466.30	42.50
20	31585.	503.29	498.11	466.30	31.80
21	31585.	495.82	490.62	466.30	24.32

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--9 Cont'd
SYSTEM PRESSURE-- 51 MM HG DATE-- 4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	12080.	483.94	481.94	465.42	16.52
21	12080.	479.54	477.54	465.42	12.11

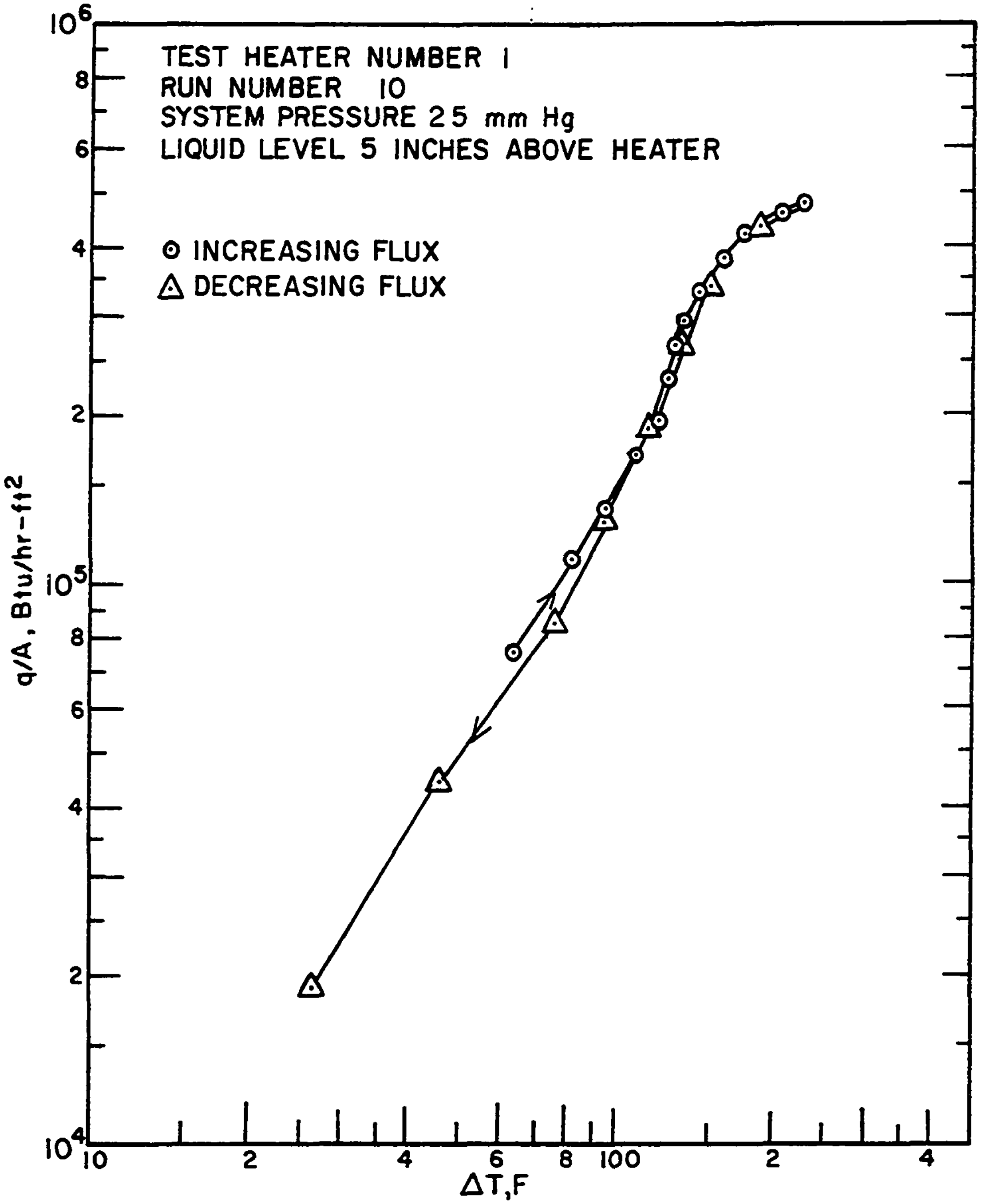

FIGURE D-10. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 10
SYSTEM PRESSURE-- 25 MM HG DATE-- 4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	77321.	503.73	491.02	427.20	63.82
21	77321.	498.90	486.17	427.20	58.96
20	113130.	527.85	509.41	428.10	81.31
21	113130.	514.71	496.17	428.10	68.07
20	138894.	545.34	522.83	427.20	95.63
21	138894.	527.85	505.19	427.20	77.98
20	164119.	567.14	540.75	427.20	113.55
21	164119.	547.52	520.93	427.20	93.73
20	196438.	575.84	544.34	427.20	117.13
21	196438.	551.89	520.08	427.20	92.88
20	225209.	588.01	552.02	429.44	122.59
21	225209.	567.14	530.86	429.44	101.43
20	256260.	597.55	556.71	428.54	128.17
21	256260.	571.49	530.24	428.54	101.70
20	291311.	610.53	564.30	427.20	137.09
21	291311.	584.53	537.83	427.20	110.62
20	329429.	625.65	573.61	427.20	146.41
21	329429.	599.71	547.15	427.20	119.94

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--10 Cont'd
SYSTEM PRESSURE--25 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	372495.	649.34	590.95	427.20	163.75
21	372495.	619.18	560.11	427.20	132.90
20	414876.	673.01	608.48	427.20	181.28
21	414876.	636.43	570.99	427.20	143.79
20	443099.	703.03	634.83	428.54	206.28
21	443099.	645.04	575.32	428.54	146.78
20	458462.	722.25	652.17	429.44	222.73
21	458462.	651.50	579.50	429.44	150.07
20	419616.	683.74	618.73	428.54	190.19
21	419616.	638.59	572.44	428.54	143.90
20	334715.	631.26	578.49	428.54	149.95
21	334715.	604.04	550.71	428.54	122.17
20	262341.	599.71	557.94	428.54	129.39
21	262341.	578.02	535.89	428.54	107.34
20	193801.	571.49	540.36	427.20	113.15
21	193801.	549.70	518.30	427.20	91.10
20	132769.	545.34	523.83	428.54	95.29
21	132769.	532.23	510.61	428.54	82.06

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--10 Cont'd
SYSTEM PRESSURE--25 MM HG DATE--4/22/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	84984.	508.12	494.17	427.20	66.97
21	84984.	497.14	483.13	427.20	55.93
20	45141.	477.33	469.84	422.74	47.10
21	45141.	472.92	465.42	422.74	42.68
20	19165.	453.05	449.84	423.18	26.65
21	19165.	448.61	445.40	423.18	22.21

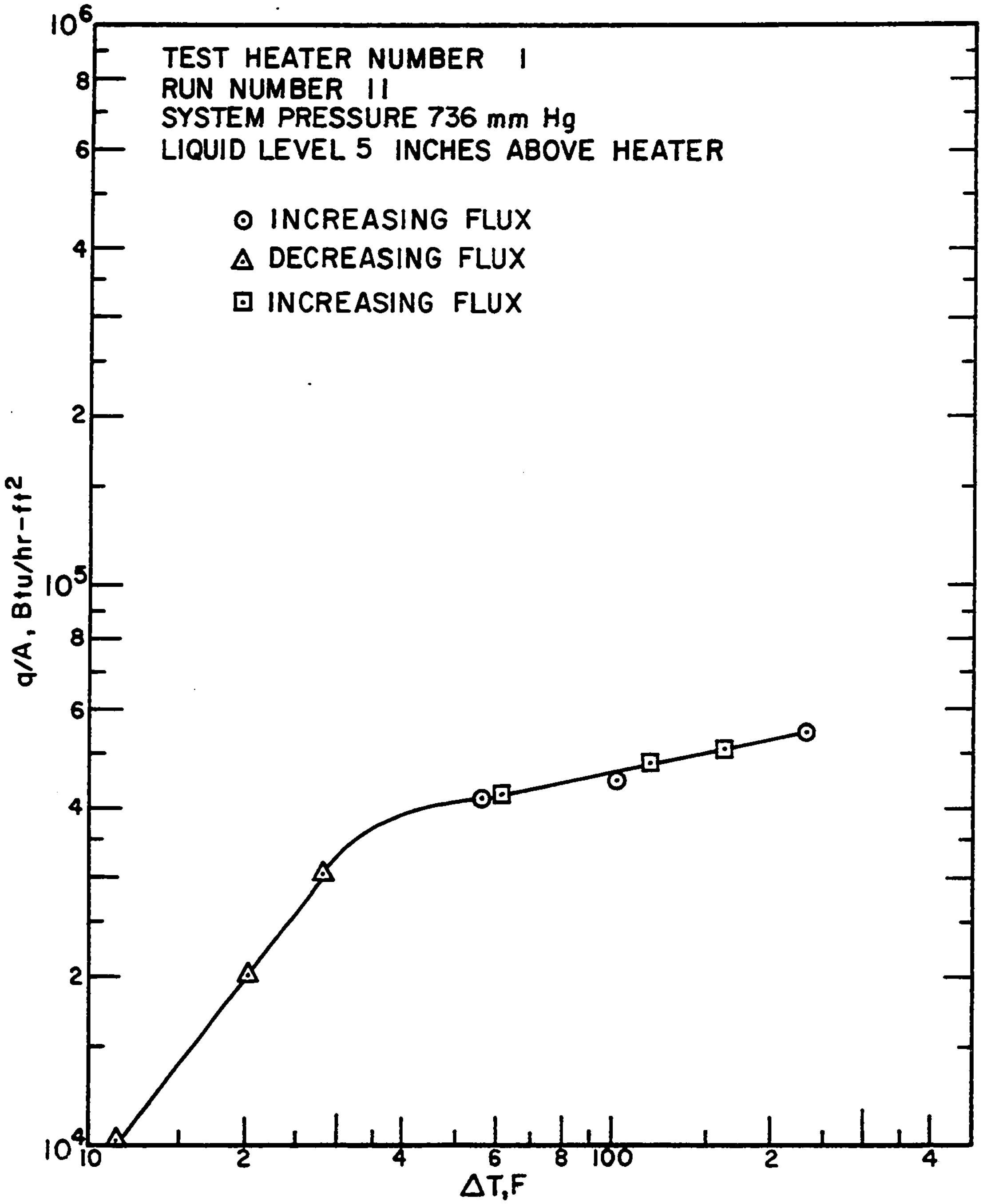

FIGURE D-11. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--11
SYSTEM PRESSURE--736 MM HG DATE--4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	41635.	732.92	726.65	671.72	54.93
21	41635.	713.72	707.40	671.72	35.68
20	47304.	779.74	772.74	671.72	101.01
21	47304.	726.52	719.38	671.72	47.66
20	54850.	904.73	896.96	671.29	225.67
21	54850.	798.88	790.82	671.29	119.53
20	31218.	705.16	700.42	671.72	28.70
21	31218.	697.03	692.27	671.72	20.55
20	20107.	694.46	691.39	670.86	20.53
21	20107.	685.89	682.81	670.86	11.95
20	9640.	683.74	682.27	670.86	11.41
21	9640.	675.16	673.68	670.86	2.82
20	43301.	739.31	732.80	671.72	61.08
21	43301.	715.85	709.29	671.72	37.57
20	49080.	794.63	787.40	671.72	115.68
21	49080.	730.78	723.39	671.72	51.67
20	52201.	837.16	829.58	671.72	157.86
21	52201.	769.10	761.34	671.72	89.62

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 12a
SYSTEM PRESSURE-- 584 MM HG DATE--4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	52770.	743.56	735.65	649.34	86.30
21	52770.	705.16	697.14	649.34	47.80
20	61897.	794.63	785.51	649.34	136.17
21	61897.	730.78	721.46	649.34	72.11
20	70489.	904.73	894.74	649.34	245.40
21	70489.	904.73	894.74	649.34	245.40

222

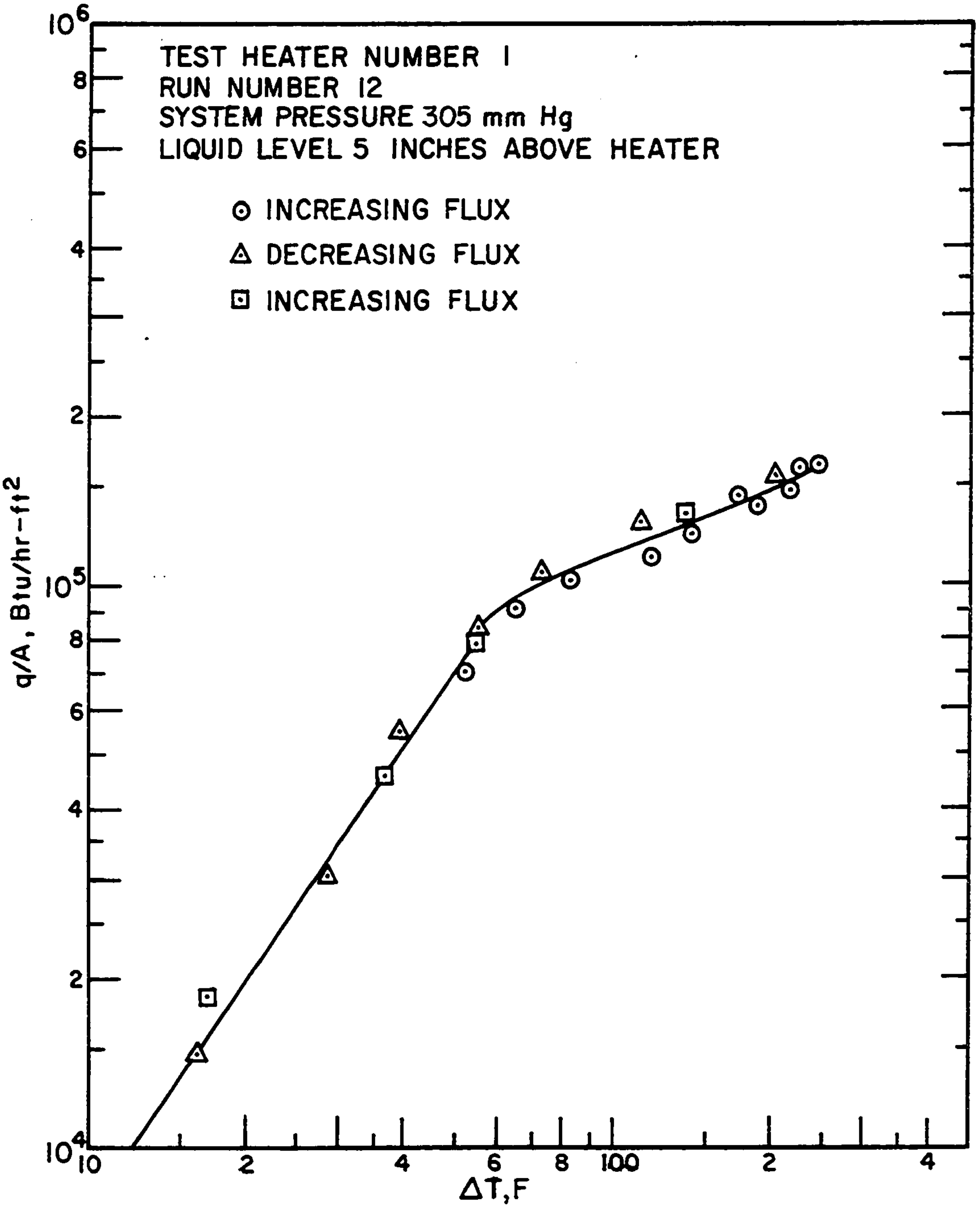

FIGURE D-12. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 12
SYSTEM PRESSURE-- 305 MM HG DATE-- 4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	70156.	653.65	642.77	592.34	50.42
21	70156.	649.34	638.44	592.34	46.10
20	80332.	660.11	647.67	591.91	55.76
21	80332.	653.65	641.19	591.91	49.27
20	91288.	670.86	656.78	591.91	64.87
21	91288.	662.26	648.14	591.91	56.23
20	103398.	690.18	674.34	591.91	82.43
21	103398.	668.71	652.75	591.91	60.84
20	116504.	726.52	708.91	591.91	117.00
21	116504.	681.60	663.69	591.91	71.78
20	129617.	754.20	734.79	592.34	142.45
21	129617.	690.18	670.31	592.34	77.97
20	141171.	794.63	773.79	592.34	181.45
21	141171.	703.03	681.48	592.34	89.14
20	147705.	832.91	811.40	593.21	218.18
21	147705.	722.25	699.87	593.21	106.66
20	148855.	792.50	770.51	592.34	178.17
21	148855.	717.99	695.39	592.34	103.05

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 305 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER--12 Cont'd
DATE--4/24/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	158787.	845.66	822.63	592.78	229.85
21	158787.	735.05	711.09	592.78	118.31
20	162622.	862.55	839.10	592.34	246.76
21	162622.	756.33	731.98	592.34	139.63
20	157885.	820.15	797.05	591.91	205.14
21	157885.	735.05	711.23	591.91	119.31
20	130435.	726.52	706.79	591.91	114.88
21	130435.	692.32	672.34	591.91	80.43
20	107042.	683.74	667.31	591.91	75.40
21	107042.	670.86	654.35	591.91	62.44
20	82485.	660.11	647.34	591.91	55.43
21	82485.	653.65	640.85	591.91	48.94
20	54850.	640.74	632.19	591.91	40.28
21	54850.	636.43	627.87	591.91	35.96
20	31463.	625.65	620.73	592.34	28.38
21	31463.	623.50	618.57	592.34	26.22
20	14577.	610.53	608.24	592.34	15.90
21	14577.	606.21	603.91	592.34	11.56

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE--305 MM HG
RUN NUMBER--12 Cont'd
DATE--4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	5754.	601.88	600.97	591.91	9.06
21	5754.	597.55	596.64	591.91	4.73
20	1224.	597.55	597.35	591.91	5.44
21	1224.	589.74	589.55	591.91	-2.36
20	5309.	601.45	600.61	592.34	8.26
21	5309.	595.38	594.54	592.34	2.19
20	19109.	612.70	609.69	592.78	16.91
21	19109.	608.37	605.36	592.78	12.58
20	44467.	636.43	629.49	592.78	36.72
21	44467.	627.81	620.85	592.78	28.07
20	80532.	660.11	647.64	592.34	55.30
21	80532.	649.34	636.83	592.34	44.48
20	130953.	752.07	732.45	592.34	140.10
21	130953.	696.60	676.58	592.34	84.23

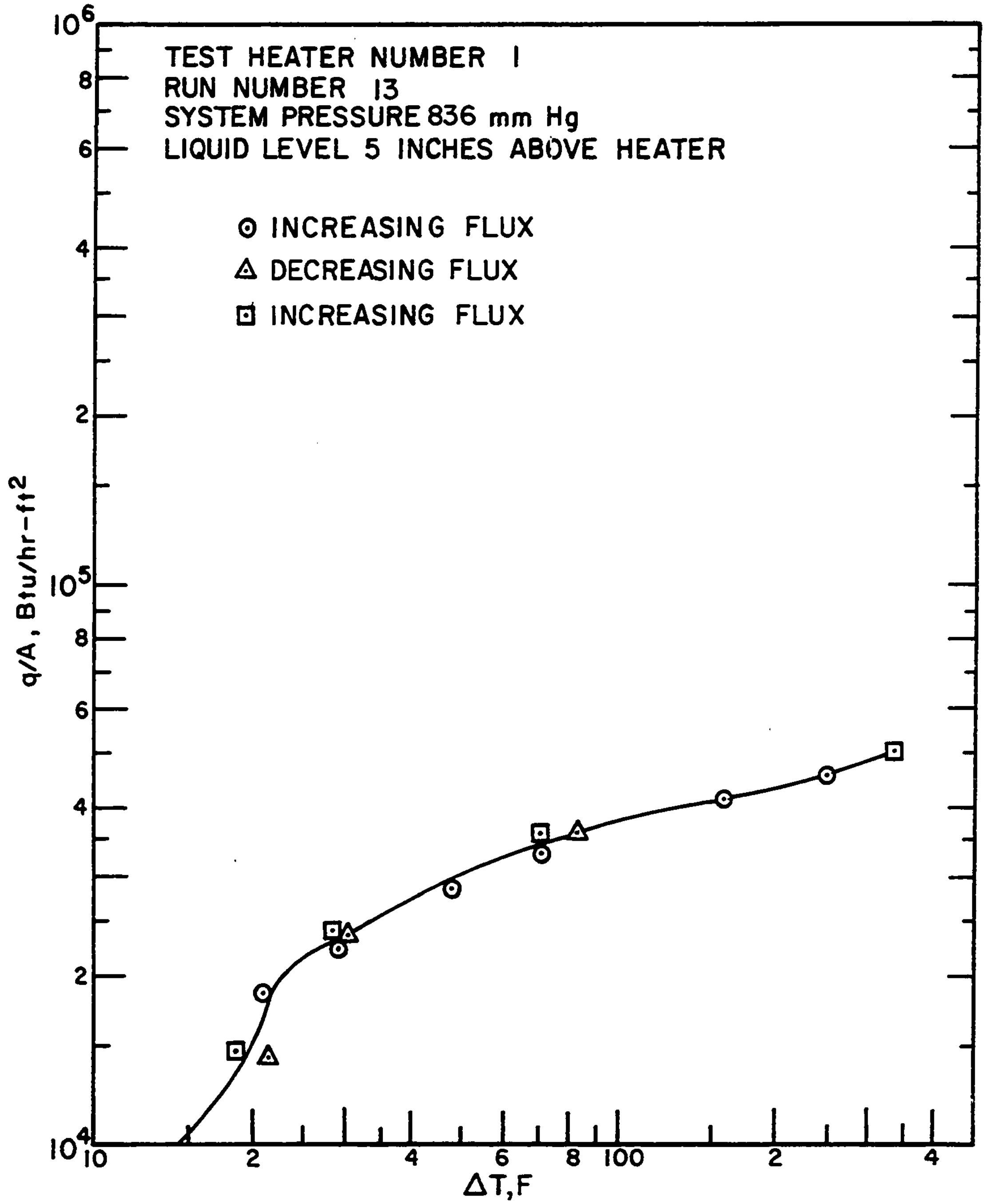

FIGURE D-13. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--13
SYSTEM PRESSURE-- 836 MM HG DATE--4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	18659.	708.16	705.33	683.74	21.58
21	18659.	695.75	692.90	683.74	9.16
20	22585.	717.13	713.71	683.74	29.97
21	22585.	703.88	700.45	683.74	16.70
20	29399.	737.18	732.76	683.74	49.01
21	29399.	715.85	711.40	683.74	27.66
20	33355.	760.58	755.61	683.74	71.87
21	33355.	727.80	722.77	683.74	39.03
20	41457.	849.91	843.92	684.17	159.75
21	41457.	755.48	749.29	684.17	65.11
20	47424.	940.63	933.99	683.74	250.24
21	47424.	805.27	798.31	683.74	114.56
20	36994.	773.35	767.87	684.17	83.69
21	36994.	739.31	733.75	684.17	49.58
20	23329.	717.99	714.46	684.17	30.28
21	23329.	706.88	703.33	684.17	19.16
20	14577.	707.73	705.52	683.74	21.77
21	14577.	696.60	694.38	683.74	10.64

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 13 Cont'd
SYSTEM PRESSURE-- 836 MM HG DATE-- 4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	7633.	694.03	692.87	682.46	10.41
21	7633.	684.60	683.43	682.46	0.98
20	14577.	705.16	702.95	683.74	19.20
21	14577.	693.18	690.95	683.74	7.21
20	23539.	717.13	713.57	684.17	29.40
21	23539.	706.45	702.87	684.17	18.70
20	36640.	760.58	755.13	683.74	71.38
21	36640.	729.93	724.41	683.74	40.67
20	51573.	1031.43	1024.43	683.74	340.69
21	51573.	989.22	982.12	683.74	298.38

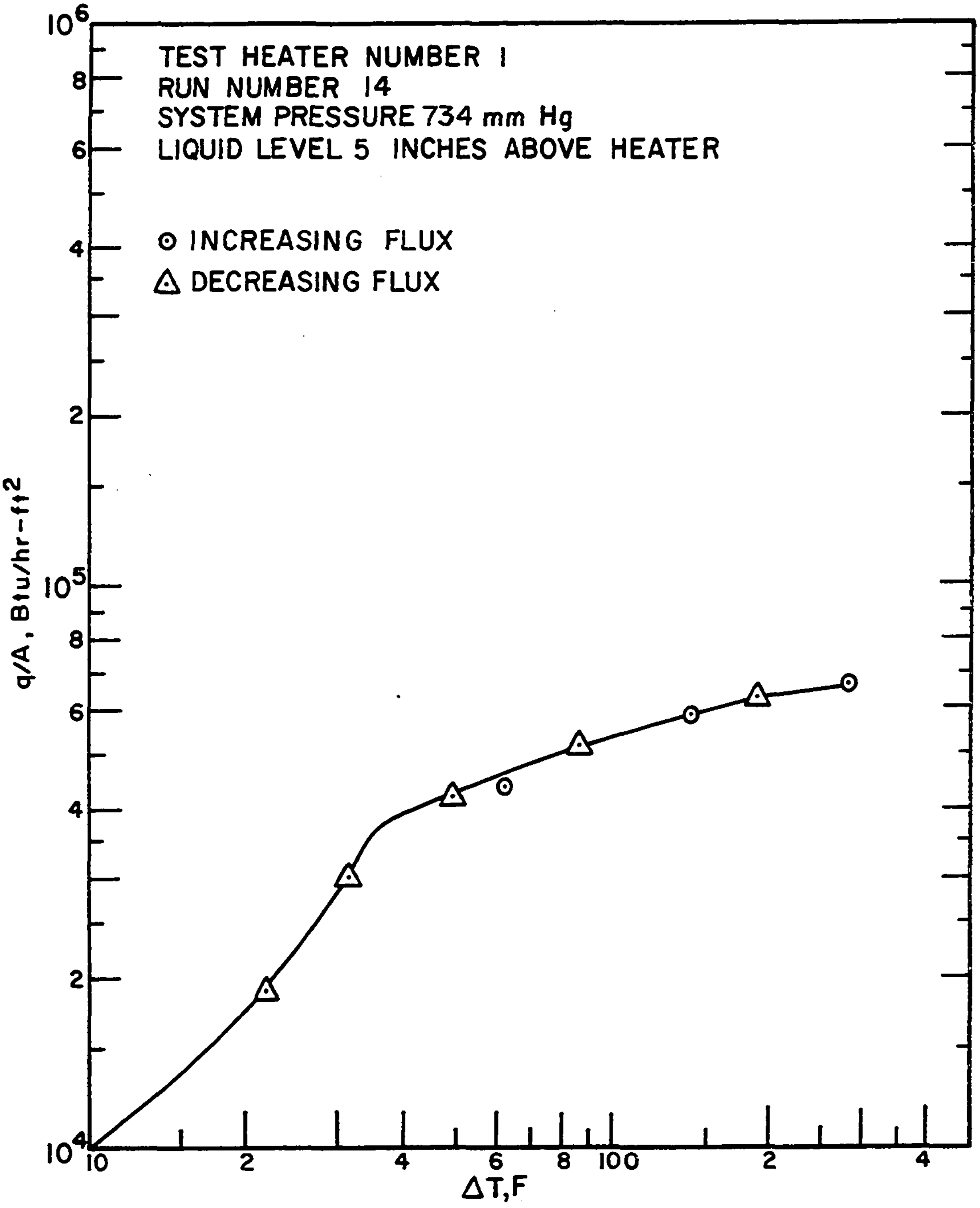

FIGURE D-14. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--- 14
SYSTEM PRESSURE--734 MM HG DATE--4/24/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	43838.	739.31	732.72	670.86	61.86
21	43838.	726.52	719.91	670.86	49.04
20	58819.	818.02	809.43	670.43	139.00
21	58819.	758.46	749.68	670.43	79.25
20	65708.	959.65	950.50	670.43	280.07
21	65708.	801.01	791.35	670.43	120.92
20	62379.	862.55	853.58	670.86	182.72
21	62379.	783.99	774.77	670.86	103.91
20	51724.	762.71	755.01	670.00	85.01
21	51724.	735.05	727.26	670.00	57.26
20	41882.	726.52	720.20	670.86	49.34
21	41882.	712.86	706.51	670.86	35.65
20	30049.	706.45	701.88	670.86	31.02
21	30049.	700.89	696.31	670.86	25.45
20	19430.	695.32	692.36	670.43	21.92
21	19430.	688.03	685.06	670.43	14.63
20	9549.	680.74	679.28	670.43	8.84
21	9549.	672.58	671.11	670.43	0.68

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--- 14 Cont'd
SYSTEM PRESSURE--- 734 MM HG DATE--- 4/24/68
POOL DEPTH ABOVE HEATER--- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	4472.	672.15	671.46	668.71	2.75
21	4472.	664.41	663.72	668.71	-4.99

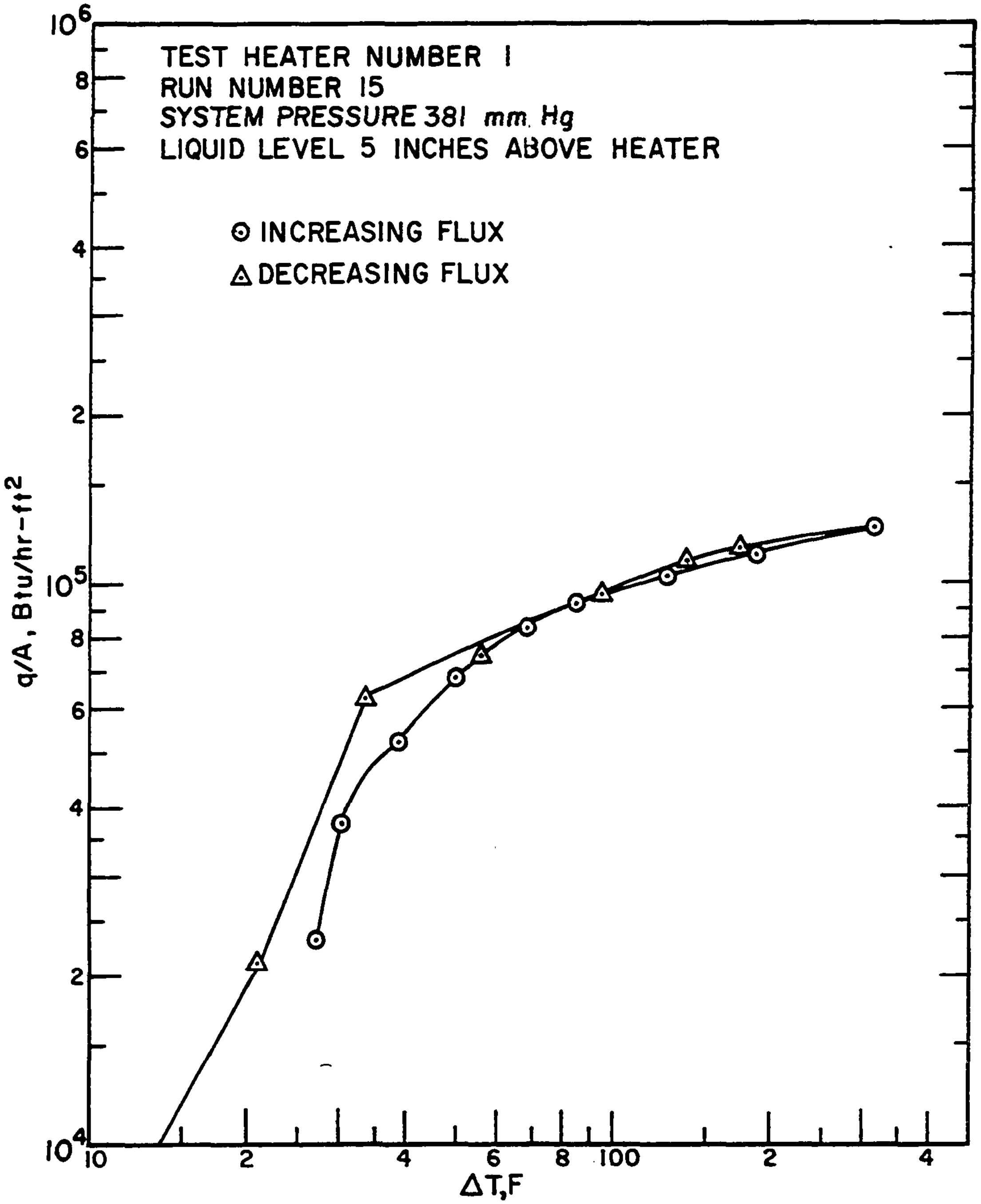

FIGURE D-15. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--15
SYSTEM PRESSURE--381 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	23578.	640.74	637.07	609.67	27.40
21	23578.	631.69	628.01	609.67	18.34
20	37514.	647.19	641.36	611.40	29.96
21	37514.	643.75	637.92	611.40	26.52
20	52224.	657.53	649.44	610.53	38.91
21	52224.	655.80	647.71	610.53	37.18
20	68208.	670.86	660.35	610.53	49.82
21	68208.	670.00	659.49	610.53	48.95
20	81517.	692.32	679.85	610.53	69.32
21	81517.	679.45	666.93	610.53	56.39
20	92193.	709.44	695.43	610.53	84.89
21	92193.	688.03	673.91	610.53	63.37
20	104382.	747.81	732.16	610.97	121.19
21	104382.	698.75	682.81	610.97	71.84
20	117701.	822.28	805.08	610.97	194.12
21	117701.	728.65	710.87	610.97	99.91
20	129896.	938.51	920.28	610.97	309.32
21	129896.	773.35	754.04	610.97	143.07

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--15 Cont'd
SYSTEM PRESSURE-- 381 MM HG DATE-- 5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	122292.	811.65	793.71	610.53	183.18
21	122292.	721.40	702.88	610.53	92.34
20	110709.	769.10	752.62	610.97	141.65
21	110709.	705.16	688.30	610.97	77.33
20	93713.	717.99	703.78	610.10	93.68
21	93713.	683.74	669.36	610.10	59.26
20	73147.	677.31	666.06	610.53	55.52
21	73147.	668.71	657.43	610.53	46.89
20	61024.	652.36	642.89	610.10	32.79
21	61024.	645.47	635.98	610.10	25.88
20	20936.	634.71	631.44	610.10	21.34
21	20936.	625.22	621.94	610.10	11.84
20	6351.	620.47	619.48	609.67	9.81
21	6351.	609.24	608.24	609.67	-1.43

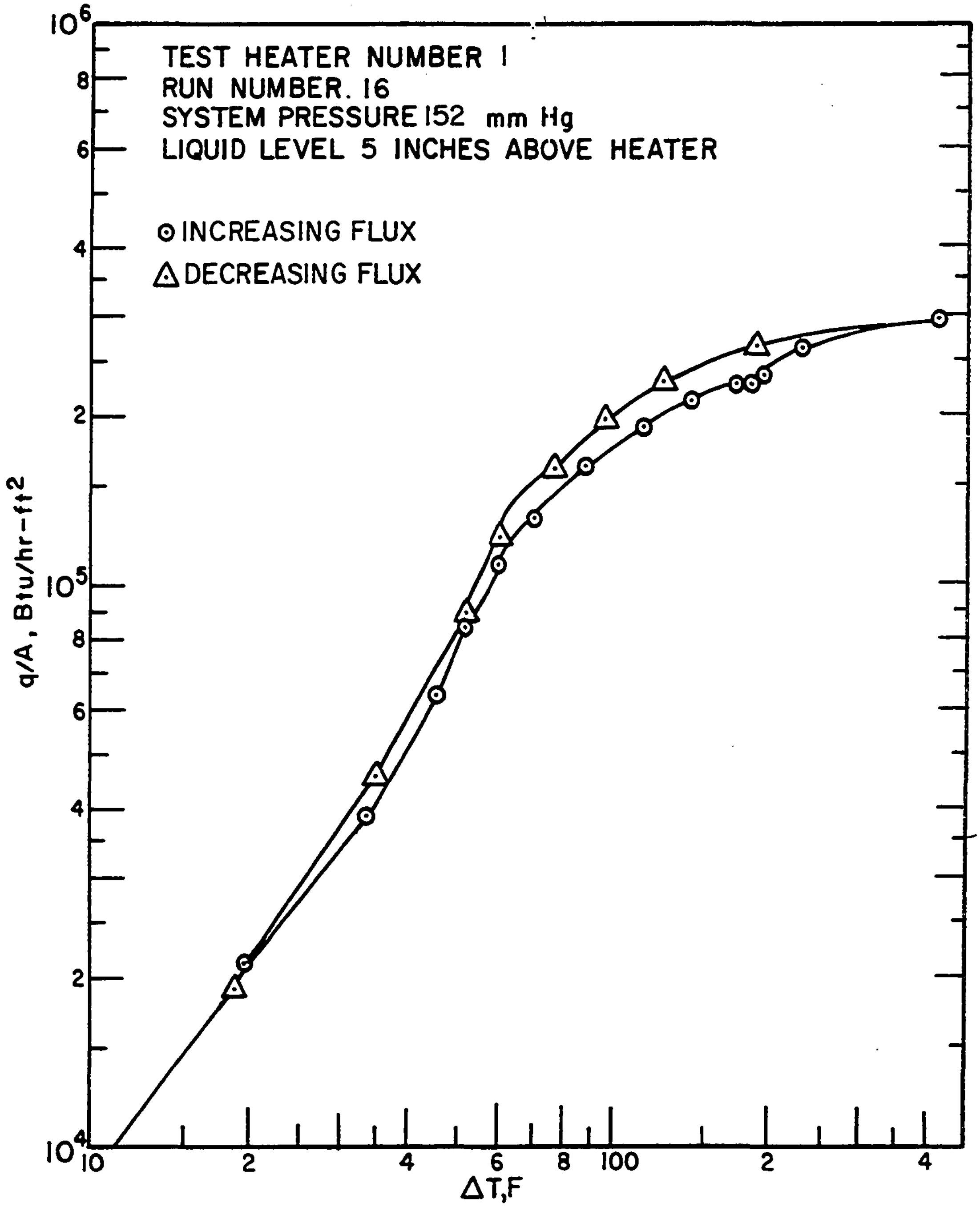

FIGURE D-16. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--16
SYSTEM PRESSURE-- 152 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	21441.	561.48	558.04	538.35	19.69
21	21441.	554.94	551.49	538.35	13.14
20	38642.	577.15	570.98	537.91	33.07
21	38642.	567.14	560.95	537.91	23.04
20	62318.	593.21	583.32	537.47	45.85
21	62318.	591.04	581.15	537.47	43.67
20	83387.	603.18	589.99	538.78	51.20
21	83387.	599.71	586.51	538.78	47.72
20	107953.	615.72	598.72	538.78	59.93
21	107953.	608.37	591.32	538.78	52.53
20	131205.	629.97	609.40	538.78	70.61
21	131205.	622.63	602.01	538.78	63.22
20	159728.	651.50	626.64	538.35	88.29
21	159728.	638.59	613.60	538.35	75.26
20	190946.	681.60	652.19	538.35	113.84
21	190946.	654.08	624.36	538.35	86.02
20	207056.	705.16	673.54	537.91	135.63
21	207056.	664.41	632.30	537.91	94.39

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--16 Cont'd
SYSTEM PRESSURE-- 152 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	225746.	735.05	700.92	537.47	163.45
21	225746.	675.16	640.27	537.47	102.79
20	231970.	745.69	710.75	537.91	172.84
21	231970.	677.74	641.91	537.91	104.00
20	245627.	754.20	717.31	537.91	179.40
21	245627.	679.45	641.53	537.91	103.62
20	263908.	801.01	762.02	538.35	223.68
21	263908.	690.18	649.57	538.35	111.22
20	282831.	989.22	950.06	538.35	411.72
21	282831.	722.25	679.23	538.35	140.88
20	261665.	769.10	730.00	537.91	192.08
21	261665.	688.03	647.74	537.91	109.83
20	228715.	697.46	662.40	537.91	124.49
21	228715.	670.86	635.45	537.91	97.54
20	191851.	662.26	632.49	537.91	94.58
21	191851.	647.19	617.26	537.91	79.34
20	158002.	638.59	613.88	537.91	75.96
21	158002.	627.81	603.00	537.91	65.09

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--16 Cont'd
SYSTEM PRESSURE--152 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	119729.	617.02	598.16	537.91	60.25
21	119729.	619.18	600.34	537.91	62.43
20	86275.	604.04	590.40	539.22	51.18
21	86275.	604.04	590.40	539.22	51.18
20	46732.	581.49	574.05	539.22	34.83
21	46732.	574.10	566.64	539.22	27.42
20	19810.	560.61	557.43	537.91	19.52
21	19810.	551.45	548.26	537.91	10.35
20	6655.	547.08	546.01	538.78	7.23
21	6655.	536.16	535.08	538.78	-3.70

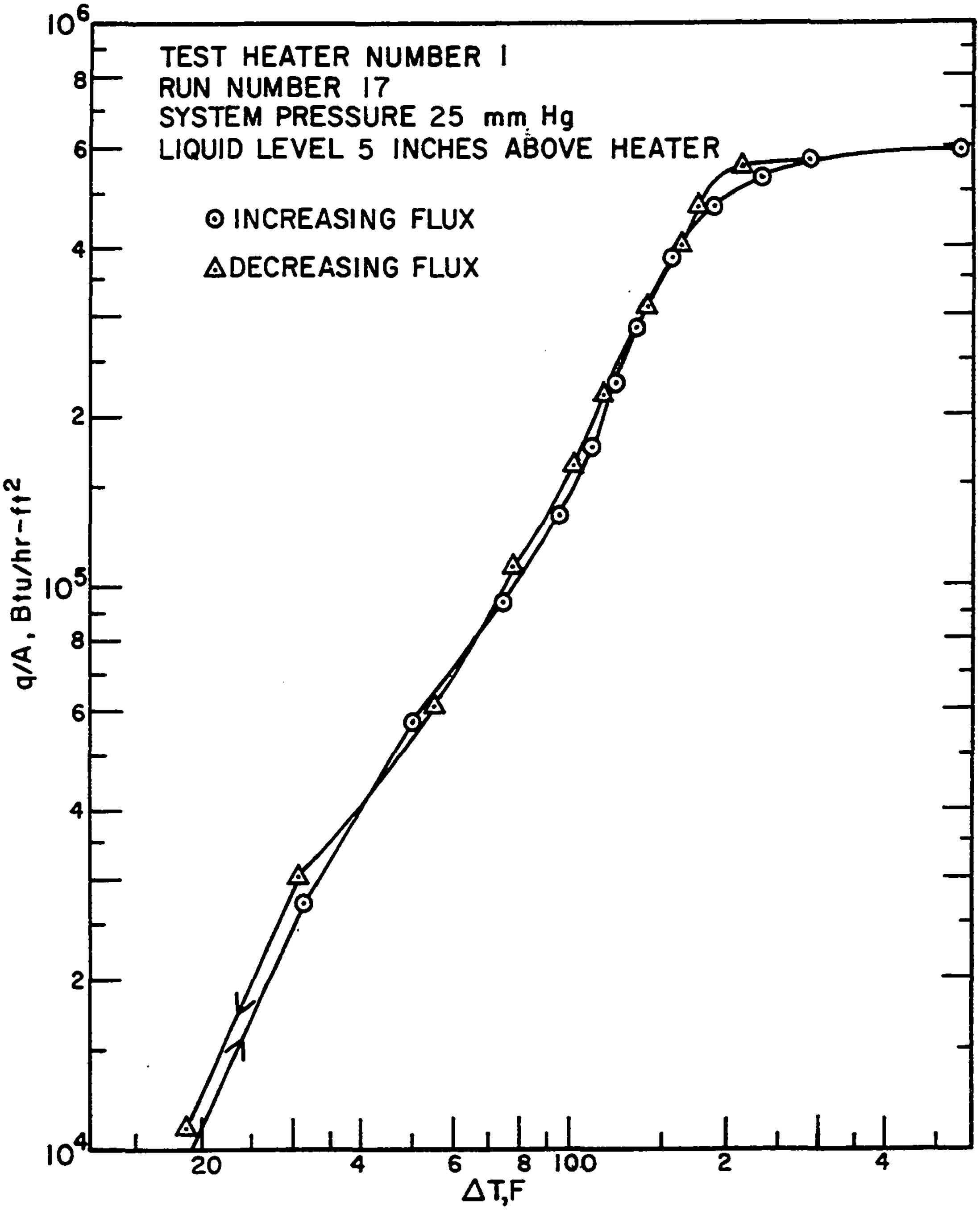

FIGURE D-17. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEN PRESSURE-- 25 MM HG
RUN NUMBER--17
DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	6399.	434.79	433.71	418.27	15.44
21	6399.	428.10	427.02	418.27	8.75
20	27895.	454.37	449.70	418.72	30.99
21	27895.	447.72	443.04	418.72	24.32
20	58959.	479.54	469.76	419.61	50.15
21	58959.	476.45	466.66	419.61	47.05
20	92253.	509.00	493.86	419.61	74.25
21	92253.	503.73	488.56	419.61	68.95
20	129170.	536.60	515.60	419.16	96.44
21	129170.	523.47	502.37	419.16	83.20
20	173685.	554.07	525.99	421.40	104.59
21	173685.	549.70	521.58	421.40	100.18
20	226559.	575.84	539.47	421.84	117.63
21	226559.	564.09	527.55	421.84	105.71
20	289855.	606.21	560.13	426.31	133.82
21	289855.	594.08	547.78	426.31	121.47
20	377510.	642.03	582.68	426.76	155.92
21	377510.	627.81	568.14	426.76	141.38

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 17 Cont'd
SYSTEM PRESSURE-- 25 MM HG DATE-- 5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	467510.	690.18	617.82	426.76	191.06
21	467510.	672.58	599.74	426.76	172.98
20	511950.	730.78	652.65	426.31	226.34
21	511950.	685.89	606.42	426.31	180.11
20	566916.	794.63	710.00	426.76	283.24
21	566916.	705.16	617.67	426.76	190.91
20	594367.	989.22	906.33	426.31	480.02
21	594367.	904.73	819.37	426.31	393.06
20	548085.	722.25	638.25	425.42	212.83
21	548085.	701.74	617.09	425.42	191.67
20	470325.	685.03	612.09	426.31	185.78
21	470325.	669.57	596.20	426.31	169.89
20	393790.	651.50	589.78	426.31	163.47
21	393790.	636.43	574.36	426.31	148.05
20	303297.	614.86	566.78	426.31	140.47
21	303297.	604.48	556.21	426.31	129.90
20	224272.	584.53	548.65	426.31	122.34
21	224272.	576.28	540.28	426.31	113.97

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--17 Cont'd
SYSTEM PRESSURE-- 25 MM HG DATE-- 5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	162043.	551.89	525.68	424.52	101.15
21	162043.	545.34	519.06	424.52	94.54
20	104774.	518.65	501.51	421.84	79.67
21	104774.	512.07	494.89	421.84	73.05
20	60766.	485.26	475.21	419.61	55.60
21	60766.	478.21	468.13	419.61	48.52
20	30049.	455.26	450.23	419.61	30.62
21	30049.	452.16	447.13	419.61	27.52
20	12287.	439.70	437.63	418.72	18.92
21	12287.	433.01	430.93	418.72	12.22

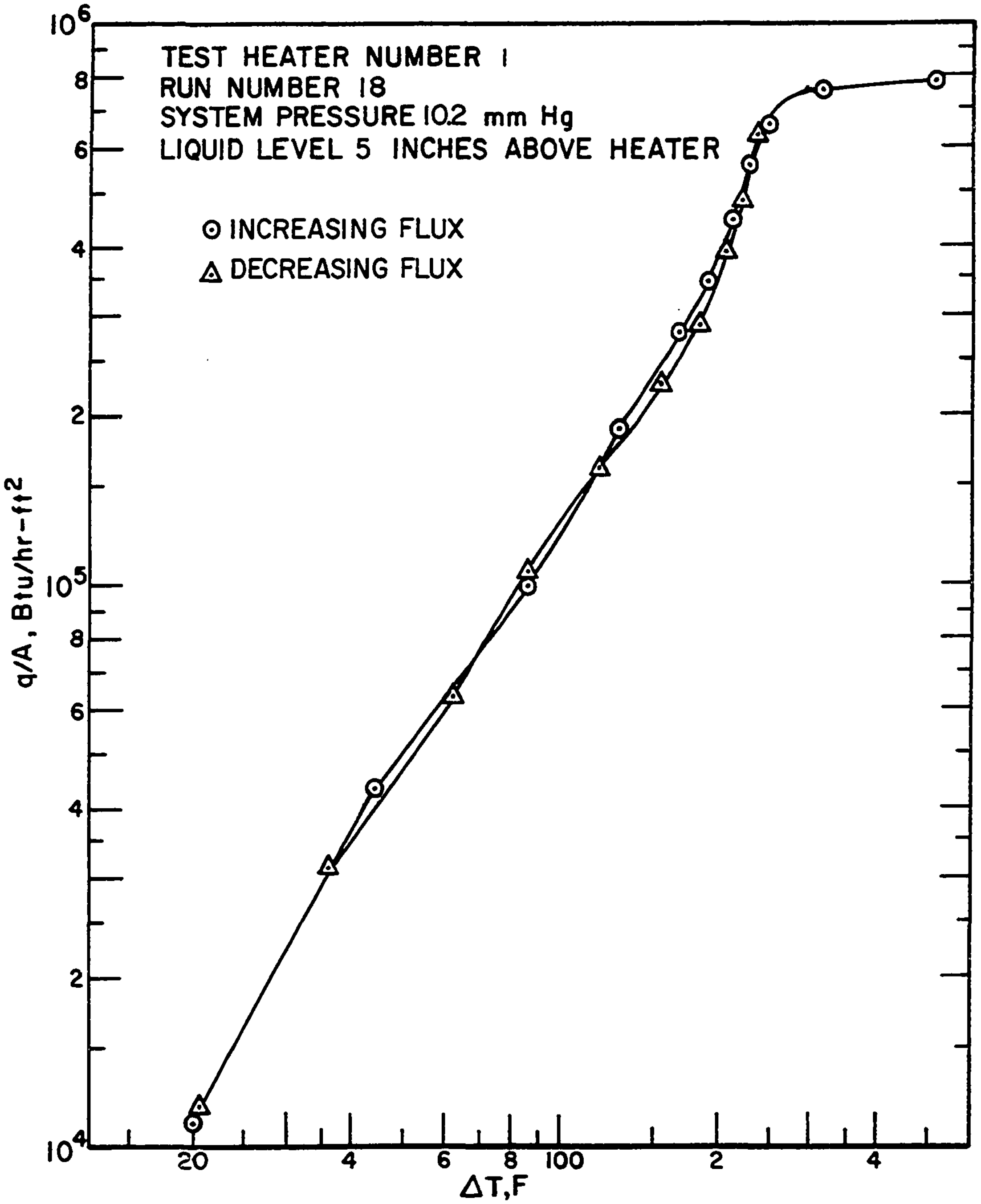

FIGURE D-18. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--18
SYSTEM PRESSURE--10.2 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	11957.	385.58	383.52	363.57	19.95
21	11957.	380.19	378.13	363.57	14.56
20	43983.	415.14	407.65	363.12	44.53
21	43983.	407.98	400.47	363.12	37.35
20	99274.	465.42	448.84	364.02	84.82
21	99274.	452.61	435.93	364.02	71.91
20	184173.	530.04	499.97	364.47	135.50
21	184173.	521.28	491.11	364.47	126.64
20	262981.	573.67	531.36	364.47	166.89
21	262981.	557.99	515.43	364.47	150.95
20	343401.	608.37	553.74	365.82	187.92
21	343401.	586.70	531.60	365.82	165.78
20	435491.	642.89	574.33	368.07	206.26
21	435491.	617.02	547.77	368.07	179.70
20	535867.	679.45	596.01	370.31	225.70
21	535867.	660.11	576.04	370.31	205.73
20	627194.	717.99	621.48	373.91	247.57
21	627194.	696.60	599.31	373.91	225.41

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--18 Cont'd
SYSTEM PRESSURE--10.2 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	737291.	798.88	688.47	374.81	313.67
21	737291.	749.94	637.50	374.81	262.69
20	768203.	989.22	881.64	374.36	507.28
21	768203.	946.97	837.79	374.36	463.43
20	615258.	715.85	621.14	373.91	247.23
21	615258.	705.16	610.07	373.91	236.16
20	472800.	673.01	599.35	371.21	228.13
21	472800.	652.36	578.11	371.21	206.89
20	387927.	638.59	577.50	368.07	209.43
21	387927.	617.02	555.42	368.07	187.35
20	293710.	599.71	552.90	366.72	186.18
21	293710.	578.02	530.80	366.72	164.08
20	226329.	558.43	521.84	365.82	156.02
21	226329.	543.15	506.35	365.82	140.53
20	159706.	514.71	488.50	364.92	123.57
21	159706.	502.86	476.52	364.92	111.60
20	104892.	468.51	451.01	364.92	86.09
21	104892.	464.10	446.56	364.92	81.64

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--18 Cont'd
SYSTEM PRESSURE-- 10.2 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	62853.	437.47	426.86	364.92	61.94
21	62853.	433.01	422.38	364.92	57.46
20	30650.	404.85	399.61	363.57	36.04
21	30650.	401.71	396.47	363.57	32.90
20	12287.	385.58	383.46	363.12	20.34
21	12287.	384.68	382.57	363.12	19.44

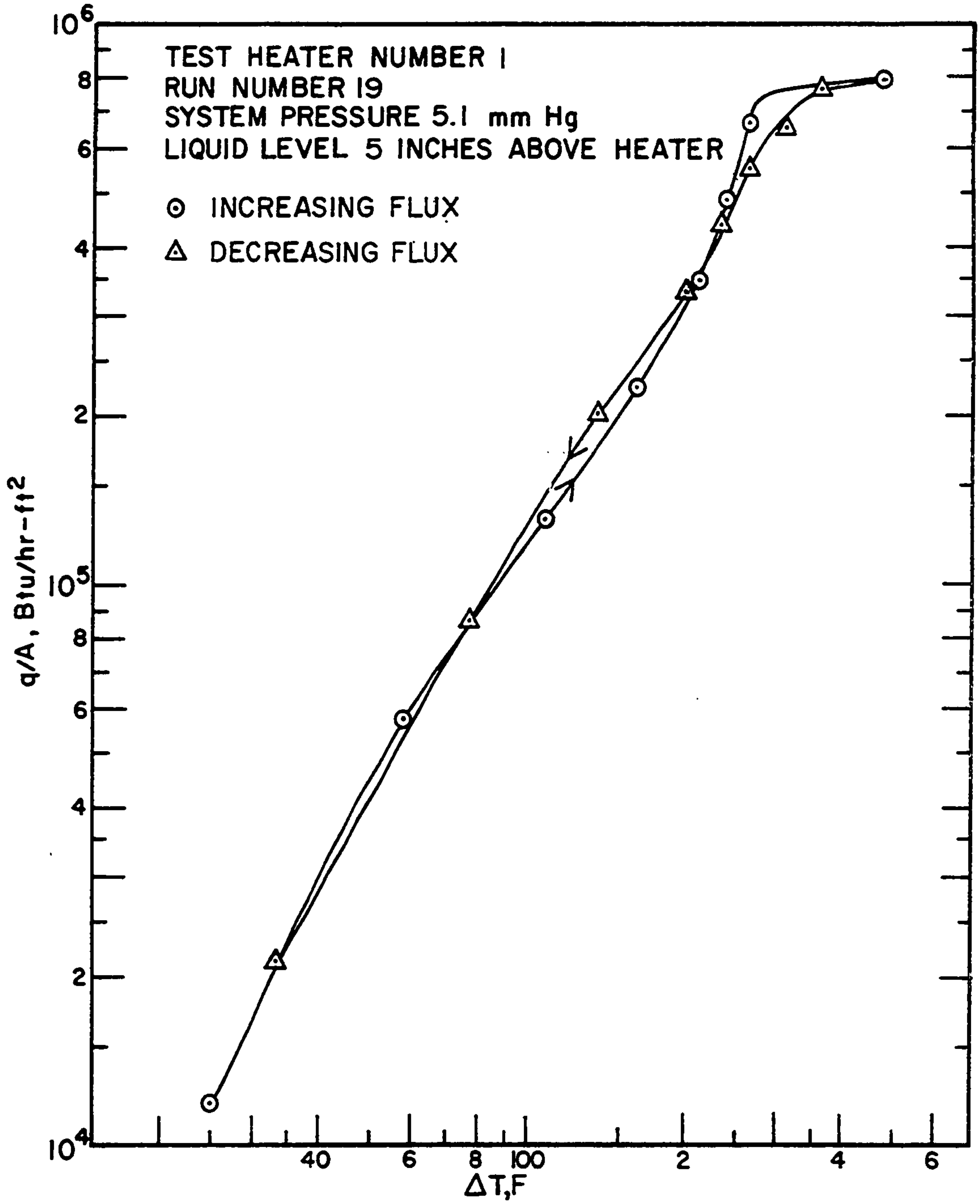

FIGURE D-19. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 19
SYSTEM PRESSURE-- 5.1 MM HG DATE-- 5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	12033.	354.57	352.48	327.89	24.58
21	12033.	350.07	347.97	327.89	20.07
20	58429.	397.24	387.21	328.80	58.41
21	58429.	391.41	381.36	328.80	52.56
20	126207.	461.89	440.76	330.60	110.15
21	126207.	444.16	422.87	330.60	92.27
20	221425.	534.41	498.29	335.12	163.16
21	221425.	506.81	470.28	335.12	135.16
20	336663.	600.58	546.86	336.93	209.93
21	336663.	573.67	519.39	336.93	182.45
20	482791.	660.11	584.49	347.80	236.69
21	482791.	632.99	556.57	347.80	208.77
20	645279.	720.12	620.86	350.07	270.79
21	645279.	709.44	609.78	350.07	259.71
20	787408.	946.97	835.01	356.82	478.18
21	787408.	820.15	702.99	356.82	346.17
20	731476.	824.40	715.90	354.57	361.32
21	731476.	762.71	651.71	354.57	297.13

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--19 Cont'd
SYSTEM PRESSURE--5.1 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	631242.	758.46	662.78	352.32	310.46
21	631242.	711.58	614.20	352.32	261.88
20	537986.	703.03	619.99	350.07	269.92
21	537986.	670.86	586.81	350.07	236.74
20	435491.	649.77	581.39	350.52	230.87
21	435491.	628.67	559.73	350.52	209.21
20	345378.	606.21	551.21	350.52	200.69
21	345378.	586.27	530.84	350.52	180.32
20	199774.	519.09	486.32	347.80	138.51
21	199774.	507.69	474.76	347.80	126.96
20	88096.	428.54	413.61	336.48	77.13
21	88096.	429.88	414.96	336.48	78.48
20	21707.	368.97	365.20	331.96	33.24
21	21707.	368.97	365.20	331.96	33.24

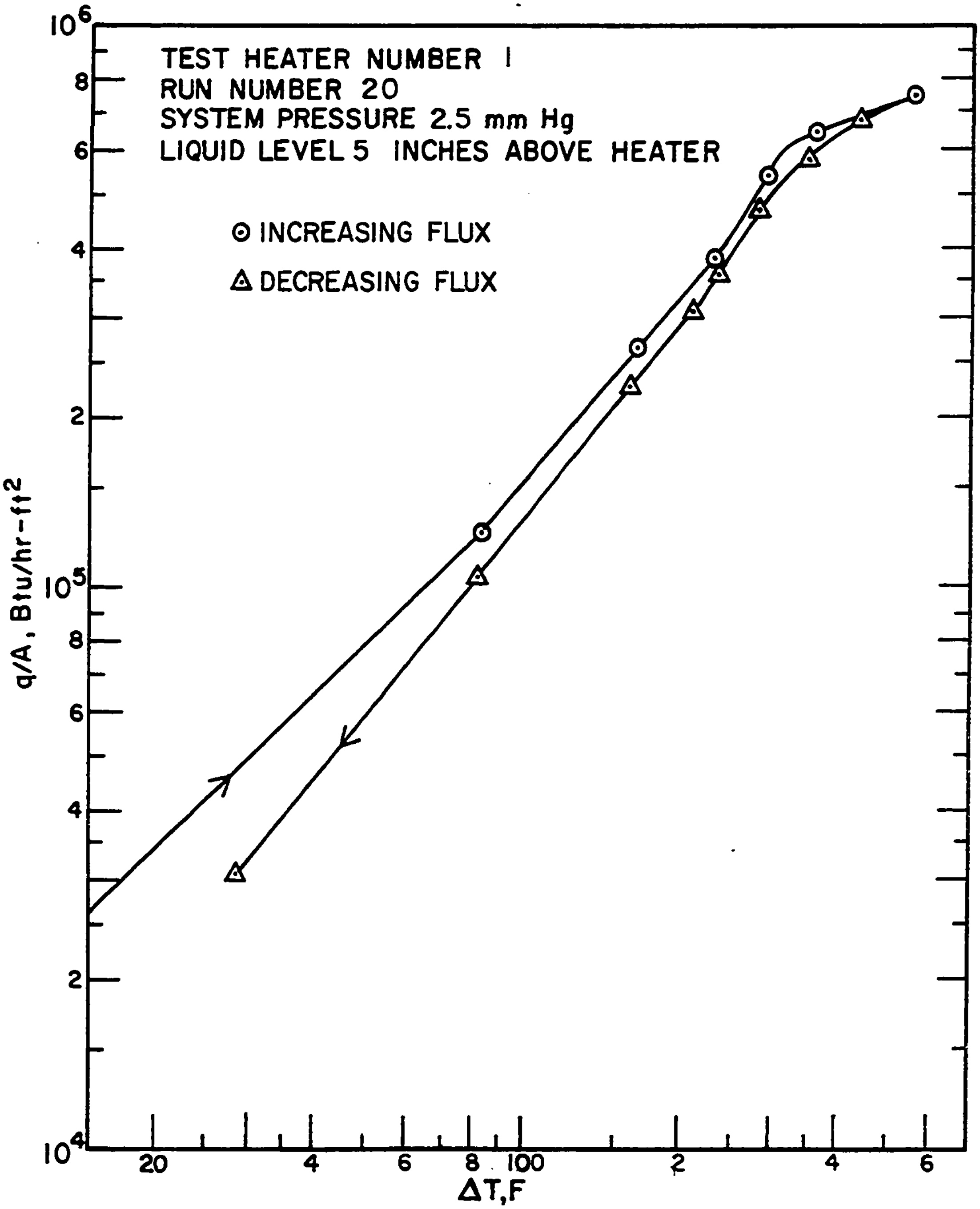

FIGURE D-20. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--20
SYSTEM PRESSURE--2.5 MM HG DATE--5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	21034.	343.27	339.59	327.44	12.14
21	21034.	342.37	338.68	327.44	11.24
20	123118.	428.54	407.65	325.19	82.46
21	123118.	424.08	403.14	325.19	77.96
20	260026.	538.78	496.38	329.70	166.68
21	260026.	521.28	478.58	329.70	148.88
20	387475.	627.81	566.54	334.22	232.32
21	387475.	588.87	526.67	334.22	192.45
20	523079.	714.57	634.22	340.10	294.12
21	523079.	670.86	589.17	340.10	249.07
20	635808.	801.01	706.14	340.55	365.58
21	635808.	735.47	638.26	340.55	297.71
20	733201.	1012.44	910.66	345.54	565.12
21	733201.	835.03	726.69	345.54	381.15
20	669263.	883.63	786.62	343.27	443.34
21	669263.	756.33	654.70	343.27	311.43
20	567697.	775.48	690.13	341.01	349.12
21	567697.	703.03	615.33	341.01	274.33

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--20 Cont'd
SYSTEM PRESSURE-- 2.5 MM HG DATE-- 5/17/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	478284.	703.03	629.34	340.10	289.24
21	478284.	655.80	580.78	340.10	240.68
20	387337.	647.19	586.40	338.74	247.66
21	387337.	606.21	544.45	338.74	205.70
20	301327.	597.55	549.47	336.48	212.98
21	301327.	573.67	525.14	336.48	188.66
20	224952.	530.04	493.27	334.22	159.05
21	224952.	521.28	484.38	334.22	150.16
20	103414.	430.78	413.25	331.96	81.29
21	103414.	426.76	409.20	331.96	77.24
20	30650.	363.57	358.24	329.70	28.54
21	30650.	363.57	358.24	329.70	28.54

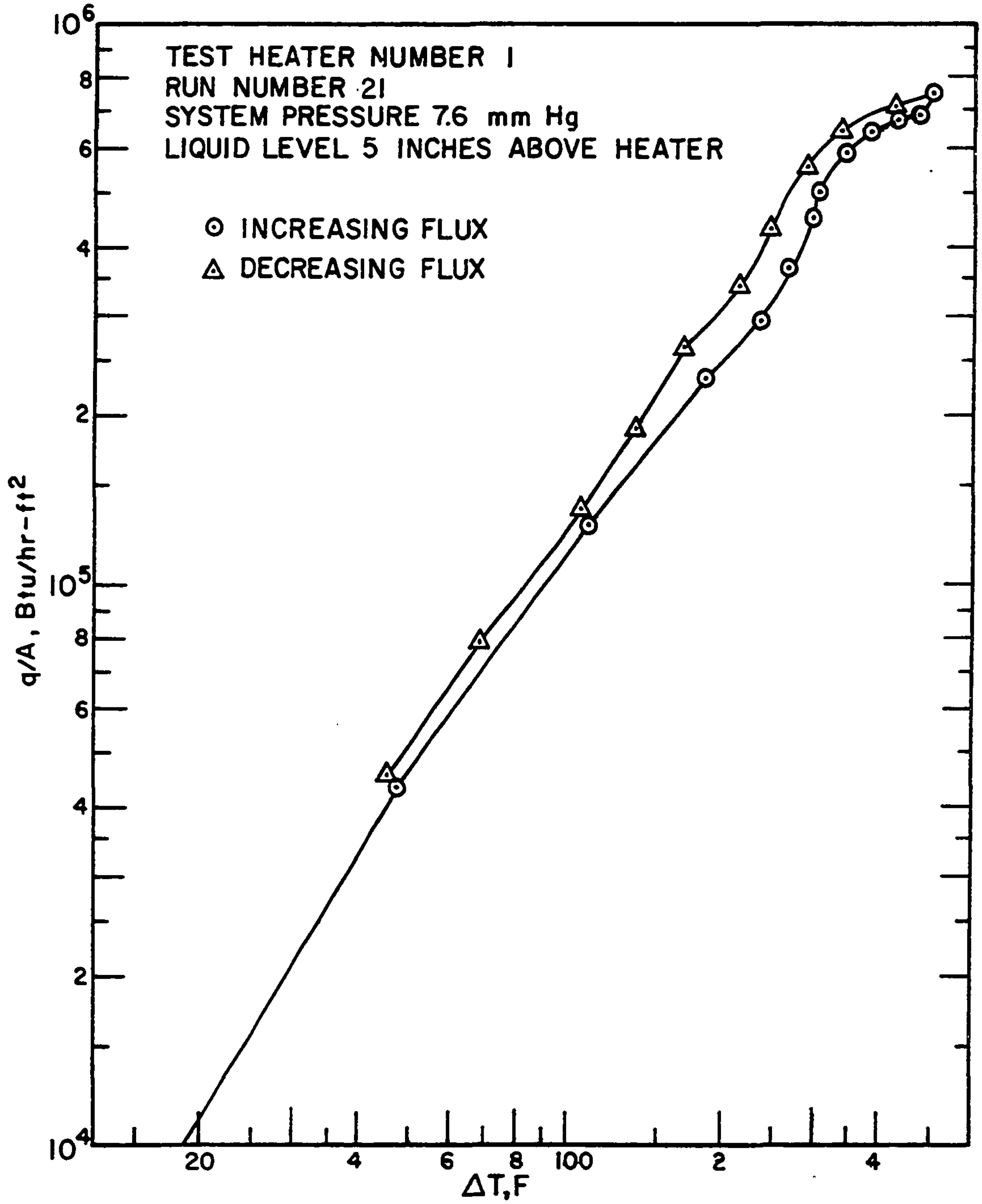

FIGURE D-21. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 21
SYSTEM PRESSURE-- 7.6 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	7255.	368.07	366.81	349.62	17.19
21	7255.	361.32	360.06	349.62	10.44
20	43501.	404.40	396.96	348.71	48.25
21	43501.	400.82	393.37	348.71	44.66
20	122478.	483.94	463.62	353.22	110.39
21	122478.	479.54	459.18	353.22	105.95
20	227421.	572.36	535.80	354.57	181.23
21	227421.	545.34	508.38	354.57	153.81
20	291886.	634.28	588.37	358.17	230.20
21	291886.	595.38	548.78	358.17	190.60
20	353926.	679.88	625.07	358.17	266.90
21	353926.	634.28	578.51	358.17	220.34
20	422720.	722.25	657.70	357.72	299.97
21	422720.	662.26	596.23	357.72	238.50
20	494212.	735.47	660.22	357.72	302.49
21	494212.	696.60	620.24	357.72	262.52
20	567993.	788.25	703.25	359.07	344.18
21	567993.	713.72	626.33	359.07	267.26

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--21 Cont'd
SYSTEM PRESSURE-- 7.6 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	616433.	832.91	742.03	361.32	380.71
21	616433.	724.39	629.80	361.32	268.48
20	653404.	883.63	788.95	361.32	427.63
21	653404.	728.65	628.45	361.32	267.12
20	686541.	930.07	832.12	362.67	469.44
21	686541.	739.31	634.34	362.67	271.66
20	728875.	963.87	861.00	364.47	496.52
21	728875.	756.33	645.46	364.47	280.99
20	681005.	885.74	787.07	364.92	422.15
21	681005.	737.18	632.99	364.92	268.07
20	621296.	794.63	701.74	363.12	338.62
21	621296.	715.85	620.19	363.12	257.07
20	546138.	739.31	656.14	361.32	294.81
21	546138.	692.32	607.67	361.32	246.34
20	423976.	673.01	607.05	358.62	248.42
21	423976.	649.34	582.78	358.62	224.16
20	340871.	625.65	571.79	355.47	216.31
21	340871.	607.07	552.82	355.47	197.34

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 21 Cont'd
SYSTEM PRESSURE-- 7.6 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	257303.	567.14	525.65	355.02	170.63
21	257303.	562.79	521.22	355.02	166.20
20	187968.	526.97	496.25	354.57	141.67
21	187968.	530.04	499.35	354.57	144.78
20	131326.	479.54	457.70	354.57	103.13
21	131326.	479.10	457.25	354.57	102.68
20	78235.	435.24	422.02	352.32	69.69
21	78235.	439.70	426.50	352.32	74.18
20	45878.	406.64	398.80	352.77	46.03
21	45878.	407.09	399.25	352.77	46.48

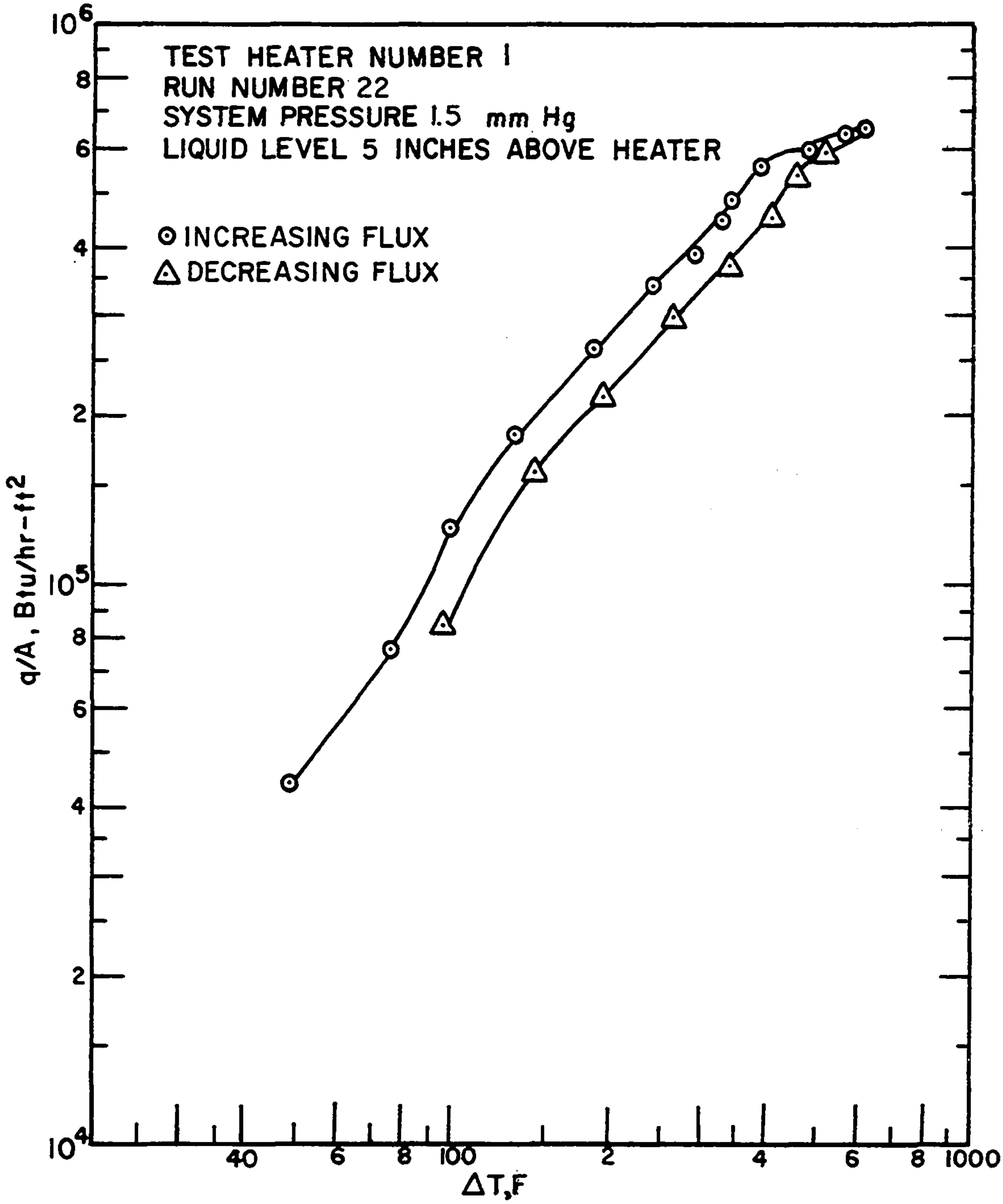

FIGURE D-22. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 22
SYSTEM PRESSURE-- 1.5 MM HG DATE--- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	44506.	353.67	345.90	296.84	49.06
21	44506.	355.47	347.71	296.84	50.87
20	76058.	381.54	368.40	291.46	76.94
21	76058.	377.05	363.89	291.46	72.42
20	121968.	410.67	389.81	290.12	99.70
21	121968.	406.19	385.30	290.12	95.18
20	180295.	461.89	431.64	296.39	135.25
21	180295.	454.37	424.04	296.39	127.64
20	251833.	525.66	484.39	300.43	183.96
21	251833.	519.09	477.71	300.43	177.28
20	338617.	612.70	558.92	316.17	242.75
21	338617.	578.02	523.51	316.17	207.34
20	378839.	681.60	622.93	325.19	297.74
21	378839.	607.51	547.15	325.19	221.96
20	431846.	724.39	658.47	329.70	328.77
21	431846.	649.34	581.53	329.70	251.83
20	468664.	749.94	679.01	331.96	347.05
21	468664.	675.16	602.21	331.96	270.25

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--22 Cont'd
SYSTEM PRESSURE-- 1.5 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	532122.	813.77	734.96	336.03	398.93
21	532122.	722.25	640.74	336.03	304.71
20	588965.	913.17	828.85	338.29	490.56
21	588965.	747.81	658.30	338.29	320.01
20	610285.	993.45	908.42	341.01	567.41
21	610285.	773.35	681.42	341.01	340.41
20	626026.	1035.65	949.64	343.27	606.37
21	626026.	798.88	705.42	343.27	362.15
20	570685.	936.40	855.40	341.01	514.39
21	570685.	760.58	674.30	341.01	333.30
20	510414.	866.77	792.63	339.65	452.99
21	510414.	737.18	659.47	339.65	319.82
20	438357.	809.52	744.66	336.48	408.17
21	438357.	675.16	606.98	336.48	270.50
20	351494.	726.52	673.03	331.06	341.98
21	351494.	619.18	563.47	331.06	232.42
20	294093.	638.59	592.40	329.70	262.70
21	294093.	584.53	537.38	329.70	207.68

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--22 Cont'd
SYSTEM PRESSURE--1.5 MM HG DATE--5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	219693.	557.56	522.04	324.28	197.76
21	219693.	533.10	497.24	324.28	172.96
20	156367.	492.74	466.86	318.42	148.44
21	156367.	486.14	460.19	318.42	141.77
20	84138.	418.72	404.40	307.17	97.23
21	84138.	412.90	398.55	307.17	91.38

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--23
SYSTEM PRESSURE--990 MM HG DATE--5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	[a]53248.	965.99	958.60	700.03	258.57
21	53248.	862.55	854.89	700.03	154.86
20	[a]62324.	1185.71	1177.65	700.46	477.20
21	62324.	958.80	950.13	700.46	249.67
20	[a]67945.	1263.90	1255.32	700.89	554.44
21	67945.	997.67	988.33	700.89	287.45
20	[a]74734.	1333.79	1324.55	700.89	623.67
21	74734.	1036.92	1026.78	700.89	325.90
20	[b]75958.	1382.87	1373.61	694.46	679.15
21	75958.	1062.21	1052.00	694.46	357.53
20	[b]76392.	1389.35	1380.06	688.89	691.17
21	76392.	1060.95	1050.67	688.89	361.78
20	[b]76392.	1392.38	1383.09	683.32	699.78
21	76392.	1066.43	1056.17	683.32	372.85
20	[b]76392.	1363.47	1354.11	673.44	680.67
21	76392.	1027.21	1016.82	673.44	343.38
20	[b]76392.	1337.66	1328.23	668.71	659.52
21	76392.	1006.11	995.64	668.71	326.93

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--23 Cont'd
SYSTEM PRESSURE-- 990 MM HG DATE--5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	[b]76392.	762.71	751.33	636.43	114.90
21	76392.	717.99	706.41	636.43	69.98

[a]Data plotted in Figure D-25.

[b]Flux held constant, pressure dropped to 935, 877, 831, 759, 718, and 510 mm Hg, respectively.

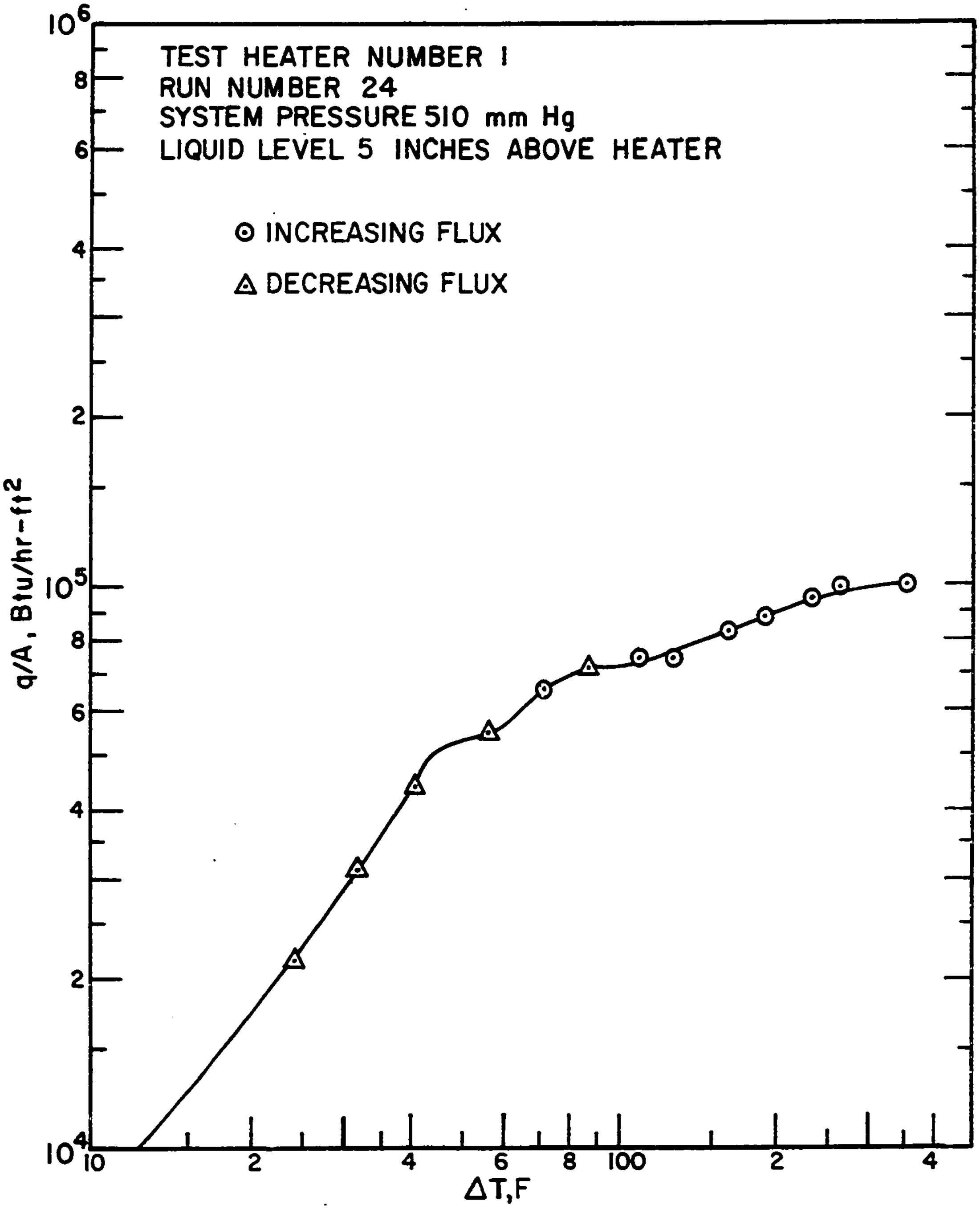

FIGURE D-23. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 24
SYSTEM PRESSURE-- 510 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	76000.	771.23	759.93	636.43	123.50
21	76000.	716.28	704.76	636.43	68.33
20	65708.	718.41	708.46	636.43	72.03
21	65708.	698.75	688.72	636.43	52.29
20	74594.	758.46	747.32	636.43	110.89
21	74594.	712.86	701.54	636.43	65.11
20	82975.	809.52	797.35	636.43	160.92
21	82975.	734.62	722.12	636.43	85.69
20	89689.	839.28	826.27	636.43	189.84
21	89689.	745.69	732.23	636.43	95.80
20	94815.	879.42	865.85	637.29	228.56
21	94815.	769.10	754.99	637.29	117.70
20	99897.	1001.89	988.18	637.29	350.88
21	99897.	822.28	807.69	637.29	170.40
20	99897.	914.86	900.74	637.29	263.45
21	99897.	792.50	777.76	637.29	140.47
20	71732.	735.05	724.25	637.29	86.96
21	71732.	709.44	698.54	637.29	61.25

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 24 Cont'd
SYSTEM PRESSURE-- 510 MM HG DATE-- 5/23/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	55424.	700.89	692.44	636.43	56.01
21	55424.	681.60	673.09	636.43	36.66
20	45074.	683.74	676.84	636.43	40.40
21	45074.	673.01	666.07	636.43	29.64
20	32099.	673.01	668.07	636.43	31.64
21	32099.	665.27	660.32	636.43	23.89
20	21760.	662.26	658.90	634.71	24.19
21	21760.	653.65	650.28	634.71	15.57
20	8536.	646.33	645.01	635.14	9.87
21	8536.	639.45	638.12	635.14	2.98

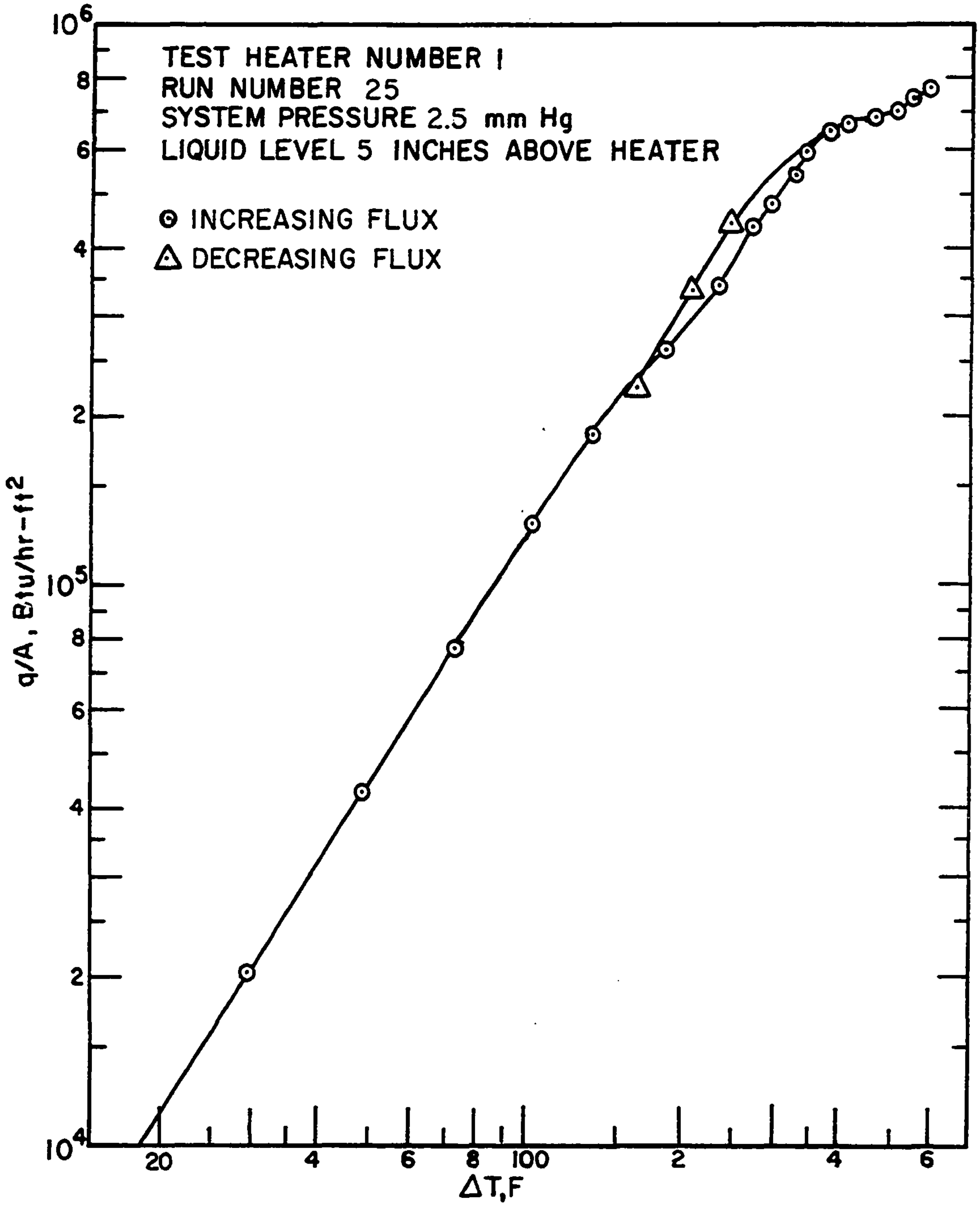

FIGURE D-24. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE--2.5 MM HG
RUN NUMBER--25
DATE--5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	4881.	319.32	318.46	303.13	15.33
21	4881.	314.82	313.95	303.13	10.83
20	20100.	335.58	332.04	302.23	29.82
21	20100.	328.80	325.25	302.23	23.03
20	43331.	360.42	352.88	304.02	48.86
21	43331.	352.32	344.75	304.02	40.73
20	77853.	394.99	381.62	308.52	73.10
21	77853.	383.78	370.34	308.52	61.83
20	121240.	433.01	412.47	313.47	99.00
21	121240.	419.16	398.51	313.47	85.04
20	121866.	437.47	416.86	315.27	101.59
21	121866.	424.08	403.36	315.27	88.09
20	180295.	486.14	456.19	316.62	139.57
21	180295.	461.89	431.64	316.62	115.02
20	257501.	545.34	503.46	321.13	182.33
21	257501.	514.71	472.31	321.13	151.18
20	331926.	606.21	553.37	327.44	225.93
21	331926.	558.43	504.69	327.44	177.15

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER---1
SYSTEM PRESSURE--- 2.5 MM HG
POOL DEPTH ABOVE HEATER--- 5 INCHES

RUN NUMBER---25 Cont'd
DATE--5/30/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	338955.	604.04	550.03	326.54	223.49
21	338955.	555.81	500.77	326.54	174.23
20	423026.	666.56	600.59	329.25	271.34
21	423026.	601.88	534.24	329.25	204.99
20	467655.	703.03	631.00	333.77	297.23
21	467655.	627.81	553.68	333.77	219.91
20	514881.	735.05	656.58	334.22	322.36
21	514881.	660.11	579.39	334.22	245.17
20	574858.	769.10	682.45	338.74	343.71
21	574858.	655.80	565.37	338.74	226.62
20	616433.	813.77	722.26	341.46	380.80
21	616433.	681.60	585.46	341.46	244.00
20	639812.	843.53	749.51	344.63	404.88
21	639812.	694.46	595.10	344.63	250.47
20	663608.	894.18	798.36	345.54	452.82
21	663608.	715.85	613.55	345.54	268.02
20	691104.	949.08	851.12	346.90	504.22
21	691104.	728.65	622.55	346.90	275.65

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 25 Cont'd
SYSTEM PRESSURE-- 2.5 MM HG DATE-- 5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	706249.	990.07	891.33	347.80	543.53
21	706249.	745.69	637.90	347.80	290.10
20	727685.	1039.87	939.80	350.07	589.73
21	727685.	776.76	666.92	350.07	316.85
20	436437.	651.50	583.01	337.39	245.62
21	436437.	610.53	540.95	337.39	203.57
20	331488.	586.70	533.54	324.73	208.80
21	331488.	554.07	500.21	324.73	175.48
20	211794.	519.09	484.33	318.42	165.91
21	211794.	502.42	467.43	318.42	149.01

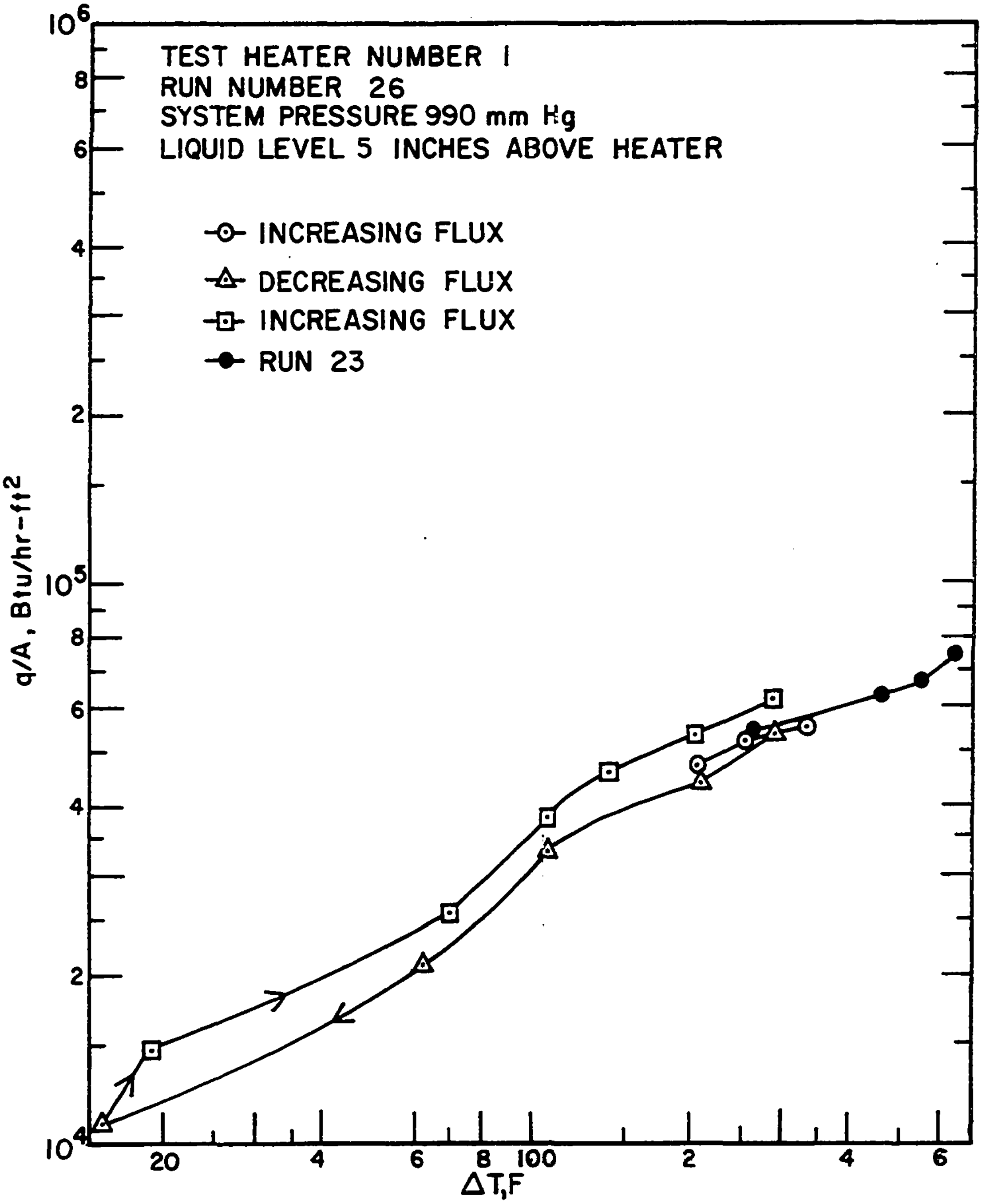

FIGURE D-25. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 26
SYSTEM PRESSURE-- 990 MM HG DATE-- 5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	48489.	915.28	908.44	700.89	207.55
21	48489.	813.77	806.68	700.89	105.79
20	53697.	963.87	956.42	700.89	255.53
21	53697.	849.06	841.30	700.89	140.41
20	58273.	1043.24	1035.36	700.46	334.90
21	58273.	890.81	882.51	700.46	182.05
20	54589.	999.78	992.29	700.46	291.83
21	54589.	858.34	850.47	700.46	150.02
20	45243.	915.28	908.90	700.89	208.01
21	45243.	805.69	799.06	700.89	98.17
20	32791.	818.45	813.66	700.46	113.21
21	32791.	752.07	747.17	700.46	46.71
20	21011.	764.84	761.72	700.46	61.26
21	21011.	725.67	722.50	700.46	22.04
20	12248.	714.57	712.71	697.46	15.25
21	12248.	700.46	698.59	697.46	1.13
20	15403.	716.28	713.95	695.75	18.20
21	15403.	700.03	697.68	695.75	1.94

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER---26 Cont'd
SYSTEM PRESSURE-- 990 MM HG DATE--- 5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	26022.	769.95	766.09	696.18	69.91
21	26022.	726.52	722.60	696.18	26.42
20	38227.	813.77	808.18	697.46	110.72
21	38227.	760.58	754.89	697.46	57.43
20	46005.	844.38	837.73	697.89	139.84
21	46005.	778.46	771.65	697.89	73.76
20	53203.	911.06	903.54	699.60	203.94
21	53203.	810.79	803.00	699.60	103.40
20	62859.	1006.11	997.50	700.89	296.62
21	62859.	876.04	867.04	700.89	166.16

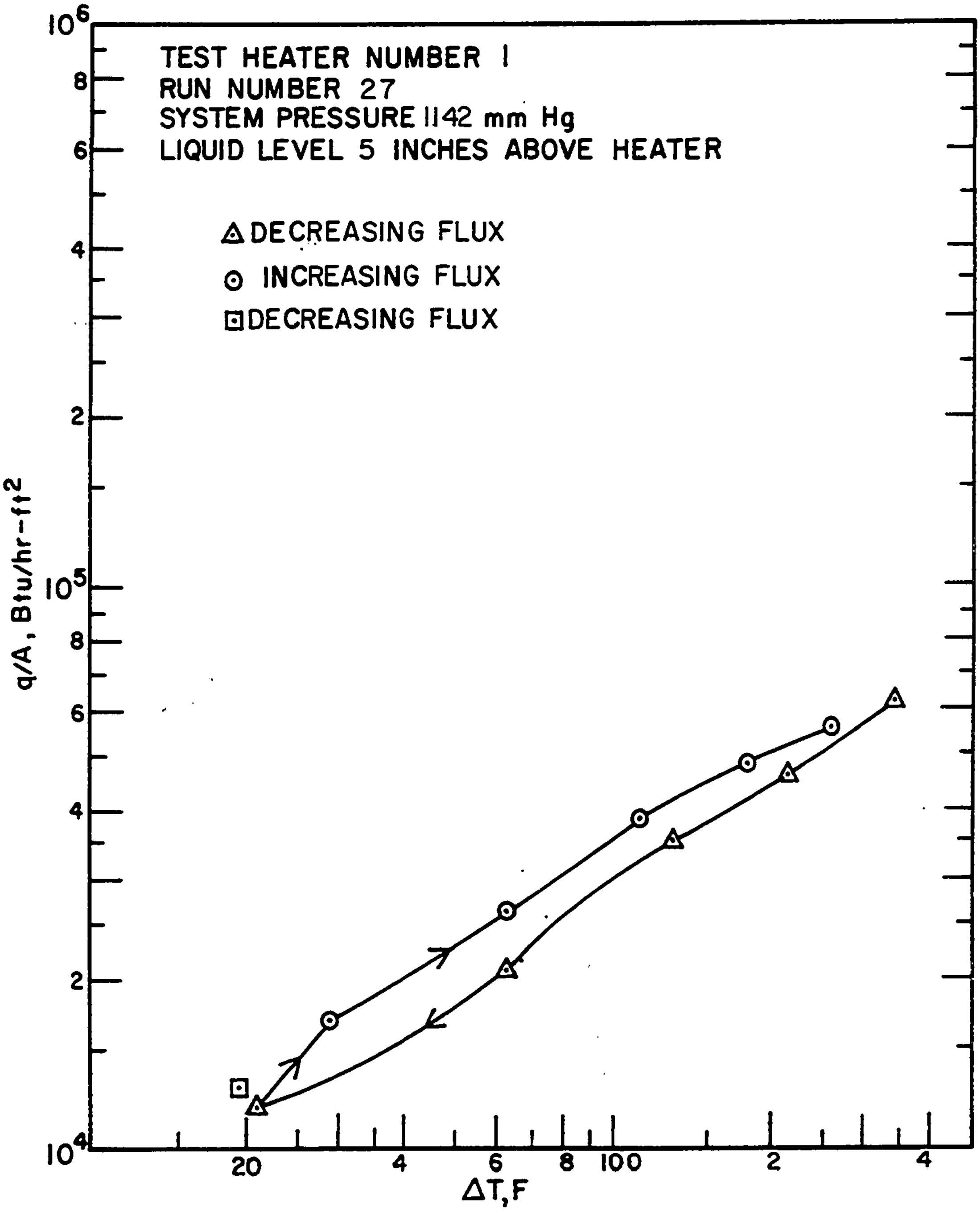

FIGURE D-26. MERCURY RESULTS.

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 27
SYSTEM PRESSURE--1142 MM HG DATE--5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	61018.	1066.43	1058.24	715.42	342.81
21	61018.	914.02	905.40	715.42	189.97
20	47055.	941.47	934.89	715.42	219.46
21	47055.	842.26	835.44	715.42	120.02
20	34724.	848.63	843.62	716.28	127.34
21	34724.	779.74	774.60	716.28	58.32
20	21446.	781.01	777.84	715.85	61.99
21	21446.	742.28	739.07	715.85	23.22
20	12248.	737.60	735.76	715.00	20.77
21	12248.	718.41	716.56	715.00	1.56
20	17295.	746.96	744.38	715.42	28.95
21	17295.	723.54	720.92	715.42	5.50
20	26877.	782.29	778.32	715.00	63.32
21	26877.	743.56	739.53	715.00	24.54
20	38844.	835.88	830.25	713.72	116.53
21	38844.	778.04	772.28	713.72	58.57
20	47678.	902.20	895.44	716.28	179.16
21	47678.	820.15	813.19	716.28	96.92

TABLE IV
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 27 Cont'd
SYSTEM PRESSURE-- 1142 MM HG DATE-- 5/30/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	55090.	979.93	972.32	716.28	256.04
21	55090.	864.66	856.74	716.28	140.47
20	12500.	735.05	733.17	713.72	19.45
21	12500.	721.40	719.51	713.72	5.80
20	5617.	718.41	717.56	712.86	4.70
21	5617.	707.30	706.45	712.86	-6.41

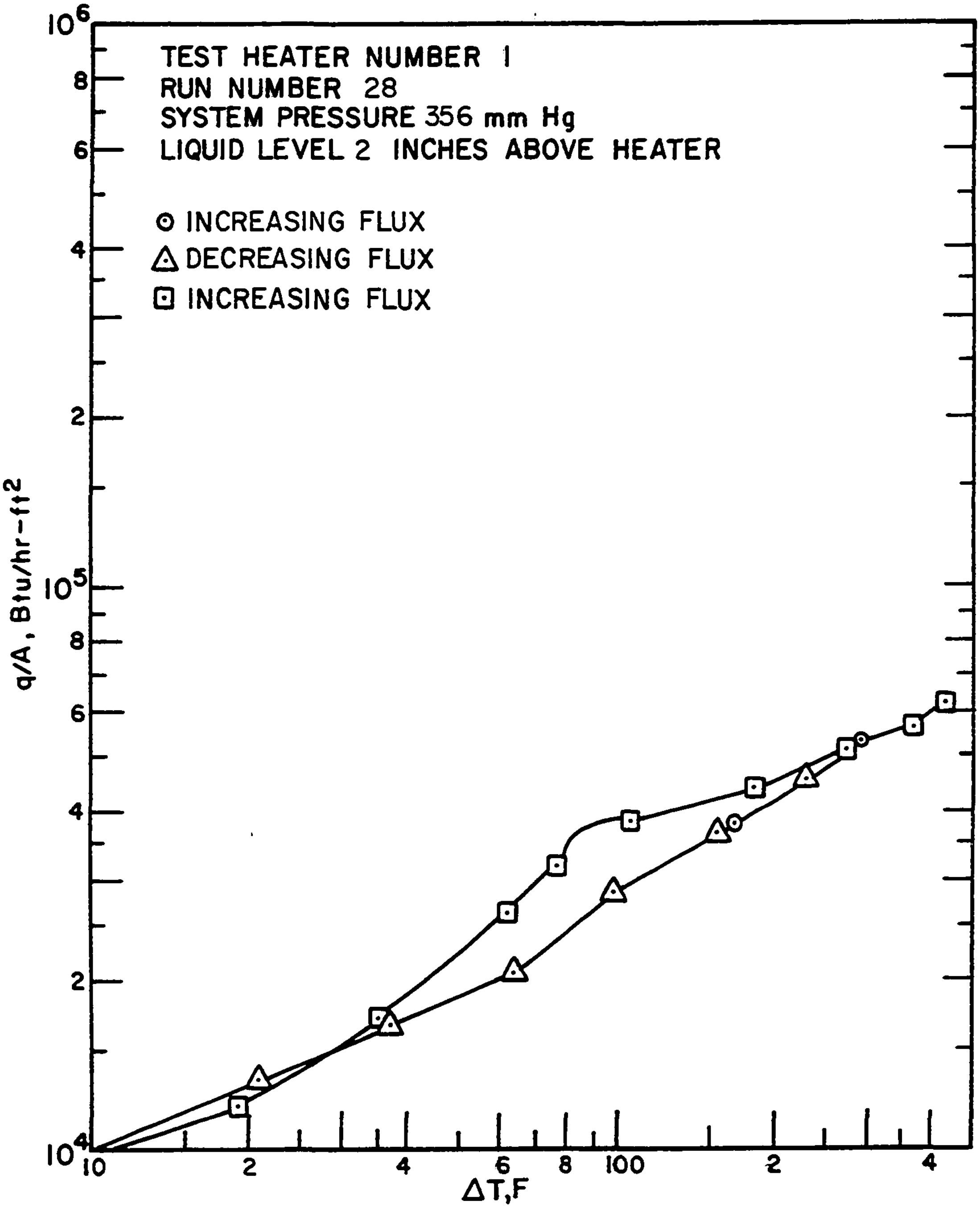

FIGURE D-27. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--28
SYSTEM PRESSURE--355 MM HG DATE--6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	37951.	775.91	770.28	604.48	165.81
21	37951.	671.72	665.88	604.48	61.40
20	53862.	904.31	896.68	604.91	291.76
21	53862.	741.43	733.35	604.91	128.44
20	46047.	837.16	830.48	605.34	225.13
21	46047.	704.31	697.30	605.34	91.96
20	36932.	766.97	761.48	604.48	157.00
21	36932.	667.42	661.73	604.48	57.25
20	28461.	707.30	702.98	604.04	98.94
21	28461.	635.14	630.70	604.04	26.65
20	21529.	670.00	666.69	603.61	63.08
21	21529.	622.63	619.26	603.61	15.65
20	16497.	642.03	639.46	602.75	36.72
21	16497.	614.86	612.27	602.75	9.52
20	12981.	624.36	622.33	601.88	20.45
21	12981.	608.37	606.33	601.88	4.45
20	6771.	609.67	608.60	601.45	7.16
21	6771.	596.25	595.18	601.45	-6.27

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 355 MM HG
POOL DEPTH ABOVE HEATER-- 2 INCHES

RUN NUMBER--28 Cont'd
DATE-- 6/1/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	11903.	620.91	619.04	600.15	18.89
21	11903.	603.61	601.73	600.15	1.59
20	16792.	636.43	633.81	600.15	33.67
21	16792.	613.99	611.35	600.15	11.21
20	16974.	635.14	632.49	597.55	34.94
21	16974.	611.83	609.16	597.55	11.61
20	26595.	664.84	660.74	599.28	61.46
21	26595.	624.79	620.63	599.28	21.35
20	32353.	681.60	676.64	600.58	76.06
21	32353.	632.12	627.07	600.58	26.49
20	37951.	712.01	706.25	602.31	103.94
21	37951.	643.32	637.42	602.31	35.10
20	44442.	790.38	783.82	604.04	179.78
21	44442.	670.86	664.02	604.04	59.97
20	51640.	878.99	871.61	605.34	266.27
21	51640.	733.34	725.57	605.34	120.23
20	57337.	968.10	960.15	604.48	355.67
21	57337.	775.48	766.98	604.48	162.50

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--28 Cont'd
SYSTEM PRESSURE--355 MM HG DATE-- 6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	60632.	1025.11	1016.85	604.91	411.94
21	60632.	801.01	792.10	604.91	187.19

280

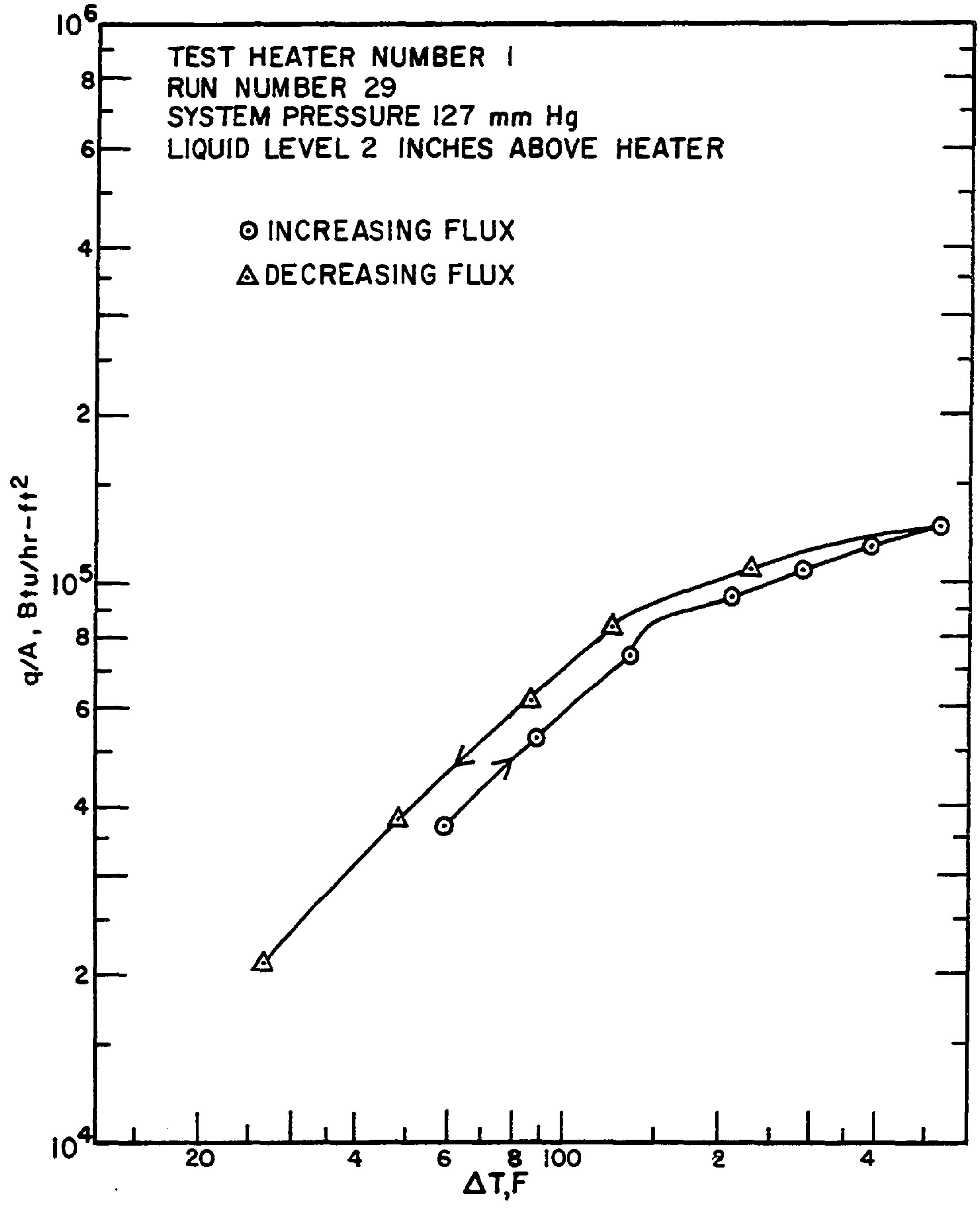

FIGURE D-28. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--29
SYSTEM PRESSURE--127 MM HG DATE--6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	36727.	588.87	583.04	523.47	59.57
21	36727.	556.25	550.34	523.47	26.87
20	52085.	620.04	611.86	522.59	89.27
21	52085.	570.19	561.85	522.59	39.26
20	72699.	672.15	660.95	523.03	137.92
21	72699.	596.68	585.16	523.03	62.12
20	92409.	743.14	729.26	523.47	205.79
21	92409.	632.12	617.66	523.47	94.19
20	107042.	828.65	813.06	523.91	289.15
21	107042.	679.45	662.99	523.91	139.08
20	119021.	938.51	921.81	523.91	397.91
21	119021.	734.62	716.68	523.91	192.77
20	127431.	1063.06	1045.90	523.47	522.43
21	127431.	777.61	758.69	523.47	235.22
20	105873.	763.99	748.21	523.47	224.73
21	105873.	647.19	630.71	523.47	107.24
20	80576.	660.11	647.64	523.47	124.17
21	80576.	596.68	583.91	523.47	60.43

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--29 Cont'd
SYSTEM PRESSURE--127 MM HG DATE---6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	60593.	618.31	608.79	523.47	85.32
21	60593.	575.84	566.17	523.47	42.69
20	38056.	577.15	571.08	523.03	48.04
21	38056.	552.32	546.19	523.03	23.16
20	20734.	552.32	548.98	523.03	25.95
21	20734.	537.91	534.55	523.03	11.52

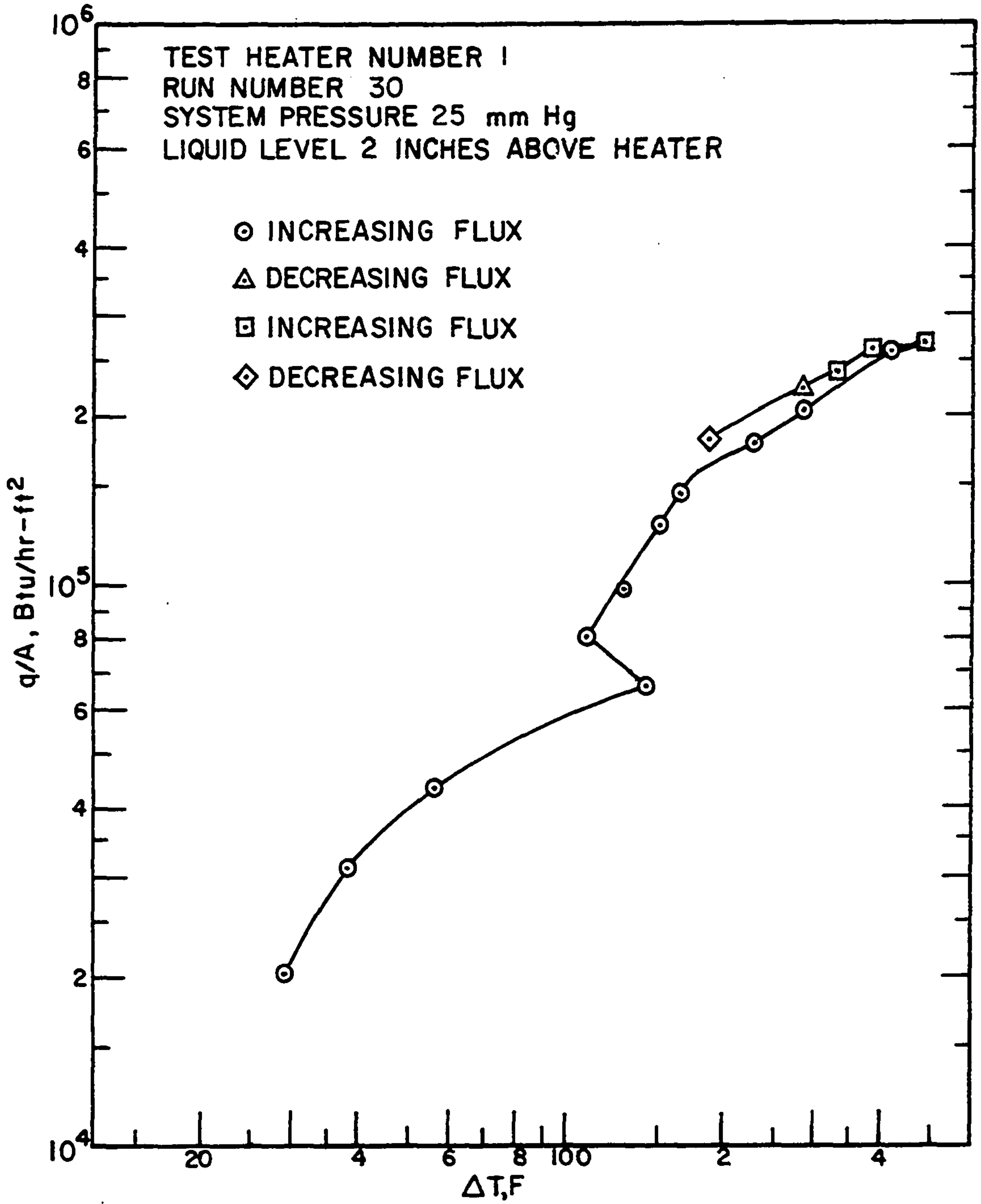

FIGURE D-29. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--30
SYSTEM PRESSURE--25 MM HG DATE--6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	20077.	450.84	447.47	418.72	28.76
21	20077.	444.60	441.23	418.72	22.51
20	30290.	460.12	455.06	416.93	38.13
21	30290.	450.39	445.31	416.93	28.39
20	44176.	483.06	475.75	419.16	56.58
21	44176.	464.10	456.73	419.16	37.56
20	67533.	574.97	564.18	419.61	144.57
21	67533.	503.29	492.19	419.61	72.58
20	79835.	542.72	529.79	420.95	108.84
21	79835.	494.94	481.77	420.95	60.82
20	97779.	563.22	547.51	420.50	127.01
21	97779.	508.12	492.07	420.50	71.56
20	121491.	591.04	571.72	421.40	150.32
21	121491.	524.35	504.51	421.40	83.11
20	140764.	614.86	592.66	423.63	169.02
21	140764.	540.97	518.12	423.63	94.49
20	173970.	673.01	646.14	422.29	223.85
21	173970.	568.01	540.04	422.29	117.75

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--30 Cont'd
SYSTEM PRESSURE-- 25 MM HG DATE-- 6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	200207.	732.92	702.65	421.40	281.25
21	200207.	596.68	564.82	421.40	143.43
20	251732.	866.77	830.45	420.95	409.50
21	251732.	669.57	630.55	420.95	209.60
20	220749.	735.05	701.68	420.95	280.73
21	220749.	608.37	573.38	420.95	152.43
20	235229.	783.99	749.06	421.40	327.66
21	235229.	627.38	590.35	421.40	168.95
20	252219.	849.91	813.30	421.40	391.90
21	252219.	651.93	612.57	421.40	191.17
20	265936.	940.63	903.21	423.18	480.03
21	265936.	683.74	642.73	423.18	219.54
20	189154.	641.60	612.02	420.95	191.07
21	189154.	568.88	538.47	420.95	117.52

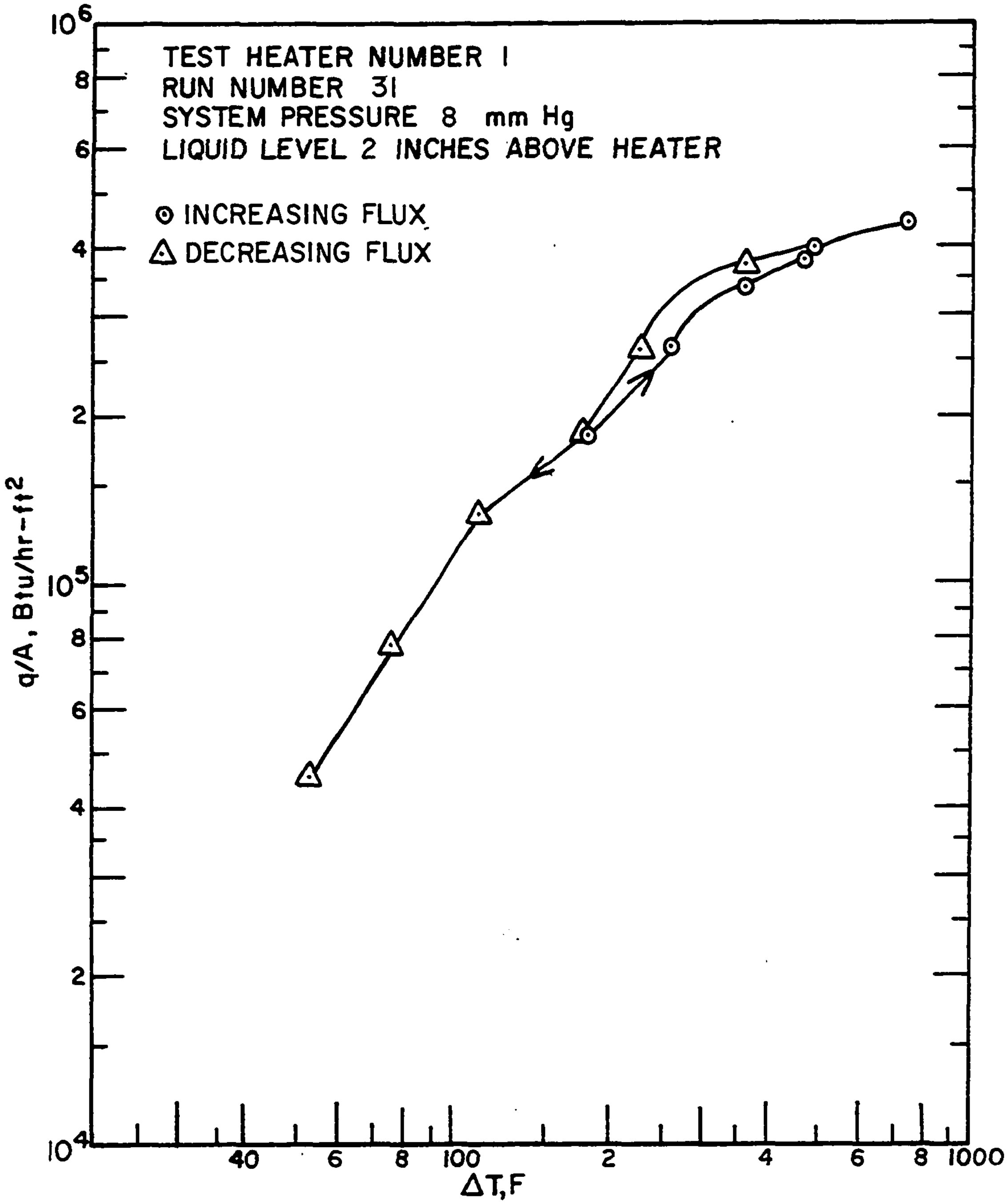

FIGURE D-30. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 31
SYSTEM PRESSURE-- 8 MM HG DATE-- 6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	188507.	562.79	532.40	349.62	182.78
21	188507.	503.73	472.63	349.62	123.01
20	252219.	651.50	612.13	353.22	258.91
21	252219.	553.19	512.31	353.22	159.08
20	326940.	764.84	715.82	356.82	359.00
21	326940.	614.86	563.00	356.82	206.17
20	369806.	873.09	819.69	358.17	461.52
21	369806.	655.80	597.98	358.17	239.81
20	388637.	904.73	849.21	358.62	490.58
21	388637.	655.80	595.00	358.62	236.38
20	423465.	1136.87	1080.85	359.07	721.78
21	423465.	698.75	633.50	359.07	274.43
20	372485.	775.48	719.78	358.17	361.61
21	372485.	621.34	562.32	358.17	204.14
20	254278.	614.86	574.61	352.32	222.29
21	254278.	542.72	501.32	352.32	149.00
20	188816.	565.40	535.00	352.32	182.67
21	188816.	505.93	474.80	352.32	122.48

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER-- 31 Cont'd

SYSTEM PRESSURE-- 8 MM HG DATE-- 6/1/68

POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	130681.	483.94	462.25	350.07	112.18
21	130681.	466.30	444.46	350.07	94.39
20	78428.	437.47	424.23	349.17	75.06
21	78428.	429.44	416.15	349.17	66.99
20	45196.	409.77	402.06	349.62	52.44
21	45196.	401.27	393.53	349.62	43.91

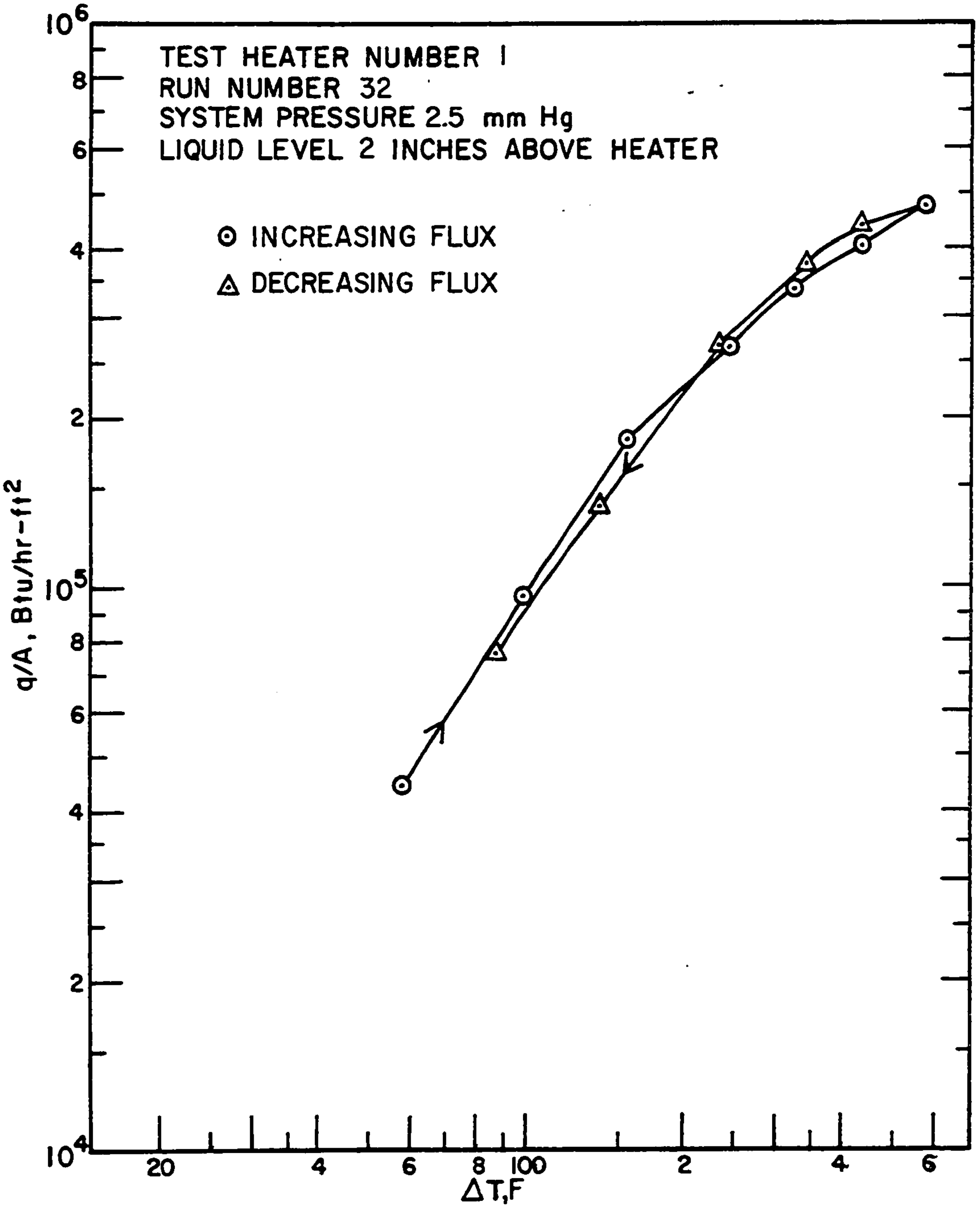

FIGURE D-31. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--32
SYSTEM PRESSURE--2.5 MM HG DATE--6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	45285.	363.57	355.70	297.29	58.41
21	45285.	355.92	348.02	297.29	50.73
20	96095.	410.67	394.25	294.60	99.65
21	96095.	392.75	376.22	294.60	81.62
20	179461.	481.74	451.88	299.08	152.79
21	179461.	454.82	424.62	299.08	125.54
20	259545.	595.81	554.42	307.17	247.26
21	259545.	510.32	467.51	307.17	160.34
20	332753.	696.18	644.99	318.42	326.57
21	332753.	575.84	522.24	318.42	203.82
20	398985.	807.39	748.37	322.93	425.44
21	398985.	630.40	567.35	322.93	244.42
20	463693.	968.10	903.16	327.44	575.72
21	463693.	694.46	622.82	327.44	295.38
20	423338.	814.20	751.69	325.19	426.50
21	423338.	648.91	582.44	325.19	257.25
20	368178.	720.12	663.94	320.68	343.26
21	368178.	608.80	550.19	320.68	229.52

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--32 Cont'd
SYSTEM PRESSURE--2.5 MM HG DATE-- 6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	258815.	591.04	549.70	308.52	241.18
21	258815.	532.23	489.91	308.52	181.39
20	135555.	464.54	441.86	299.98	141.88
21	135555.	441.93	419.04	299.98	119.06
20	78170.	399.48	386.07	298.64	87.43
21	78170.	388.27	374.80	298.64	76.17

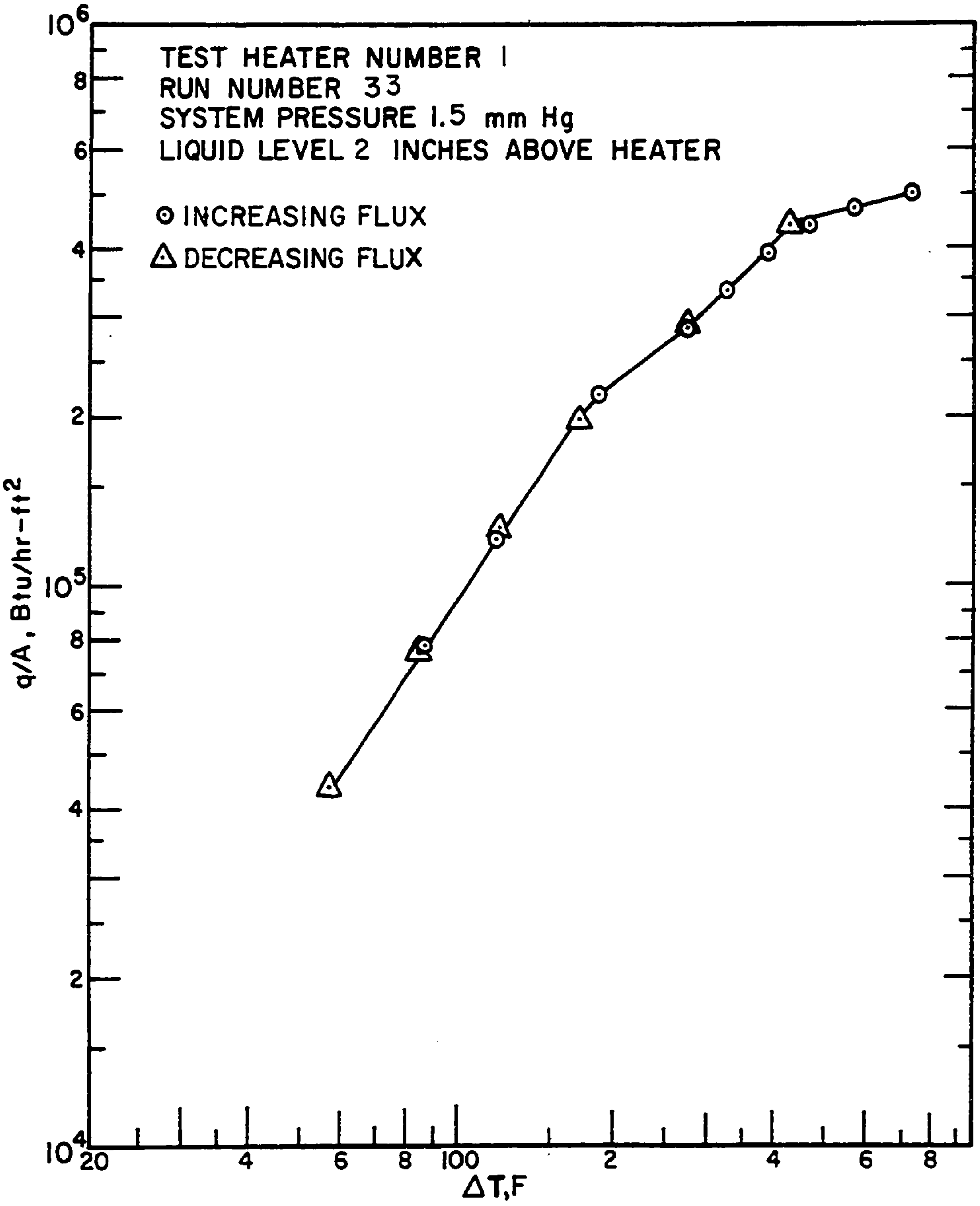

FIGURE D-32. MERCURY RESULTS.

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1 RUN NUMBER--33
SYSTEM PRESSURE--1.5 MM HG DATE--6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	77853.	378.40	364.93	276.25	88.68
21	77853.	364.92	351.37	276.25	75.12
20	120197.	421.84	401.39	280.72	120.67
21	120197.	398.58	377.93	280.72	97.21
20	214101.	519.09	483.95	293.70	190.25
21	214101.	486.58	450.99	293.70	157.28
20	275358.	617.02	573.45	302.23	271.22
21	275358.	539.22	494.30	302.23	192.08
20	327084.	694.46	644.13	310.32	333.81
21	327084.	586.70	534.25	310.32	223.93
20	373644.	770.80	714.83	318.87	395.96
21	373644.	623.50	564.34	318.87	245.47
20	421313.	856.65	795.38	324.73	470.64
21	421313.	661.40	595.57	324.73	270.83
20	456548.	967.68	903.74	326.54	577.20
21	456548.	708.59	638.44	326.54	311.90
20	476990.	1132.65	1069.39	330.15	739.24
21	476990.	755.48	683.41	330.15	353.26

TABLE V
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--1
SYSTEM PRESSURE-- 1.5 MM HG
RUN NUMBER--33 Cont'd
DATE-- 6/1/68
POOL DEPTH ABOVE HEATER-- 2 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	422367.	809.52	747.05	326.09	420.96
21	422367.	662.26	596.28	326.09	270.19
20	292266.	631.69	585.68	310.77	274.91
21	292266.	565.84	518.63	310.77	207.86
20	188892.	499.34	468.12	299.98	168.14
21	188892.	475.13	443.60	299.98	143.62
20	126893.	437.47	416.01	291.46	124.55
21	126893.	425.86	404.30	291.46	112.84
20	76886.	389.17	375.92	288.77	87.15
21	76886.	379.30	366.00	288.77	77.23
20	43534.	353.22	345.62	286.98	58.64
21	43534.	348.26	340.64	286.98	53.66

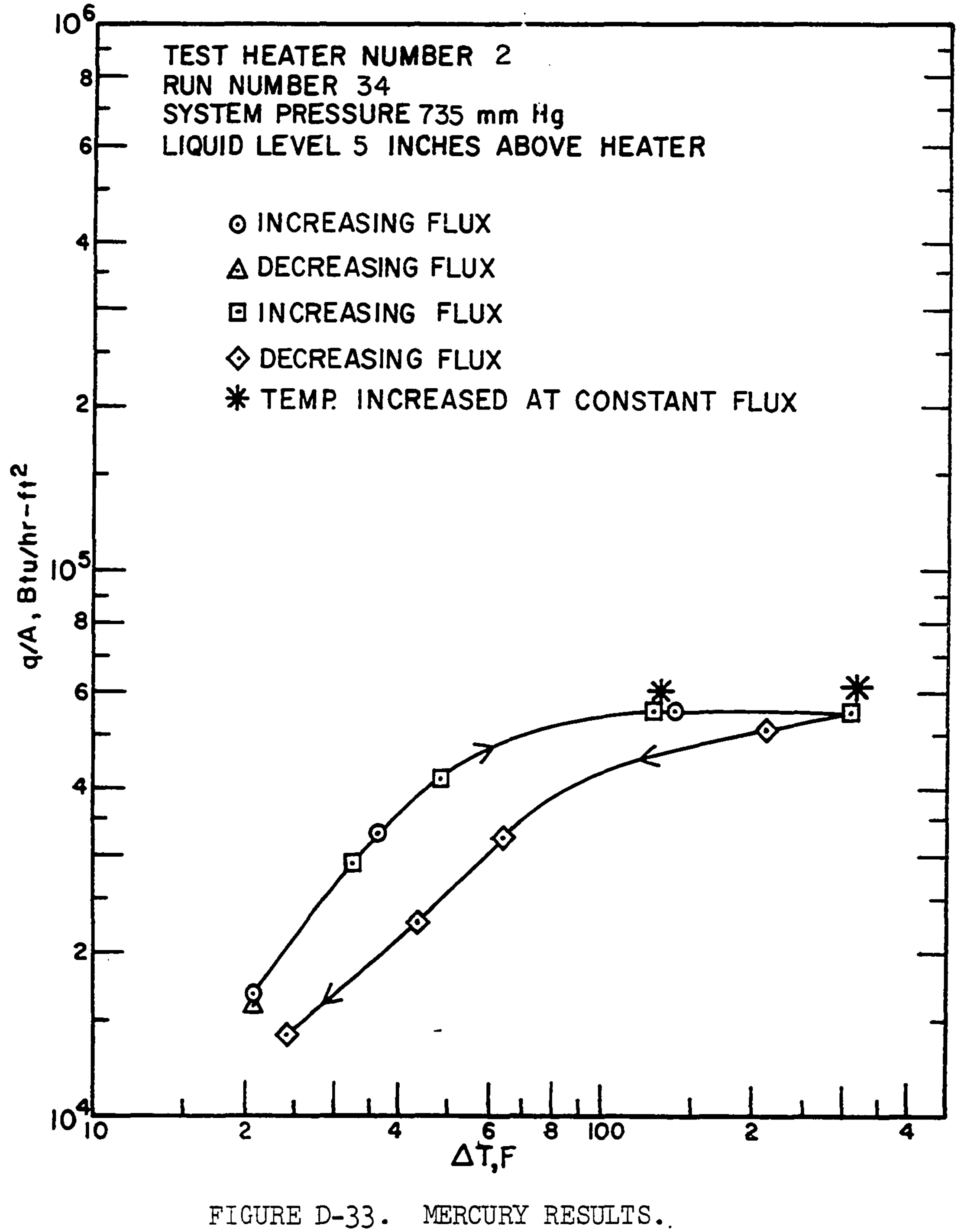

FIGURE D-33. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--34
SYSTEM PRESSURE-- 735 MM HG DATE--6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	16663.	694.46	691.92	671.29	20.63
21	16663.	700.89	698.35	671.29	27.06
22	16663.	677.31	674.75	671.29	3.46
20	32776.	712.01	707.04	670.86	36.17
21	32776.	725.67	720.72	670.86	49.86
22	32776.	693.18	688.17	670.86	17.31
20	54845.	811.65	803.62	672.58	131.04
21	54845.	816.32	808.31	672.58	135.73
22	54845.	718.84	710.54	672.58	37.96
20	15609.	694.46	692.08	671.29	20.79
21	15609.	698.75	696.37	671.29	25.08
22	15609.	681.17	678.78	671.29	7.48
20	28947.	707.30	702.91	671.29	31.61
21	28947.	715.85	711.47	671.29	40.18
22	28947.	696.60	692.19	671.29	20.90
20	40963.	726.09	719.91	671.72	48.19
21	40963.	732.06	725.90	671.72	54.17
22	40963.	706.88	700.65	671.72	28.93
20	57358.	798.88	790.45	670.43	120.02
21	57358.	818.02	809.65	670.43	139.21
22	57358.	737.60	728.98	670.43	58.55

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--34 Cont'd
SYSTEM PRESSURE-- 735 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	*55611.	992.60	984.95	670.43	314.52
21	55611.	993.45	985.80	670.43	315.37
22	55611.	789.10	780.89	670.43	110.46
20	50011.	881.10	873.96	670.86	203.10
21	50011.	875.20	868.04	670.86	197.18
22	50011.	749.52	742.03	670.86	71.17
20	32809.	738.88	733.95	670.43	63.52
21	32809.	748.24	743.33	670.43	72.90
22	32809.	701.74	696.75	670.43	26.32
20	23243.	716.71	713.19	670.43	42.76
21	23243.	717.99	714.47	670.43	44.04
22	23243.	693.18	689.63	670.43	19.20
20	14065.	695.75	693.60	670.00	23.60
21	14065.	700.46	698.32	670.00	28.31
22	14065.	677.74	675.58	670.00	5.57

*System was left running for 15 minutes at previous setting. Flux decreased slightly, temperature increased considerably. Perhaps silver plating had dissolved away.

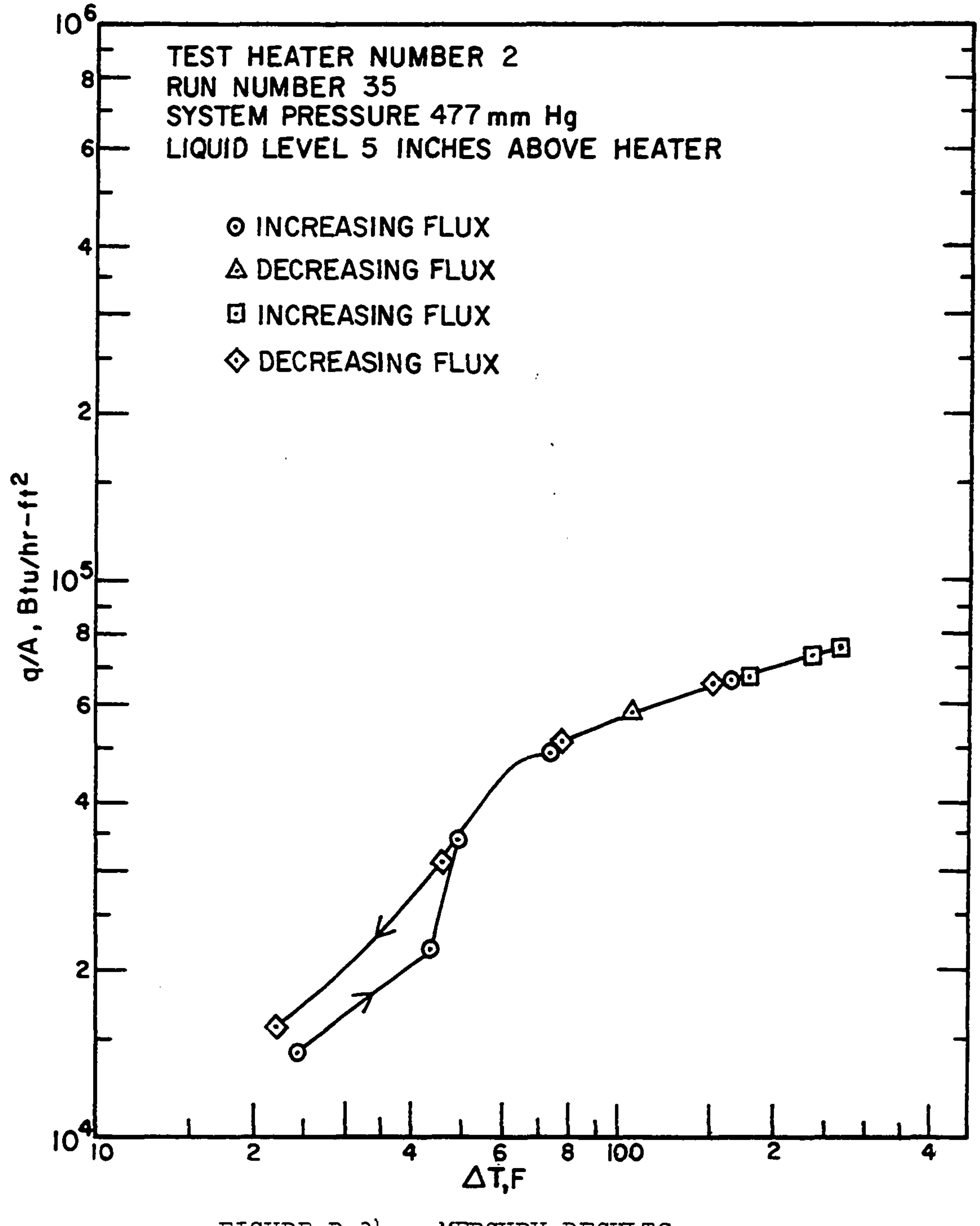

FIGURE D-34. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2
SYSTEM PRESSURE-- 477 MM HG
POOL DEPTH ABOVE HEATER-- 5 INCHES

RUN NUMBER--35
DATE-- 6/18/68

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	13986.	655.80	653.64	629.97	23.67
21	13986.	662.26	660.10	629.97	30.13
22	13986.	638.59	636.41	629.97	6.44
20	22337.	675.59	672.16	629.54	42.62
21	22337.	678.59	675.17	629.54	45.63
22	22337.	649.34	645.88	629.54	16.34
20	34278.	684.17	678.92	629.54	49.38
21	34278.	688.89	683.65	629.54	54.11
22	34278.	661.40	656.10	629.54	26.57
20	49431.	711.58	704.08	629.97	74.11
21	49431.	729.51	722.05	629.97	92.09
22	49431.	675.16	667.56	629.97	37.59
20	66821.	801.01	791.19	630.40	160.79
21	66821.	809.52	799.73	630.40	169.33
22	66821.	698.75	688.55	630.40	58.16
20	56871.	745.69	737.16	630.40	106.77
21	56871.	749.94	741.43	630.40	111.03
22	56871.	683.74	675.02	630.40	44.63
20	66821.	815.90	806.13	630.83	175.30
21	66821.	824.83	815.09	630.83	184.26
22	66821.	703.03	692.85	630.83	62.02

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 | RUN NUMBER-- 35 Cont'd
SYSTEM PRESSURE-- 477 MM HG | DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	72461.	870.98	860.59	630.83	229.76
21	72461.	870.56	860.17	630.83	229.34
22	72461.	715.85	704.87	630.83	74.04
20	75855.	896.29	885.50	631.26	254.24
21	75855.	903.46	892.71	631.26	261.44
22	75855.	725.24	713.78	631.26	82.52
20	66469.	794.63	784.84	630.40	154.44
21	66469.	806.97	797.22	630.40	166.82
22	66469.	696.18	686.03	630.40	55.63
20	50621.	713.72	706.04	630.40	75.64
21	50621.	724.82	717.17	630.40	86.77
22	50621.	673.87	666.08	630.40	35.68
20	30672.	679.45	674.75	629.97	44.78
21	30672.	688.03	683.34	629.97	53.37
22	30672.	659.25	654.51	629.97	24.54
20	16240.	654.51	652.00	630.40	21.60
21	16240.	657.10	654.58	630.40	24.18
22	16240.	642.03	639.50	630.40	9.10

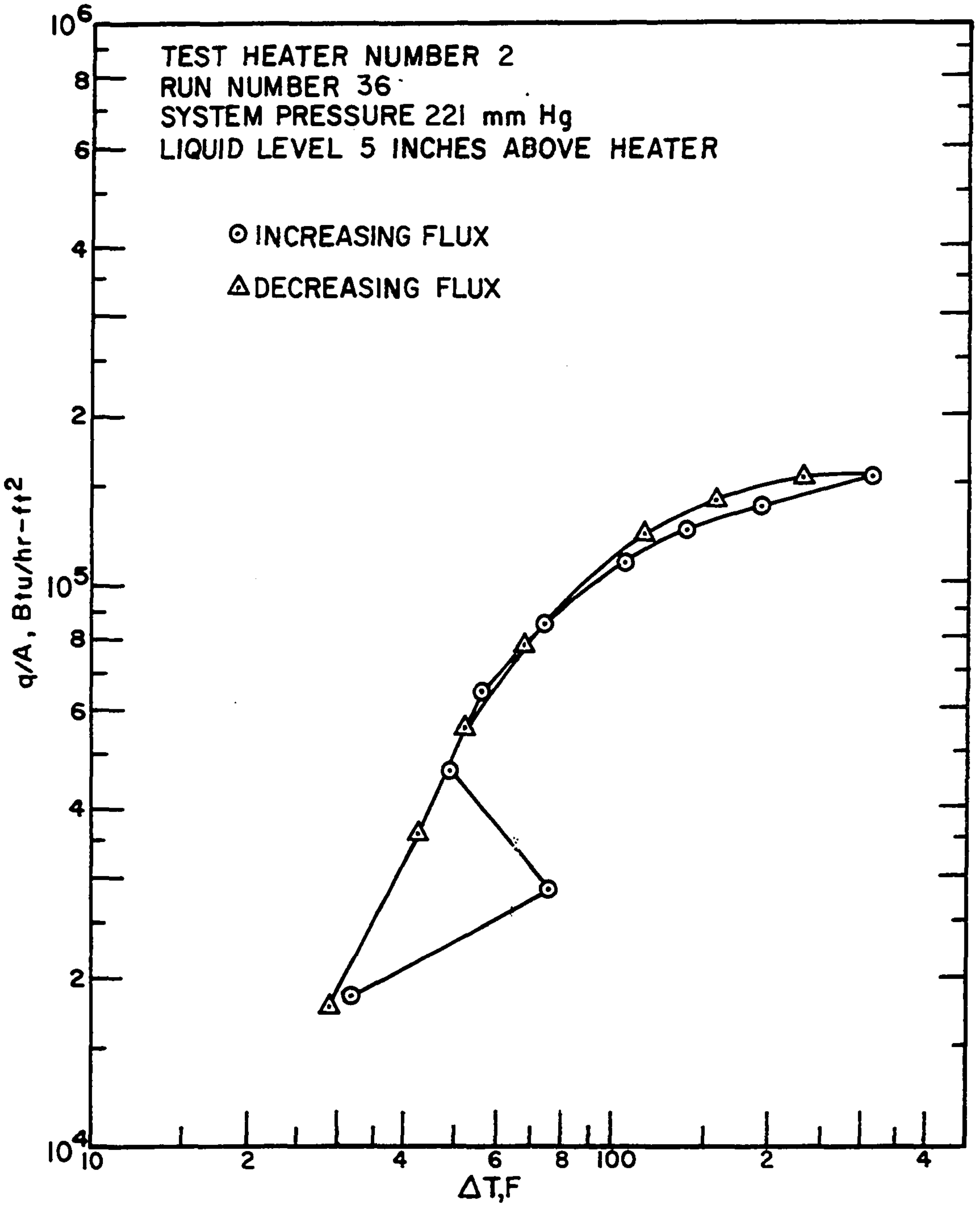

FIGURE D-35. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--36
SYSTEM PRESSURE-- 221 MM HG DATE--6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	17985.	601.01	598.17	565.84	32.34
21	17985.	604.04	601.21	565.84	35.37
22	17985.	578.89	576.02	565.84	10.19
20	29575.	647.19	642.60	566.27	76.33
21	29575.	651.50	646.91	566.27	80.64
22	29575.	601.88	597.21	566.27	30.94
20	48107.	622.63	615.09	565.84	49.25
21	48107.	629.97	622.44	565.84	56.61
22	48107.	608.80	601.22	565.84	35.38
20	64689.	632.99	622.87	566.27	56.60
21	64689.	639.45	629.36	566.27	63.09
22	64689.	616.16	605.98	566.27	39.71
20	84193.	654.08	641.02	566.71	74.31
21	84193.	660.11	647.08	566.71	80.37
22	84193.	629.97	616.79	566.71	50.08
20	105422.	685.89	669.72	566.27	103.45
21	105422.	697.03	680.93	566.27	114.66
22	105422.	640.74	624.29	566.27	58.02
20	124571.	722.68	703.82	566.71	137.11
21	124571.	731.64	712.84	566.71	146.13
22	124571.	653.65	634.30	566.71	67.59

TABLE VI

POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 36 Cont'd

SYSTEM PRESSURE-- 221 MM HG DATE-- 6/18/68

POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	144231.	779.74	758.33	566.71	191.63
21	144231.	796.76	775.48	566.71	208.78
22	144231.	666.56	644.25	566.71	77.55
20	158260.	894.18	871.62	566.27	305.34
21	158260.	913.17	890.76	566.27	324.49
22	158260.	696.60	672.39	566.27	106.12
20	152249.	814.62	792.30	566.27	226.03
21	152249.	839.28	817.16	566.27	250.89
22	152249.	679.45	656.01	566.27	89.74
20	142699.	743.99	722.54	566.27	156.27
21	142699.	778.04	756.85	566.27	190.58
22	142699.	666.56	644.49	566.27	78.22
20	119309.	697.46	679.23	566.27	112.96
21	119309.	720.12	702.04	566.27	135.77
22	119309.	649.34	630.78	566.27	64.51
20	78940.	647.19	634.91	565.40	69.52
21	78940.	655.80	643.57	565.40	78.17
22	78940.	626.95	614.58	565.40	49.18
20	56804.	625.65	616.75	564.96	51.79
21	56804.	642.03	633.18	564.96	68.22
22	56804.	609.67	600.72	564.96	35.75

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--36 Cont'd
SYSTEM PRESSURE-- 221 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	35905.	614.86	609.21	566.27	42.94
21	35905.	625.65	620.03	566.27	53.76
22	35905.	598.85	593.17	566.27	26.90
20	18210.	595.38	592.50	563.66	28.84
21	18210.	600.58	597.70	563.66	34.04
22	18210.	578.02	575.11	563.66	11.46

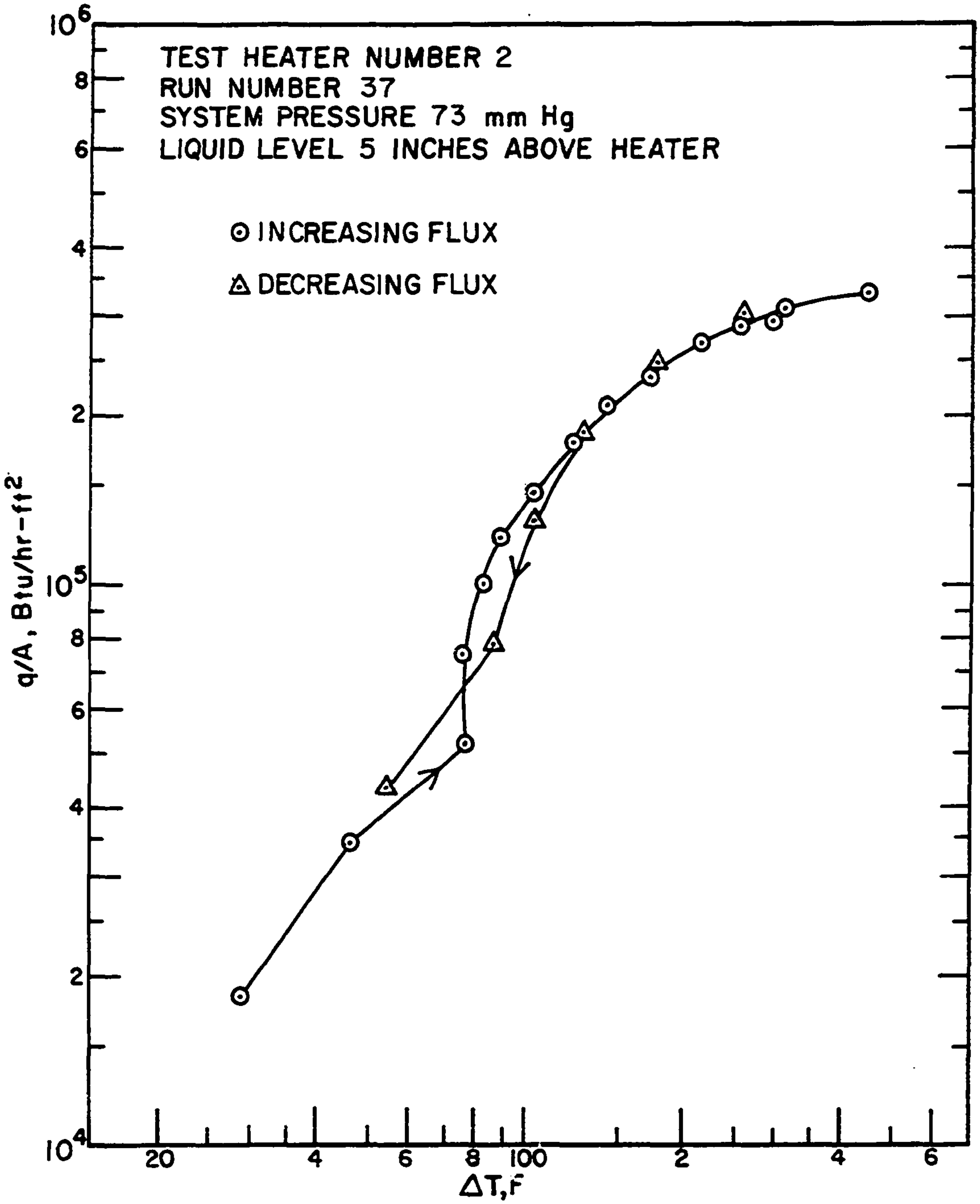

FIGURE D-36. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--37
SYSTEM PRESSURE-- 73 MM HG DATE--6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	18074.	519.09	516.14	488.35	27.80
21	18074.	526.10	523.16	488.35	34.81
22	18074.	501.54	498.57	488.35	10.22
20	34528.	540.10	534.51	487.46	47.04
21	34528.	553.19	547.63	487.46	60.17
22	34528.	518.65	513.02	487.46	25.55
20	51865.	573.23	564.94	488.35	76.60
21	51865.	590.61	582.37	488.35	94.03
22	51865.	537.91	529.51	488.35	41.16
20	77004.	575.84	563.54	488.79	74.75
21	77004.	587.57	575.32	488.79	86.54
22	77004.	552.76	540.34	488.79	51.56
20	100264.	584.53	568.65	487.91	80.65
21	100264.	604.91	589.05	487.91	101.15
22	100264.	566.71	550.61	487.91	62.71
20	118513.	595.38	576.56	487.02	89.53
21	118513.	606.21	587.47	487.02	100.44
22	118513.	574.54	555.57	487.02	68.54
20	142699.	612.70	590.17	486.58	103.58
21	142699.	627.81	605.41	486.58	118.83
22	142699.	592.34	569.64	486.58	83.06

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 37 Cont'd
SYSTEM PRESSURE-- 73 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	172675.	635.14	608.09	487.02	121.06
21	172675.	648.91	622.00	487.02	134.98
22	172675.	608.37	581.04	487.02	94.02
20	200910.	657.96	626.73	487.02	139.70
21	200910.	670.86	639.78	487.02	152.76
22	200910.	619.18	587.48	487.02	100.46
20	235052.	691.89	655.78	487.02	168.76
21	235052.	700.89	664.89	487.02	177.87
22	235052.	632.12	595.19	487.02	108.16
20	268529.	746.54	706.07	487.02	219.05
21	268529.	758.03	717.73	487.02	230.71
22	268529.	656.23	614.38	487.02	127.36
20	285711.	781.01	738.48	487.02	251.45
21	285711.	781.44	738.91	487.02	251.88
22	285711.	665.70	621.31	487.02	134.28
20	293392.	814.62	771.46	487.02	284.43
21	293392.	819.73	776.64	487.02	289.61
22	293392.	673.01	627.54	487.02	140.51
20	304388.	835.03	790.56	487.46	303.09
21	304388.	862.55	818.51	487.46	331.04
22	304388.	683.74	636.74	487.46	149.28

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--37 Cont'd
SYSTEM PRESSURE-- 73 MM HG DATE--6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	326771.	978.66	933.21	487.91	445.31
21	326771.	999.78	954.65	487.91	466.75
22	326771.	722.68	672.92	487.91	185.02
20	291641.	788.67	745.36	487.02	258.34
21	291641.	811.65	768.69	487.02	281.67
22	291641.	668.28	623.00	487.02	135.98
20	242251.	701.31	664.22	485.26	178.96
21	242251.	713.72	676.79	485.26	191.53
22	242251.	644.18	606.28	485.26	121.02
20	178977.	648.48	620.58	487.91	132.67
21	178977.	662.26	634.50	487.91	146.60
22	178977.	613.56	585.29	487.91	97.38
20	125334.	610.53	590.74	486.58	104.16
21	125334.	616.59	596.84	486.58	110.26
22	125334.	592.78	572.85	486.58	86.27
20	79397.	586.70	574.07	487.02	87.04
21	79397.	588.87	576.25	487.02	89.22
22	79397.	562.79	550.03	487.02	63.01
20	43632.	545.34	538.29	485.70	52.58
21	43632.	560.61	553.60	485.70	67.90
22	43632.	533.10	526.02	485.70	40.31

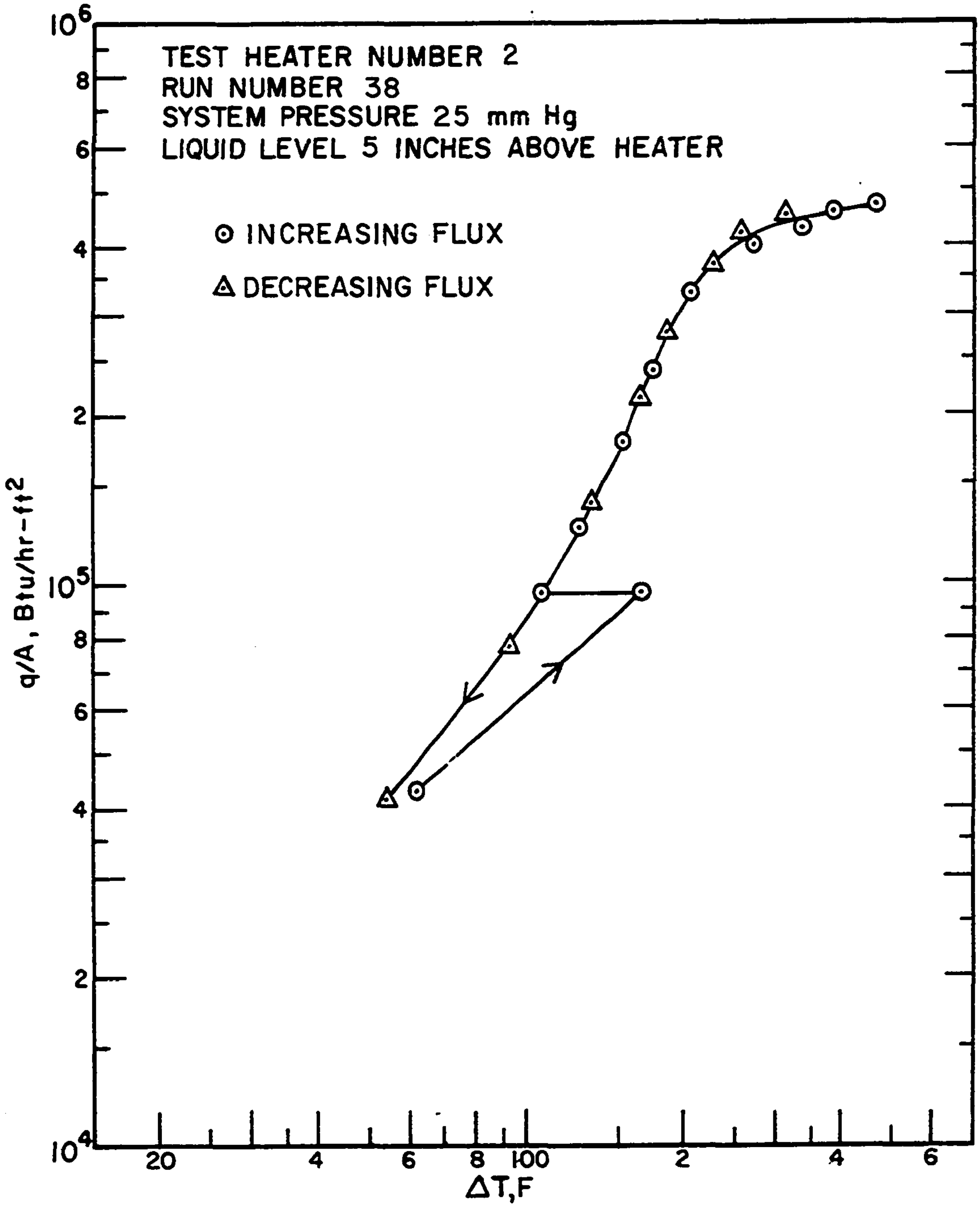

FIGURE D-37. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--38
SYSTEM PRESSURE-- 25 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	43773.	494.50	487.29	426.31	60.98
21	43773.	501.98	494.78	426.31	68.47
22	43773.	477.33	470.07	426.31	43.76
20	96158.	601.88	586.66	426.31	160.35
21	96158.	627.81	612.74	426.31	186.43
22	96158.	543.59	528.02	426.31	101.71
20	96596.	551.89	536.29	426.31	109.98
21	96596.	575.84	560.40	426.31	134.09
22	96596.	521.72	505.94	426.31	79.63
20	121618.	569.32	549.81	427.65	122.16
21	121618.	582.36	562.95	427.65	135.30
22	121618.	545.34	525.64	427.65	97.99
20	179569.	606.21	577.76	426.76	151.00
21	179569.	614.86	586.50	426.76	159.74
22	179569.	581.49	552.77	426.76	126.01
20	240046.	635.14	597.46	424.08	173.38
21	240046.	651.50	614.05	424.08	189.97
22	240046.	605.78	567.67	424.08	143.59
20	316032.	676.88	627.93	425.42	202.52
21	316032.	692.32	643.66	425.42	218.24
22	316032.	622.63	572.67	425.42	147.25

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER---2 RUN NUMBER--38 Cont'd

SYSTEM PRESSURE---25 MM HG DATE--6/18/68

POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	395376.	758.46	698.92	425.86	273.06
21	395376.	766.12	706.75	425.86	280.89
22	395376.	660.54	598.79	425.86	172.92
20	426358.	820.15	757.32	426.31	331.01
21	426358.	839.28	776.88	426.31	350.57
22	426358.	679.02	612.84	426.31	186.53
20	451677.	873.09	807.73	426.76	380.98
21	451677.	913.17	848.73	426.76	421.97
22	451677.	694.46	624.70	426.76	197.94
20	470910.	949.08	882.69	427.65	455.04
21	470910.	974.44	908.62	427.65	480.97
22	470910.	712.01	639.71	427.65	212.06
20	434810.	809.52	745.19	427.20	317.98
21	434810.	843.96	780.42	427.20	353.21
22	434810.	676.45	608.87	427.20	181.66
20	395520.	743.56	683.68	425.86	257.81
21	395520.	772.93	713.69	425.86	287.83
22	395520.	656.23	594.36	425.86	168.49
20	358862.	712.86	657.96	426.31	231.65
21	358862.	736.32	681.90	426.31	255.59
22	358862.	642.89	586.52	426.31	160.21

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 | RUN NUMBER-- 38 <u>Cont'd</u>
SYSTEM PRESSURE-- 25 MM HG | DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	277016.	657.96	614.80	426.31	188.49
21	277016.	669.57	626.60	426.31	200.29
22	277016.	608.37	564.39	426.31	138.08
20	208752.	621.34	588.43	424.97	163.45
21	208752.	626.52	593.67	424.97	168.70
22	208752.	597.11	563.89	424.97	138.92
20	139586.	575.41	553.05	425.86	127.19
21	139586.	584.53	562.26	425.86	136.39
22	139586.	564.09	541.64	425.86	115.78
20	78427.	530.48	517.72	426.76	90.96
21	78427.	543.15	530.46	426.76	103.70
22	78427.	508.12	495.25	426.76	68.50
20	41412.	487.46	480.62	426.76	53.86
21	41412.	496.26	489.44	426.76	62.69
22	41412.	476.01	469.13	426.76	42.38

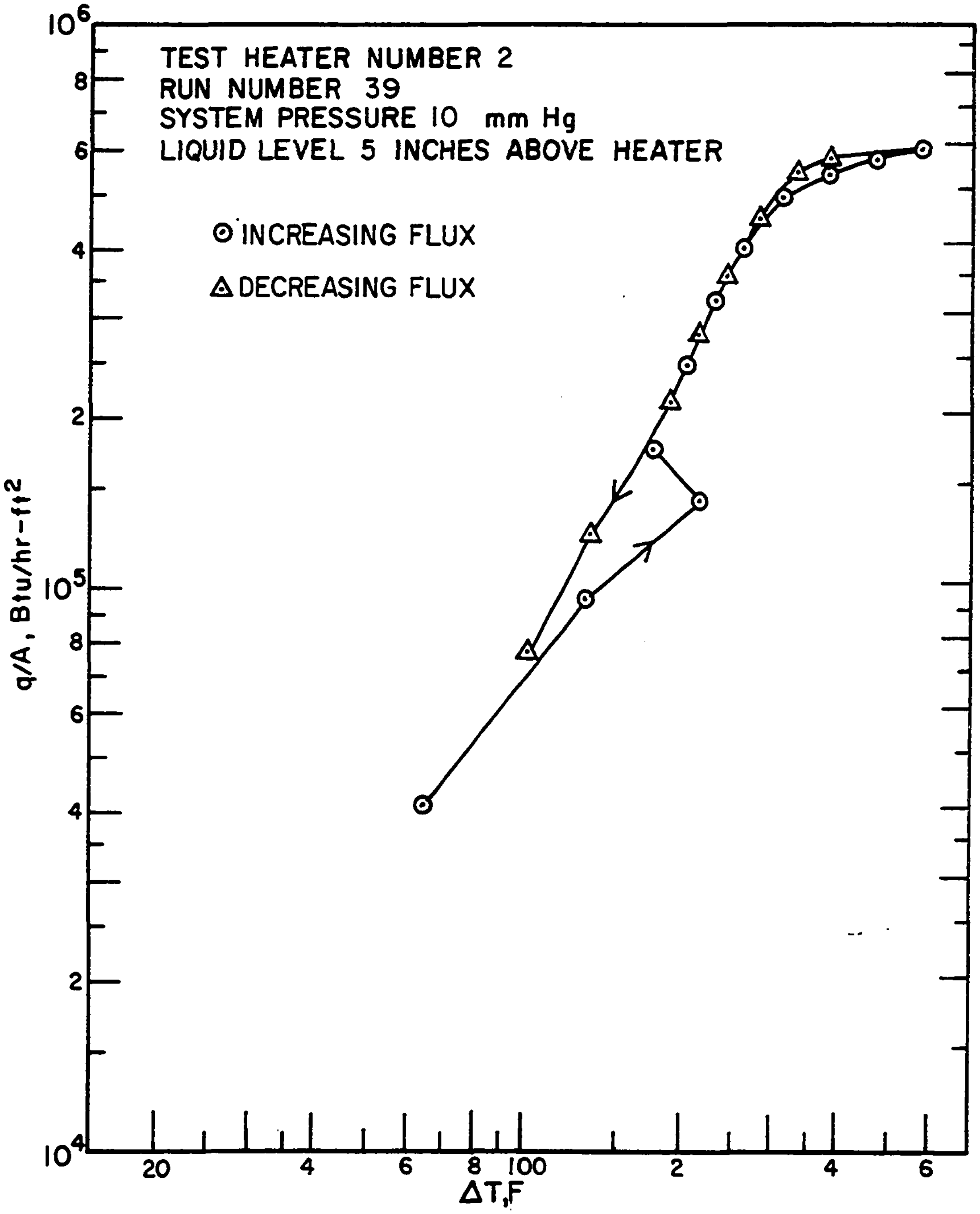

FIGURE D-38. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 39
SYSTEM PRESSURE-- 10 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	41820.	433.01	425.94	361.32	64.62
21	41820.	435.69	428.63	361.32	67.30
22	41820.	416.93	409.82	361.32	48.49
20	94234.	511.20	495.74	366.72	129.02
21	94234.	528.73	513.38	366.72	146.66
22	94234.	470.72	455.01	366.72	88.29
20	145607.	606.21	583.16	367.62	215.54
21	145607.	629.11	606.26	367.62	238.64
22	145607.	512.07	488.16	367.62	120.55
20	174486.	566.71	538.64	366.72	171.92
21	174486.	569.32	541.28	366.72	174.56
22	174486.	534.41	505.99	366.72	139.27
20	244703.	607.07	568.24	367.17	201.07
21	244703.	619.18	580.52	367.17	213.36
22	244703.	565.40	525.93	367.17	158.76
20	316142.	647.19	597.68	370.31	227.36
21	316142.	655.80	606.45	370.31	236.14
22	316142.	604.91	554.59	370.31	184.27
20	398664.	691.03	629.48	370.76	258.71
21	398664.	709.44	648.31	370.76	277.54
22	398664.	638.16	575.35	370.76	204.58

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 39 Cont'd
SYSTEM PRESSURE-- 10 MM HG DATE-- 6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	480649.	755.48	682.85	372.56	310.29
21	480649.	766.97	694.65	372.56	322.09
22	480649.	668.28	593.24	372.56	220.68
20	533082.	829.50	750.99	372.56	378.43
21	533082.	843.53	765.42	372.56	392.86
22	533082.	691.03	608.40	372.56	235.84
20	576757.	919.51	837.14	373.46	463.68
21	576757.	936.40	854.52	373.46	481.06
22	576757.	712.86	624.08	373.46	250.62
20	598940.	1018.78	936.07	373.91	562.16
21	598940.	1052.52	970.74	373.91	596.84
22	598940.	729.93	638.27	373.91	264.36
20	560468.	847.78	765.72	373.46	392.26
21	560468.	875.20	793.94	373.46	420.48
22	560468.	707.30	620.89	373.46	247.43
20	525538.	792.50	714.07	372.56	341.51
21	525538.	824.40	746.88	372.56	374.32
22	525538.	688.03	606.49	372.56	233.93
20	437316.	720.12	653.25	371.66	281.59
21	437316.	743.56	677.27	371.66	305.61
22	437316.	649.34	580.66	371.66	209.00

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--39 Cont'd
SYSTEM PRESSURE-- 10 MM HG DATE--6/18/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	349652.	667.85	613.47	372.11	241.35
21	349652.	682.89	628.81	372.11	256.70
22	349652.	617.02	561.56	372.11	189.45
20	281489.	627.81	583.44	370.76	212.68
21	281489.	638.16	593.96	370.76	223.20
22	281489.	586.70	541.63	370.76	170.86
20	212370.	594.51	560.68	369.87	190.81
21	212370.	595.38	561.56	369.87	191.69
22	212370.	560.61	526.32	369.87	156.46
20	122601.	523.03	503.00	368.97	134.04
21	122601.	527.85	507.86	368.97	138.89
22	122601.	497.58	477.35	368.97	108.38
20	78139.	481.74	468.78	367.17	101.61
21	78139.	483.94	470.99	367.17	103.83
22	78139.	475.13	462.14	367.17	94.97

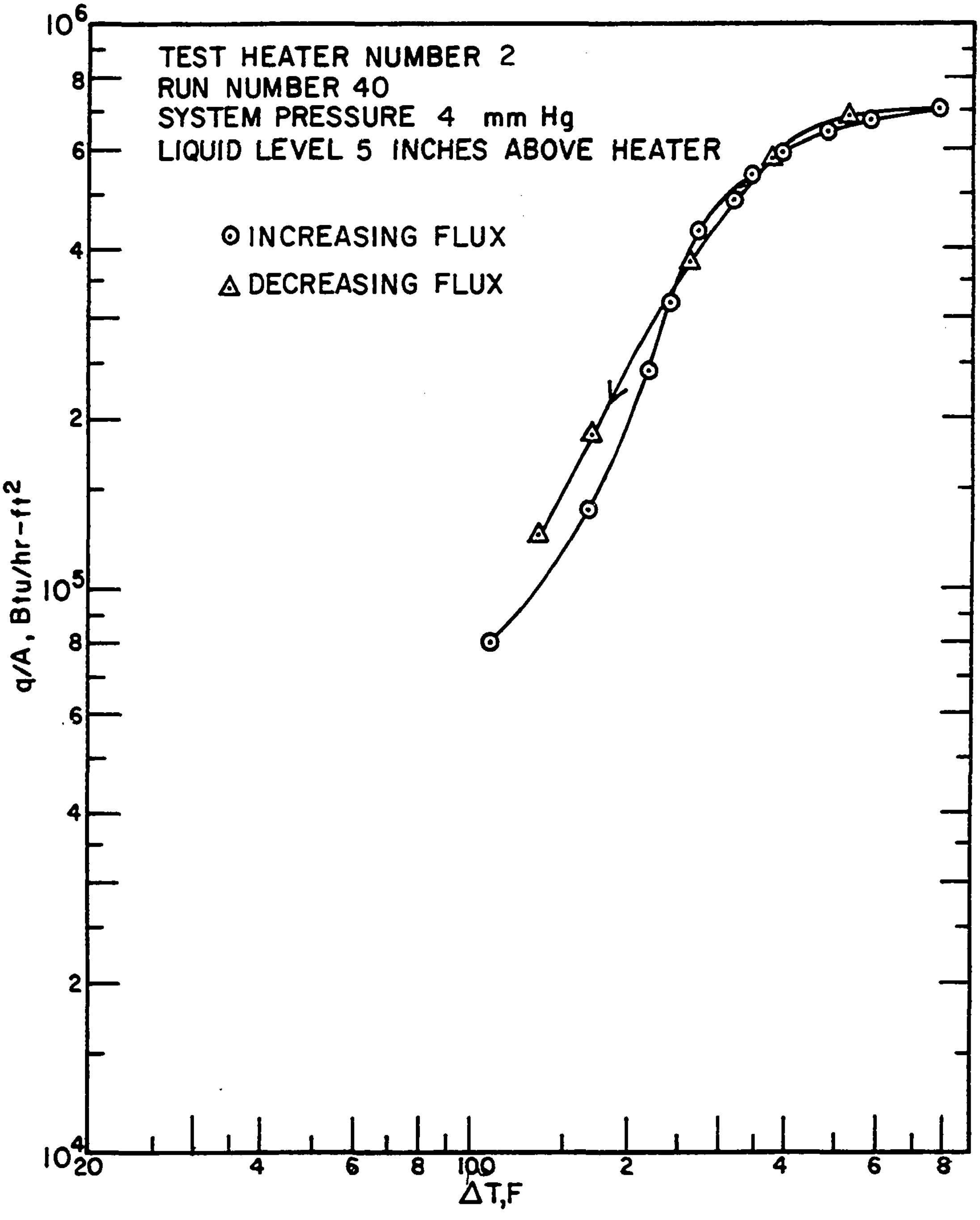

FIGURE D-39. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--40
SYSTEM PRESSURE-- 4 MM HG DATE-- 6/19/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	79957.	436.13	422.62	313.92	108.71
21	79957.	437.47	423.97	313.92	110.05
22	79957.	412.90	399.26	313.92	85.35
20	143324.	502.42	478.79	317.52	161.27
21	143324.	513.39	489.87	317.52	172.35
22	143324.	468.07	444.12	317.52	126.60
20	242542.	591.04	552.31	329.70	222.61
21	242542.	586.70	547.91	329.70	218.21
22	242542.	551.89	512.56	329.70	182.86
20	316073.	623.50	573.54	331.96	241.58
21	316073.	634.28	584.53	331.96	252.57
22	316073.	583.66	532.93	331.96	200.97
20	407192.	673.87	610.57	332.86	277.71
21	407192.	691.03	628.14	332.86	295.28
22	407192.	627.81	563.39	332.86	230.52
20	486909.	721.40	646.88	338.74	308.14
21	486909.	739.73	665.72	338.74	326.97
22	486909.	665.70	589.59	338.74	250.85
20	531704.	760.58	680.29	338.74	341.54
21	531704.	777.61	697.81	338.74	359.07
22	531704.	695.75	613.47	338.74	274.73

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 40 Cont'd
SYSTEM PRESSURE-- 4 MM HG DATE-- 6/19/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	581846.	822.28	736.25	342.37	393.88
21	581846.	838.01	752.47	342.37	410.10
22	581846.	703.03	613.11	342.37	270.74
20	629865.	913.17	822.91	341.01	481.90
21	629865.	927.53	837.72	341.01	496.71
22	629865.	728.65	632.12	341.01	291.11
20	663036.	1008.22	916.20	342.82	573.38
21	663036.	1041.98	951.00	342.82	608.18
22	663036.	752.92	652.13	342.82	309.31
20	692423.	1221.99	1132.34	345.54	786.80
21	692423.	1281.01	1193.01	345.54	847.47
22	692423.	783.99	679.86	345.54	334.32
20	659258.	953.31	860.07	343.27	516.80
21	659258.	1004.00	912.38	343.27	569.11
22	659258.	746.11	645.65	343.27	302.38
20	567179.	800.16	715.66	339.65	376.01
21	567179.	826.53	742.83	339.65	403.18
22	567179.	700.89	613.20	339.65	273.55
20	368150.	642.03	584.17	338.29	245.88
21	368150.	654.94	597.36	338.29	259.07
22	368150.	621.34	563.01	338.29	224.72

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--40 Cont'd
SYSTEM PRESSURE-- 4 MM HG DATE--6/19/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	191330.	532.23	501.01	336.48	164.53
21	191330.	545.34	514.28	336.48	177.80
22	191330.	530.48	499.24	336.48	162.76
20	126082.	488.35	467.46	334.67	132.78
21	126082.	501.54	480.76	334.67	146.09
22	126082.	482.18	461.24	334.67	126.57

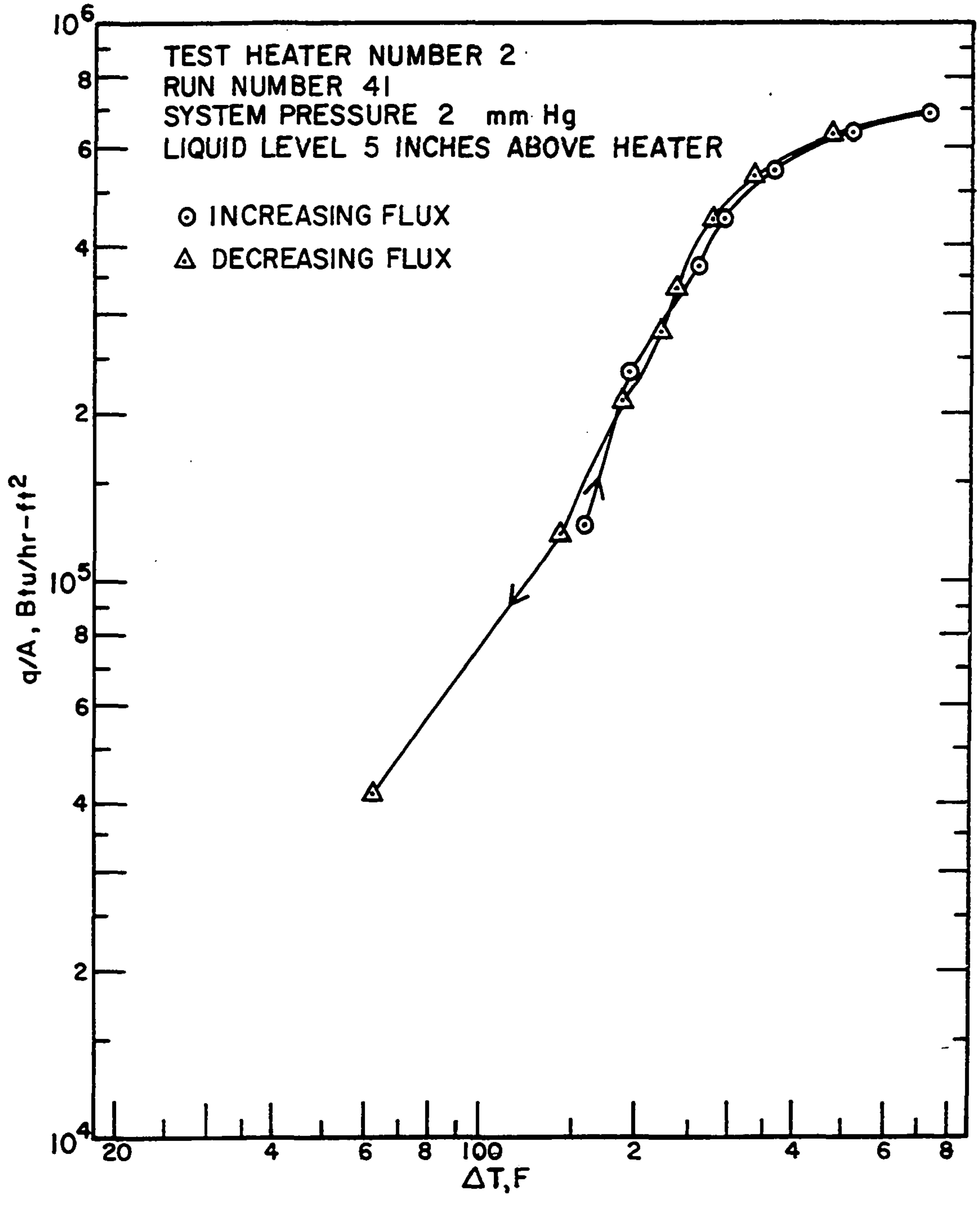

FIGURE D-40. MERCURY RESULTS.

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--41
SYSTEM PRESSURE-- 2 MM HG DATE-- 6/19/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	127320.	487.91	466.81	310.77	156.04
21	127320.	509.44	488.52	310.77	177.76
22	127320.	463.21	441.90	310.77	131.14
20	243232.	552.32	512.89	317.97	194.92
21	243232.	558.43	519.09	317.97	201.12
22	243232.	540.10	500.47	317.97	182.50
20	358546.	634.28	577.77	320.22	257.55
21	358546.	647.62	591.41	320.22	271.18
22	358546.	609.67	552.63	320.22	232.40
20	449719.	688.03	618.41	322.03	296.38
21	449719.	707.30	638.18	322.03	316.16
22	449719.	653.65	583.11	322.03	261.08
20	546353.	781.44	699.53	336.03	363.50
21	546353.	802.29	721.00	336.03	384.97
22	546353.	704.31	620.01	336.03	283.98
20	633333.	941.89	852.03	341.01	511.02
21	633333.	965.56	876.43	341.01	535.42
22	633333.	758.46	662.46	341.01	321.45
20	674901.	1158.04	1068.88	343.27	725.61
21	674901.	1175.91	1087.27	343.27	744.00
22	674901.	777.61	675.92	343.27	332.65

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--41 Cont'd

SYSTEM PRESSURE-- 2 MM HG DATE--6/19/68

POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	634686.	915.28	824.38	343.27	481.11
21	634686.	957.11	867.52	343.27	524.25
22	634686.	741.43	644.61	343.27	301.34
20	532807.	754.20	673.54	341.01	332.53
21	532807.	777.19	697.21	341.01	356.20
22	532807.	698.75	616.39	341.01	275.39
20	445463.	682.89	613.80	337.39	276.41
21	445463.	703.03	634.46	337.39	297.07
22	445463.	662.26	592.63	337.39	255.24
20	348821.	627.81	572.72	334.22	238.50
21	348821.	638.59	583.72	334.22	249.50
22	348821.	612.70	557.28	334.22	223.06
20	279543.	588.01	543.27	321.58	221.69
21	279543.	591.04	546.35	321.58	224.78
22	279543.	579.32	534.43	321.58	212.85
20	210720.	534.41	500.04	318.42	181.62
21	210720.	545.34	511.12	318.42	192.70
22	210720.	534.85	500.49	318.42	182.07
20	123946.	479.54	458.93	317.07	141.86
21	123946.	475.13	454.49	317.07	137.42
22	123946.	470.72	450.04	317.07	132.97

TABLE VI
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--41 Cont'd
SYSTEM PRESSURE-- 2 MM HG DATE--6/19/68
POOL DEPTH ABOVE HEATER-- 5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	42091.	379.30	372.03	310.77	61.26
21	42091.	385.13	377.88	310.77	67.11
22	42091.	383.78	376.53	310.77	65.76

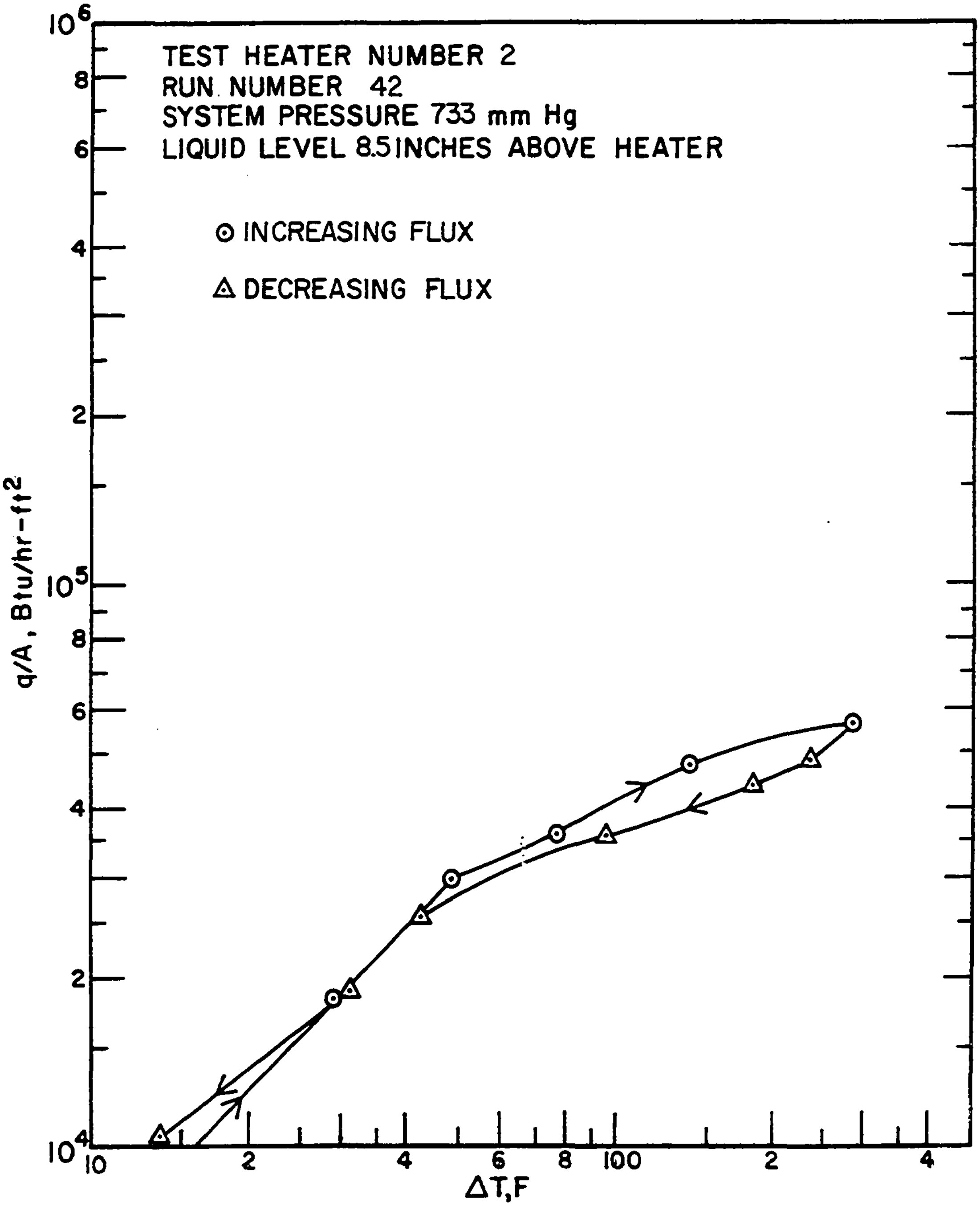

FIGURE D-41. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--42
SYSTEM PRESSURE-- 733 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	4786.	659.25	658.51	651.93	6.58
21	4786.	661.83	661.09	651.93	9.17
22	4786.	649.34	648.60	651.93	-3.33
20	18659.	683.32	680.46	651.06	29.39
21	18659.	685.03	682.17	651.06	31.11
22	18659.	672.58	669.71	651.06	18.65
20	29799.	703.03	698.49	649.34	49.15
21	29799.	708.59	704.06	649.34	54.72
22	29799.	691.46	686.91	649.34	37.57
20	37257.	734.19	728.59	651.50	77.09
21	37257.	735.05	729.44	651.50	77.95
22	37257.	706.45	700.79	651.50	49.29
20	49646.	796.76	789.45	650.63	138.82
21	49646.	801.86	794.57	650.63	143.94
22	49646.	746.11	738.67	650.63	88.04
20	58455.	944.85	936.68	653.65	283.03
21	58455.	984.15	976.09	653.65	322.44
22	58455.	811.65	803.09	653.65	149.44
20	49661.	904.73	897.69	659.25	238.45
21	49661.	928.80	921.82	659.25	262.57
22	49661.	811.65	804.38	659.25	145.13

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--42 Cont'd
SYSTEM PRESSURE-- 733 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	42490.	841.41	835.25	657.53	177.73
21	42490.	843.96	837.81	657.53	180.28
22	42490.	771.23	764.92	657.53	107.39
20	35761.	760.58	755.26	657.96	97.30
21	35761.	759.31	753.98	657.96	96.02
22	35761.	735.05	729.67	657.96	71.71
20	25585.	705.16	701.28	658.82	42.46
21	25585.	709.44	705.56	658.82	46.74
22	25585.	694.46	690.56	658.82	31.74
20	19165.	692.32	689.39	657.96	31.44
21	19165.	693.61	690.68	657.96	32.72
22	19165.	682.46	679.52	657.96	21.56
20	11040.	671.72	670.02	657.10	12.93
21	11040.	678.16	676.47	657.10	19.38
22	11040.	663.12	661.42	657.10	4.32

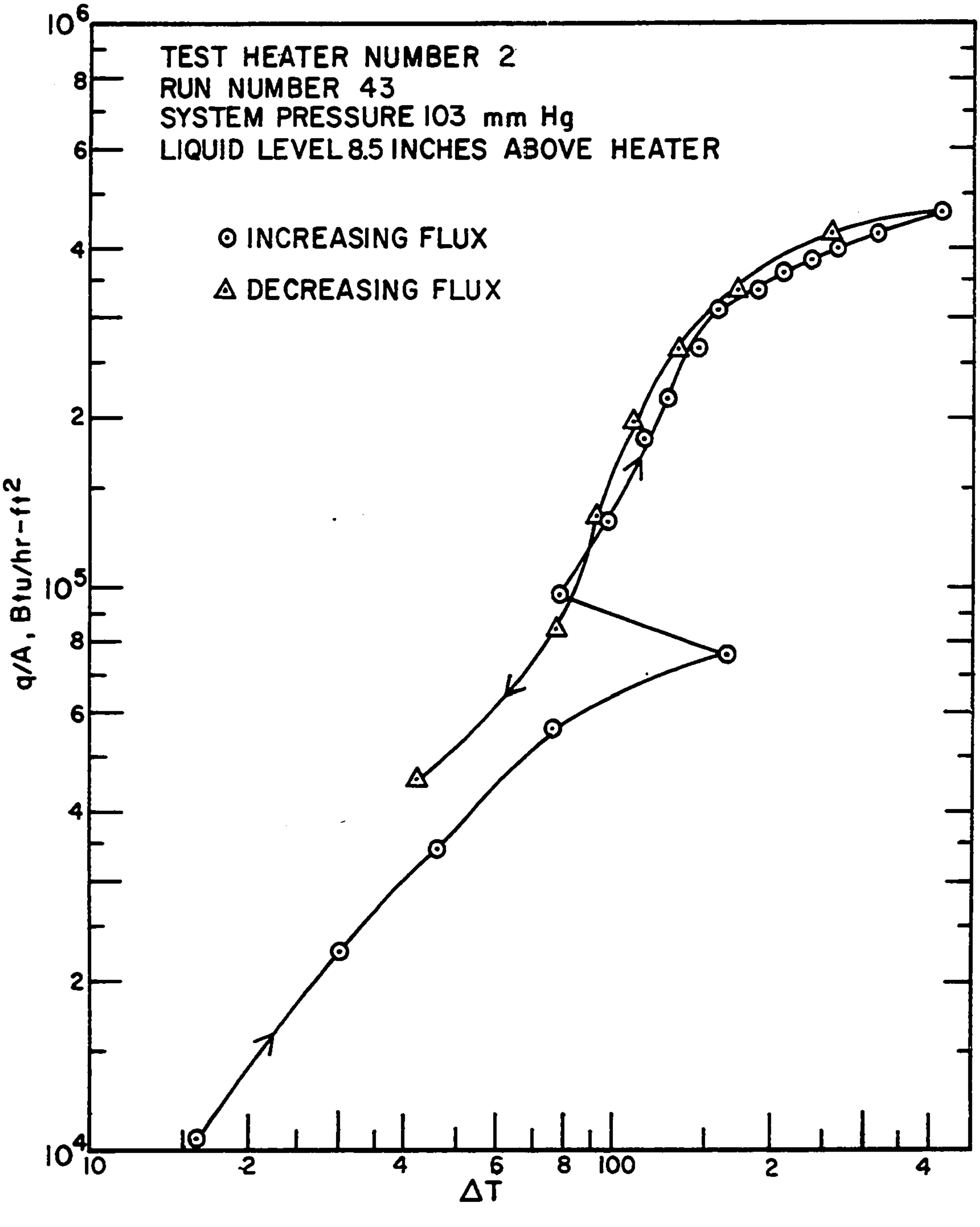

FIGURE D-42. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2
SYSTEM PRESSURE-- 103 MM HG
RUN NUMBER-- 43
DATE-- 6/27/68

POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	10695.	534.85	533.12	517.34	15.78
21	10695.	536.16	534.43	517.34	17.09
22	10695.	527.41	525.67	517.34	8.34
20	22787.	547.96	544.28	514.27	30.01
21	22787.	551.89	548.22	514.27	33.95
22	22787.	543.59	539.91	514.27	25.64
20	33725.	567.14	561.74	514.71	47.03
21	33725.	567.14	561.74	514.71	47.03
22	33725.	562.35	556.94	514.71	42.23
20	56481.	604.04	595.12	516.90	78.22
21	56481.	608.37	599.46	516.90	82.57
22	56481.	597.55	588.60	516.90	71.70
20	75481.	685.89	674.32	511.64	162.68
21	75481.	698.75	687.23	511.64	175.59
22	75481.	640.31	628.54	511.64	116.90
20	98313.	608.37	592.85	513.83	79.02
21	98313.	614.86	599.37	513.83	85.54
22	98313.	615.72	600.24	513.83	86.41
20	125361.	632.12	612.49	516.90	95.59
21	125361.	641.60	622.03	516.90	105.14
22	125361.	627.38	607.71	516.90	90.81

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER-- 43 Cont'd
SYSTEM PRESSURE-- 103 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	150209.	644.18	620.74	517.77	102.97
21	150209.	651.50	628.12	517.77	110.35
22	150209.	641.60	618.14	517.77	100.37
20	185704.	655.80	626.93	518.21	108.71
21	185704.	666.56	637.80	518.21	119.59
22	185704.	651.50	622.57	518.21	104.36
20	210720.	673.01	640.43	518.21	122.22
21	210720.	683.74	651.29	518.21	133.08
22	210720.	675.16	642.60	518.21	124.39
20	260694.	700.89	660.94	518.65	142.29
21	260694.	717.99	678.29	518.65	159.64
22	260694.	694.46	654.42	518.65	135.77
20	303659.	724.39	678.21	519.09	159.12
21	303659.	743.56	697.70	519.09	178.61
22	303659.	714.57	668.22	519.09	149.13
20	330542.	755.90	706.17	517.77	188.40
21	330542.	774.21	724.81	517.77	207.04
22	330542.	727.80	677.56	517.77	159.78
20	352619.	775.48	722.78	516.90	205.88
21	352619.	794.63	742.29	516.90	225.40
22	352619.	734.62	681.12	516.90	164.22

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--43 Cont'd
SYSTEM PRESSURE--103 MM HG DATE--6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	375838.	803.14	747.49	519.53	227.96
21	375838.	826.10	770.91	519.53	251.38
22	375838.	741.43	684.52	519.53	164.99
20	396587.	833.33	775.21	519.09	256.12
21	396587.	852.01	794.28	519.09	275.19
22	396587.	751.22	691.34	519.09	172.25
20	425251.	900.51	839.61	521.28	318.33
21	425251.	934.29	874.10	521.28	352.82
22	425251.	766.97	703.09	521.28	181.81
20	462758.	1001.89	937.83	521.72	416.11
21	462758.	1020.89	957.23	521.72	435.51
22	462758.	786.12	717.02	521.72	195.30
20	414359.	832.91	772.15	520.84	251.30
21	414359.	852.01	791.67	520.84	270.82
22	414359.	750.37	687.76	520.84	166.91
20	328138.	740.16	690.51	517.77	172.73
21	328138.	762.71	713.47	517.77	195.70
22	328138.	717.99	667.93	517.77	150.15
20	256583.	687.18	647.66	516.02	131.64
21	256583.	700.89	661.57	516.02	145.55
22	256583.	688.03	648.53	516.02	132.51

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--43 Cont'd
SYSTEM PRESSURE-- 103 MM HG DATE--6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	196572.	654.08	623.48	517.77	105.71
21	196572.	664.41	633.93	517.77	116.16
22	196572.	668.28	637.85	517.77	120.07
20	131611.	625.65	604.99	513.39	91.60
21	131611.	636.86	616.28	513.39	102.89
22	131611.	623.93	603.25	513.39	89.86
20	84227.	601.45	588.12	510.32	77.80
21	84227.	604.04	590.73	510.32	80.41
22	84227.	602.75	589.42	510.32	79.10
20	47456.	563.22	555.61	514.27	41.34
21	47456.	566.71	559.10	514.27	44.84
22	47456.	566.71	559.10	514.27	44.84

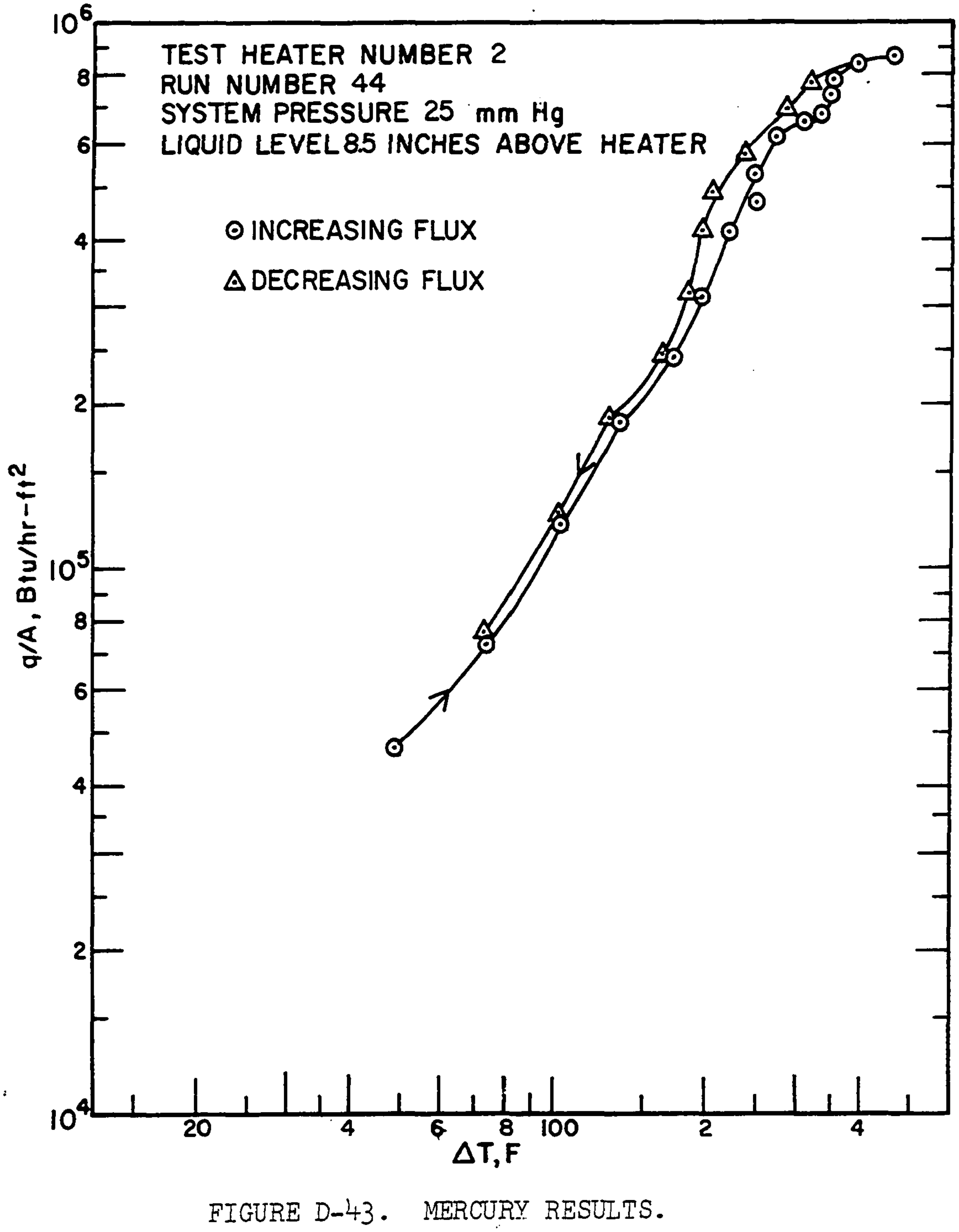

FIGURE D-43. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--44

SYSTEM PRESSURE--25 MM HG DATE--6/27/68

POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	48403.	492.74	484.76	435.24	49.52
21	48403.	494.94	486.97	435.24	51.73
22	48403.	489.67	481.67	435.24	46.43
20	73899.	519.97	507.90	434.35	73.55
21	73899.	519.09	507.02	434.35	72.67
22	73899.	521.28	509.22	434.35	74.87
20	117263.	552.76	533.83	433.01	100.82
21	117263.	562.79	543.93	433.01	110.92
22	117263.	554.07	535.14	433.01	102.14
20	177002.	606.21	578.17	441.93	136.24
21	177002.	608.37	580.35	441.93	138.42
22	177002.	604.04	575.98	441.93	134.05
20	247920.	641.60	602.77	432.56	170.21
21	247920.	651.50	612.81	432.56	180.25
22	247920.	644.61	605.82	432.56	173.26
20	314404.	675.16	626.44	433.01	193.43
21	314404.	685.89	637.37	433.01	204.36
22	314404.	673.01	624.25	433.01	191.24
20	400994.	715.00	653.63	433.90	219.73
21	400994.	731.64	670.65	433.90	236.75
22	400994.	696.60	634.81	433.90	200.91

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2
SYSTEM PRESSURE-- 25 MM HG

RUN NUMBER-- 44 Cont'd
DATE--6/27/68

POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	462529.	755.48	685.63	437.02	248.60
21	462529.	775.48	706.15	437.02	269.12
22	462529.	722.25	651.54	437.02	214.51
20	518408.	766.97	688.89	439.25	249.64
21	518408.	796.76	719.53	439.25	280.27
22	518408.	726.52	647.26	439.25	208.01
20	601478.	806.97	717.49	447.72	269.77
21	601478.	855.39	767.46	447.72	319.74
22	601478.	755.48	664.29	447.72	216.57
20	655518.	849.91	753.76	444.16	309.60
21	655518.	889.96	795.18	444.16	351.02
22	655518.	773.35	674.48	444.16	230.32
20	682251.	873.93	774.66	450.84	323.82
21	682251.	908.95	810.90	450.84	360.07
22	682251.	786.12	683.63	450.84	232.79
20	727458.	896.29	791.15	452.16	338.99
21	727458.	938.51	834.93	452.16	382.77
22	727458.	801.01	692.19	452.16	240.02
20	767480.	898.40	787.45	450.84	336.61
21	767480.	940.63	831.32	450.84	380.48
22	767480.	820.15	706.02	450.84	255.18

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--44 Cont'd
SYSTEM PRESSURE-- 25 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	823363.	963.87	847.39	451.72	395.67
21	823363.	968.10	851.79	451.72	400.07
22	823363.	828.65	706.41	451.72	254.69
20	852977.	1031.43	913.45	453.05	460.40
21	852977.	1073.60	957.28	453.05	504.24
22	852977.	862.55	737.36	453.05	284.31
20	764452.	881.53	770.35	452.16	318.19
21	764452.	930.07	820.79	452.16	368.63
22	764452.	805.69	691.41	452.16	239.25
20	691132.	840.56	738.75	449.95	288.80
21	691132.	872.25	771.59	449.95	321.64
22	691132.	789.53	685.80	449.95	235.85
20	575088.	769.95	683.29	449.51	233.79
21	575088.	807.39	721.92	449.51	272.41
22	575088.	749.94	662.64	449.51	213.13
20	497322.	726.52	650.53	446.39	204.14
21	497322.	777.61	703.04	446.39	256.66
22	497322.	724.39	648.34	446.39	201.95
20	409805.	706.88	643.95	445.94	198.01
21	409805.	721.83	659.26	445.94	213.32
22	409805.	708.59	645.70	445.94	199.76

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--44 Cont'd
SYSTEM PRESSURE--25 MM HG DATE--6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	317421.	671.29	622.03	437.47	184.56
21	317421.	685.03	636.02	437.47	198.55
22	317421.	683.32	634.28	437.47	196.81
20	243232.	642.46	604.38	431.67	172.71
21	243232.	648.91	610.92	431.67	179.26
22	243232.	648.91	610.92	431.67	179.26
20	181347.	596.25	567.40	437.47	129.93
21	181347.	621.34	592.77	437.47	155.30
22	181347.	598.85	570.03	437.47	132.56
20	122743.	561.48	541.73	437.47	104.26
21	122743.	557.99	538.21	437.47	100.74
22	122743.	565.40	545.68	437.47	108.21
20	78810.	516.02	503.13	430.78	72.35
21	78810.	517.34	504.45	430.78	73.67
22	78810.	522.59	509.74	430.78	78.96

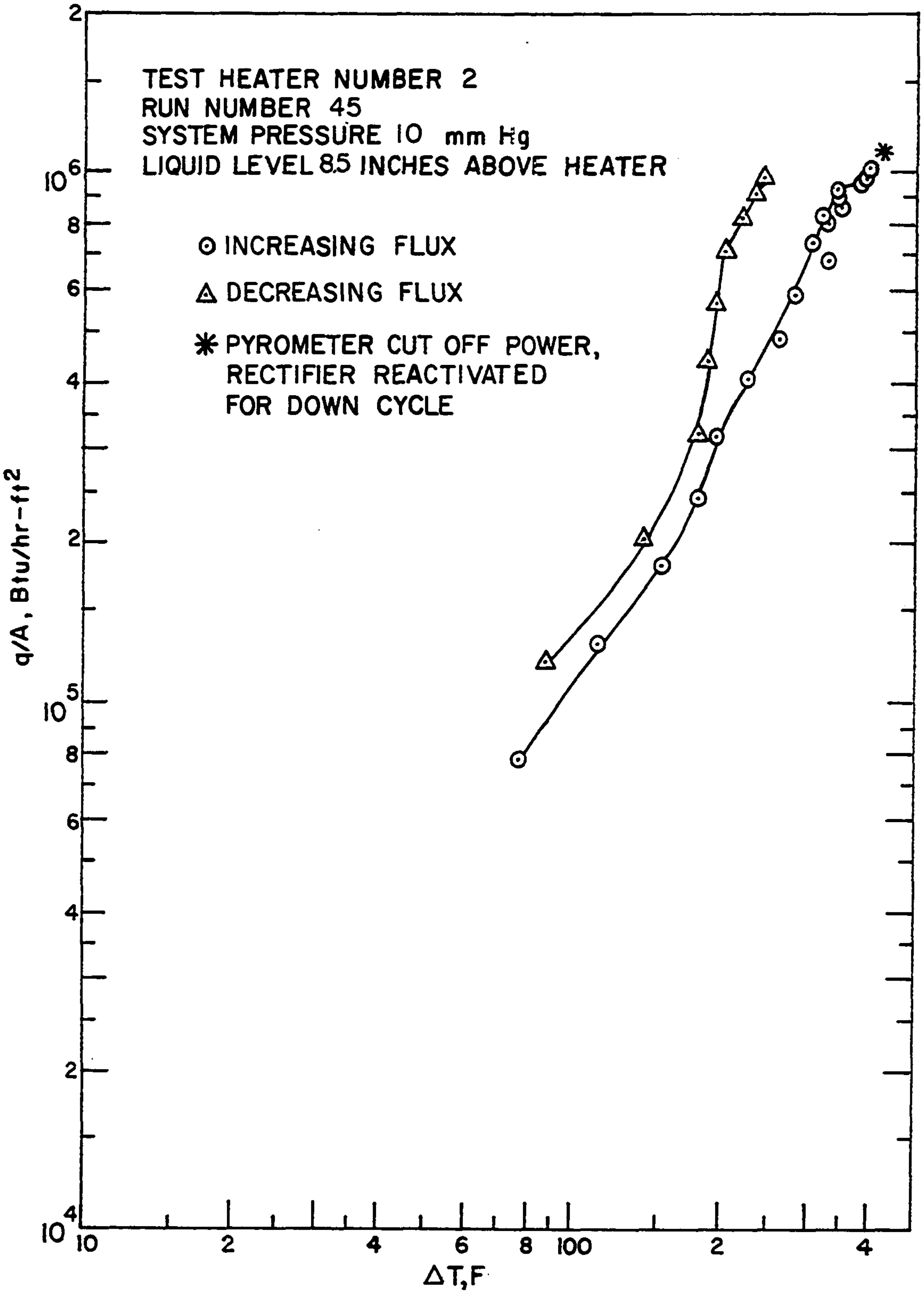

FIGURE D-44. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--45
SYSTEM PRESSURE-- 10 MM HG DATE--6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	79001.	474.25	461.11	381.54	79.56
21	79001.	475.13	461.99	381.54	80.45
22	79001.	476.89	463.76	381.54	82.22
20	123239.	516.90	496.71	386.03	110.69
21	123239.	515.58	495.39	386.03	109.36
22	123239.	517.34	497.16	386.03	111.13
20	174870.	565.40	537.26	385.13	152.12
21	174870.	571.49	543.42	385.13	158.29
22	174870.	567.14	539.02	385.13	153.89
20	245744.	614.43	575.53	401.71	173.82
21	245744.	631.26	592.62	401.71	190.91
22	245744.	622.63	583.86	401.71	182.15
20	318376.	649.34	599.52	403.06	196.46
21	318376.	668.71	619.25	403.06	216.19
22	318376.	638.59	588.56	403.06	185.50
20	402802.	687.18	624.88	403.95	220.93
21	402802.	707.30	645.48	403.95	241.53
22	402802.	689.75	627.51	403.95	223.56
20	492761.	724.39	649.04	386.03	263.02
21	492761.	756.75	682.31	386.03	296.28
22	492761.	726.52	651.24	386.03	265.21

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--45 Cont'd

SYSTEM PRESSURE-- 10 MM HG DATE-- 6/27/68

POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	592838.	766.97	677.50	390.96	286.54
21	592838.	807.82	719.68	390.96	328.72
22	592838.	761.44	671.78	390.96	280.82
20	698522.	819.30	715.58	391.86	323.73
21	698522.	847.78	745.13	391.86	353.28
22	698522.	789.10	684.23	391.86	292.37
20	747252.	828.65	717.94	415.14	302.80
21	747252.	873.09	764.14	415.14	349.00
22	747252.	796.76	684.74	415.14	269.60
20	801174.	862.13	744.69	416.48	328.21
21	801174.	909.37	793.90	416.48	377.42
22	801174.	804.41	684.47	416.48	267.99
20	833209.	869.30	747.37	420.06	327.31
21	833209.	917.82	797.99	420.06	377.93
22	833209.	809.52	684.90	420.06	264.84
20	863345.	894.18	768.87	417.82	351.05
21	863345.	928.80	805.02	417.82	387.20
22	863345.	819.30	690.53	417.82	272.71
20	890793.	900.51	771.42	421.40	350.02
21	890793.	947.39	820.42	421.40	399.03
22	890793.	827.80	695.26	421.40	273.86

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--45 Cont'd
SYSTEM PRESSURE-- 10 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	922567.	908.53	775.10	422.29	352.81
21	922567.	961.76	830.82	422.29	408.53
22	922567.	834.18	697.11	422.29	274.82
20	964844.	938.51	800.30	420.06	380.25
21	964844.	974.44	837.96	420.06	417.91
22	964844.	848.21	705.43	420.06	285.37
20	997934.	963.87	822.08	423.18	398.89
21	997934.	1004.00	864.18	423.18	441.00
22	997934.	862.13	715.07	423.18	291.89
20	1017756.	968.10	823.63	423.63	400.00
21	1017756.	1014.98	872.85	423.63	449.22
22	1017756.	866.77	716.96	423.63	293.33
20	989037.	809.52	660.95	424.08	236.88
21	989037.	841.41	694.59	424.08	270.51
22	989037.	918.66	775.90	424.08	351.82
20	907464.	788.25	651.17	423.63	227.53
21	907464.	820.15	684.68	423.63	261.05
22	907464.	854.12	720.33	423.63	296.70
20	833699.	762.71	635.83	420.95	214.88
21	833699.	797.61	672.37	420.95	251.42
22	833699.	823.13	699.06	420.95	278.11

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--45 Cont'd
SYSTEM PRESSURE-- 10 MM HG DATE-- 6/27/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	716084.	732.92	623.07	419.16	203.91
21	716084.	767.40	658.96	419.16	239.80
22	716084.	774.21	666.05	419.16	246.89
20	581219.	700.89	611.00	412.01	198.99
21	581219.	732.92	644.11	412.01	232.10
22	581219.	725.67	636.62	412.01	224.61
20	444996.	670.43	601.09	410.22	190.87
21	444996.	697.03	628.38	410.22	218.16
22	444996.	694.46	625.75	410.22	215.53
20	323074.	638.59	587.81	409.32	178.49
21	323074.	665.70	615.45	409.32	206.12
22	323074.	638.59	587.81	409.32	178.49
20	206846.	567.58	534.28	398.58	135.70
21	206846.	595.38	562.44	398.58	163.86
22	206846.	604.04	571.22	398.58	172.64
20	121466.	502.42	482.41	394.99	87.41
21	121466.	525.66	505.84	394.99	110.84
22	121466.	488.79	468.67	394.99	73.67

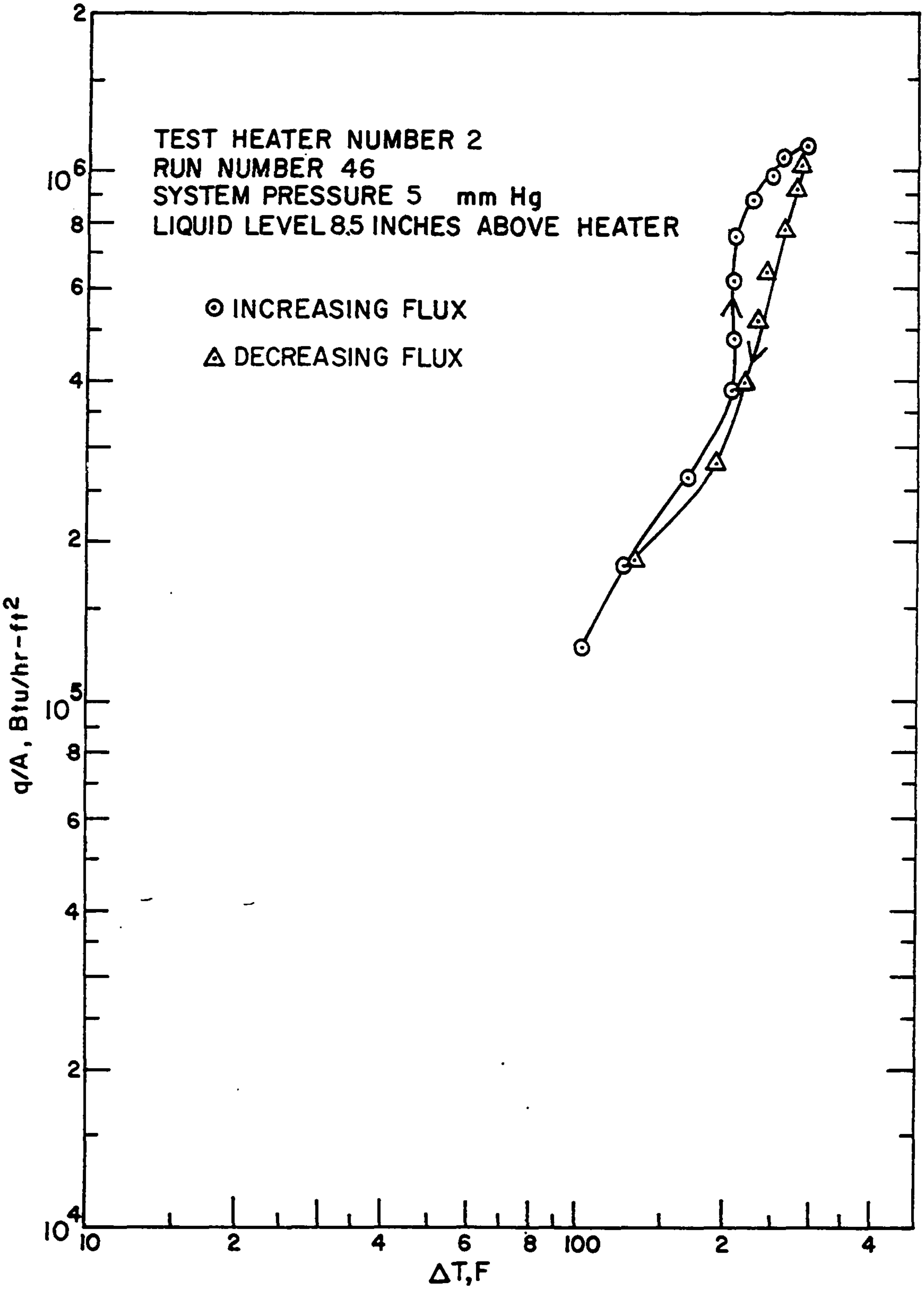

FIGURE D-45. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--46
SYSTEM PRESSURE-- 5 MM HG DATE-- 6/28/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	121466.	480.86	460.68	356.82	103.85
21	121466.	494.94	474.88	356.82	118.05
22	121466.	477.33	457.12	356.82	100.30
20	175065.	514.27	485.52	364.47	121.05
21	175065.	557.12	528.85	364.47	164.38
22	175065.	519.53	490.84	364.47	126.37
20	263398.	585.40	543.22	373.91	169.31
21	263398.	625.65	584.13	373.91	210.22
22	263398.	582.80	540.57	373.91	166.67
20	373206.	650.63	592.16	382.89	209.27
21	373206.	677.31	619.42	382.89	236.54
22	373206.	656.66	598.33	382.89	215.44
20	487243.	675.16	599.27	391.86	207.42
21	487243.	706.88	631.90	391.86	240.04
22	487243.	704.31	629.26	391.86	237.40
20	616552.	700.89	605.43	399.48	205.96
21	616552.	739.31	645.23	399.48	245.75
22	616552.	737.18	643.02	399.48	243.55
20	756448.	735.47	619.41	407.09	212.33
21	756448.	779.31	665.15	407.09	258.06
22	756448.	786.12	672.24	407.09	265.16

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2
SYSTEM PRESSURE-- 5 MM HG

RUN NUMBER--46 Cont'd
DATE-- 6/28/68

POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	871428.	766.12	633.52	410.67	222.85
21	871428.	811.65	681.28	410.67	270.61
22	871428.	832.91	703.55	410.67	292.89
20	997905.	812.50	662.73	415.14	247.59
21	997905.	849.06	701.30	415.14	286.16
22	997905.	885.74	739.95	415.14	324.81
20	1057982.	837.16	679.55	417.82	261.73
21	1057982.	886.59	731.82	417.82	313.99
22	1057982.	908.95	755.43	417.82	337.60
20	1099752.	875.20	713.47	418.27	295.20
21	1099752.	946.97	789.36	418.27	371.09
22	1099752.	960.49	803.64	418.27	385.38
20	1020463.	854.12	703.21	416.48	286.73
21	1020463.	922.88	775.68	416.48	359.20
22	1020463.	930.91	784.13	416.48	367.65
20	907508.	832.91	698.07	414.24	283.82
21	907508.	900.51	768.94	414.24	354.69
22	907508.	883.63	751.26	414.24	337.02
20	780445.	788.25	670.77	407.98	262.79
21	780445.	855.39	740.76	407.98	332.78
22	780445.	826.53	710.70	407.98	302.72

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--46 Cont'd
SYSTEM PRESSURE--5 MM HG DATE--6/28/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	643137.	743.56	645.61	403.95	241.55
21	643137.	809.52	713.83	403.95	309.88
22	643137.	769.10	671.97	403.95	268.02
20	514843.	709.44	630.23	399.92	230.30
21	514843.	769.10	691.63	399.92	291.70
22	514843.	708.16	628.91	399.92	228.98
20	398223.	668.71	606.70	387.37	219.33
21	398223.	715.85	654.93	387.37	267.56
22	398223.	664.41	602.30	387.37	214.93
20	280919.	617.02	572.56	378.40	194.16
21	280919.	664.84	621.19	378.40	242.79
22	280919.	619.18	574.75	378.40	196.36
20	175238.	519.09	490.37	365.82	124.55
21	175238.	562.79	534.55	365.82	168.73
22	175238.	520.84	492.14	365.82	126.32

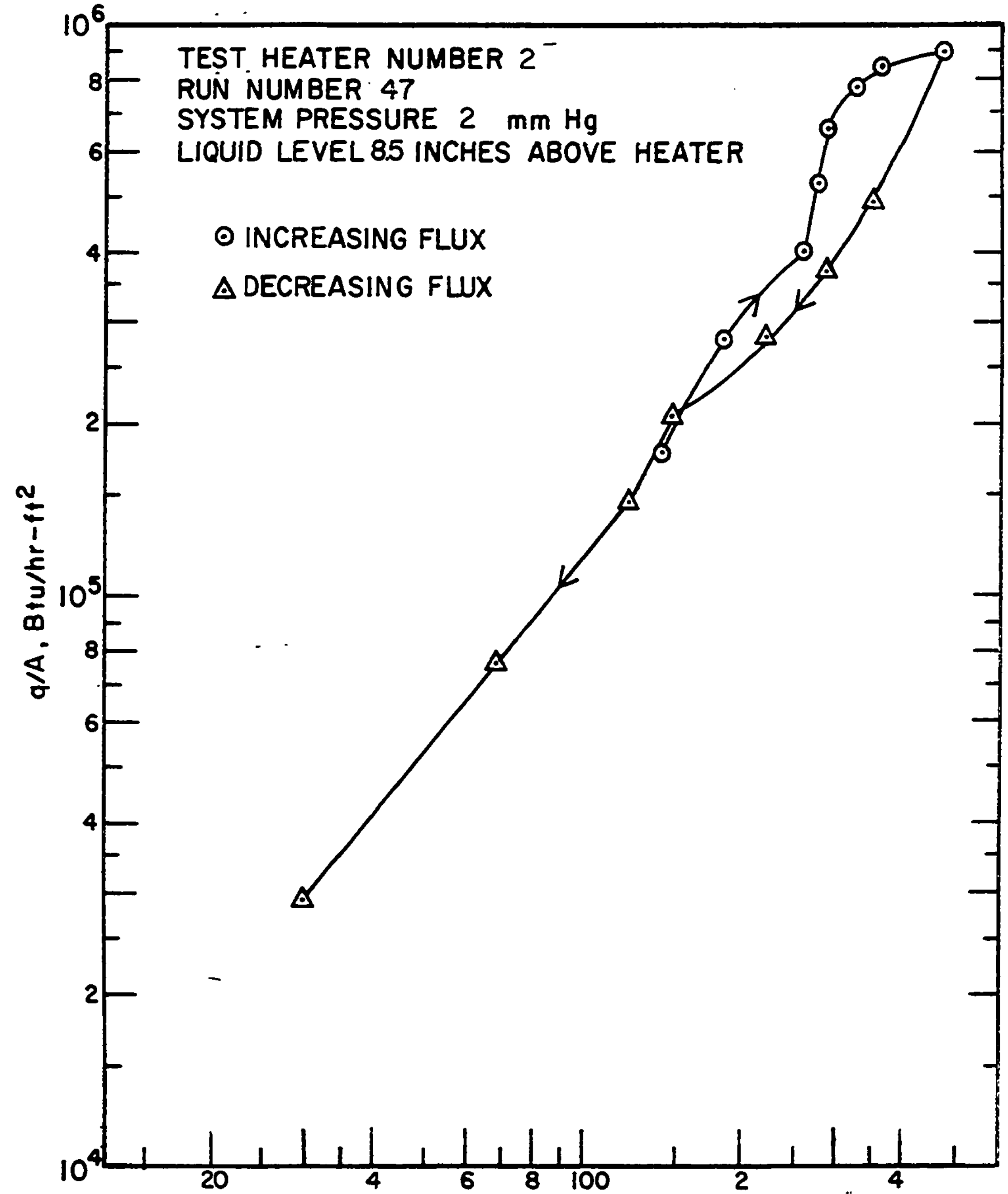

FIGURE D-46. MERCURY RESULTS.

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--47
SYSTEM PRESSURE-- 2 MM HG DATE-- 6/28/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	175951.	510.32	481.38	340.55	140.82
21	175951.	527.85	499.11	340.55	158.55
22	175951.	508.12	479.16	340.55	138.60
20	275712.	574.10	529.74	344.63	185.11
21	275712.	640.74	597.50	344.63	252.87
22	275712.	568.01	523.54	344.63	178.91
20	395648.	667.85	606.23	349.17	257.06
21	395648.	720.55	660.13	349.17	310.97
22	395648.	654.08	592.13	349.17	242.97
20	512628.	730.78	652.55	376.15	276.39
21	512628.	773.35	696.34	376.15	320.19
22	512628.	736.32	658.25	376.15	282.09
20	644815.	783.14	686.27	402.16	284.10
21	644815.	837.58	742.61	402.16	340.45
22	644815.	783.99	687.15	402.16	284.98
20	757241.	838.43	726.60	405.30	321.30
21	757241.	923.73	815.26	405.30	409.97
22	757241.	826.53	714.21	405.30	308.92
20	812247.	881.53	763.25	409.32	353.93
21	812247.	984.15	870.08	409.32	460.76
22	812247.	865.50	746.55	409.32	337.22

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--47 Cont'd
SYSTEM PRESSURE--2 MM HG DATE--6/28/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	885033.	1005.27	881.66	410.67	470.99
21	885033.	1055.89	934.40	410.67	523.73
22	885033.	949.08	823.03	410.67	412.36
20	483090.	798.88	727.04	376.15	350.89
21	483090.	862.55	792.33	376.15	416.18
22	483090.	766.97	694.28	376.15	318.13
20	360716.	710.30	655.06	372.11	282.95
21	360716.	764.84	710.71	372.11	338.59
22	360716.	652.36	595.90	372.11	223.79
20	273886.	623.50	580.27	362.67	217.59
21	273886.	656.23	613.54	362.67	250.87
22	273886.	601.88	558.29	362.67	195.61
20	201650.	530.04	497.10	348.26	148.84
21	201650.	571.49	539.09	348.26	190.83
22	201650.	534.41	501.53	348.26	153.27
20	145318.	488.35	464.26	343.72	120.53
21	145318.	497.58	473.58	343.72	129.86
22	145318.	475.13	450.91	343.72	107.19
20	77220.	419.61	406.48	337.84	68.64
21	77220.	430.78	417.70	337.84	79.86
22	77220.	407.98	394.78	337.84	56.95

TABLE VII
POOL BOILING MERCURY DATA

TEST HEATER NUMBER--2 RUN NUMBER--47 Cont'd
SYSTEM PRESSURE-- 2 MM HG DATE-- 6/28/68
POOL DEPTH ABOVE HEATER--8.5 INCHES

THERMOCOUPLE NUMBER	HEAT FLUX BTU/HR-SQ FT	T MEASURED DEGREES F	T SURFACE DEGREES F	T BULK DEGREES F	DELTA T DEGREES F
20	29768.	368.07	362.90	333.32	29.59
21	29768.	373.01	367.86	333.32	34.54
22	29768.	362.22	357.05	333.32	23.73

APPENDIX E

MEASUREMENT ERRORS AND HEAT LOSSES

Measurement Errors

Temperature measurement.--Thermocouples located beneath the surface of the heater could be in error for any of the following reasons: (1) calibration error, (2) interfacial thermal resistance, (3) induced EMF, (4) temperature drop across the thermocouple bead, and (5) random error.

The first of these was discussed in Appendix B and may be considered negligible. The second was apparently alleviated by filling the interfacial cavity with low-melting alloy. If interfacial resistance had been present, it would have manifested itself by decreasing the slope of the boiling curve, i.e., negligible error at low fluxes with error increasing proportional to the flux level. Observed slopes of the experimental boiling curves agreed quite well with previous studies and predictive correlations (see Chapter IV). Also, interfacial resistance would tend to increase (and further decrease the slope of the boiling curve) with prolonged operation since an oxide film would likely form at the interface. No such decrease in slope was observed other than that attributed to other overriding factors, e.g., lowering pool depth.

Induced EMF can be present anytime a thermocouple is in direct contact with a current-carrying material. Induced EMF's were observed and measured by the method described by Davenport, Magee, and Leppert (40) and later used by Mednick (90). With the fast-response oscillographic recorder monitoring thermocouple output, the rectifier was quickly turned off and on. Induced voltage could then be read directly as the amplitude difference between the "off" and "on" thermocouple output. For Heaters A and B, induced voltages as large as 1 millivolt were observed. Heaters 1 and 2 demonstrated very small induced voltages during initial runs and none at all after they had been in use for a while. It was felt that this indicated that the free end of the heater had achieved good electrical contact with the mercury so that most of the current was being carried by the mercury pool rather than by the heater sheath.

At the high operating fluxes attained in this study, temperature drop across the thermocouple bead itself could have become important since extrapolations were made through the stainless steel wall with no allowance for the finite thickness of the thermocouple bead, i.e., it was assumed that the thermocouple gave the temperature of the underside of the tube wall. To check this approach for accuracy, a relaxation computer program was written to analyze heat flow through a composite slab.

The conventional relaxation technique may be summarized as follows. In a two dimensional homogeneous system, Laplace's equation

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \tag{E-1}$$

can be transformed into the finite-difference equation

$$T_1 + T_2 + T_3 + T_4 - 4T_0 = 0 \qquad \text{(E-2)}$$

where T_0 is the temperature at a central point in a rectangular grid, and T_1, T_2, T_3, and T_4 are neighboring temperatures. Equation E-2 is then set equal to R_0 (residual at point 0) and evaluated at all points on the grid for assumed temperatures. An iterative technique can then be employed to minimize all resulting residuals to some specified limit of convergence.

To analyze the composite slab problem with a grid as shown in Figure E-1, a heat balance was made around point 0. Simplifying the resulting equation gave

$$k_1T_1 + k_2T_2 + k_3T_3 + k_4T_4 - (k_1 + k_2 + k_3 + k_4)\, T_0 = 0 \qquad \text{(E-3)}$$

which was then set equal to R_0. The upper and lower boundaries of the grid in Figure E-1 were set at constant temperatures. The left hand boundary was considered adiabatic (axis of symmetry). All points on the grid were given initial temperatures for a linear gradient through all of the slab. A thermal conductivity was assigned to each point with a simple average being used at the boundary between regions I and II.

A computer program was written to perform the laborious iterations required to determine the temperature profile in the slab. It was found that at a flux of 10^6 Btu/hr-ft^2, the thermocouple would be in error by less

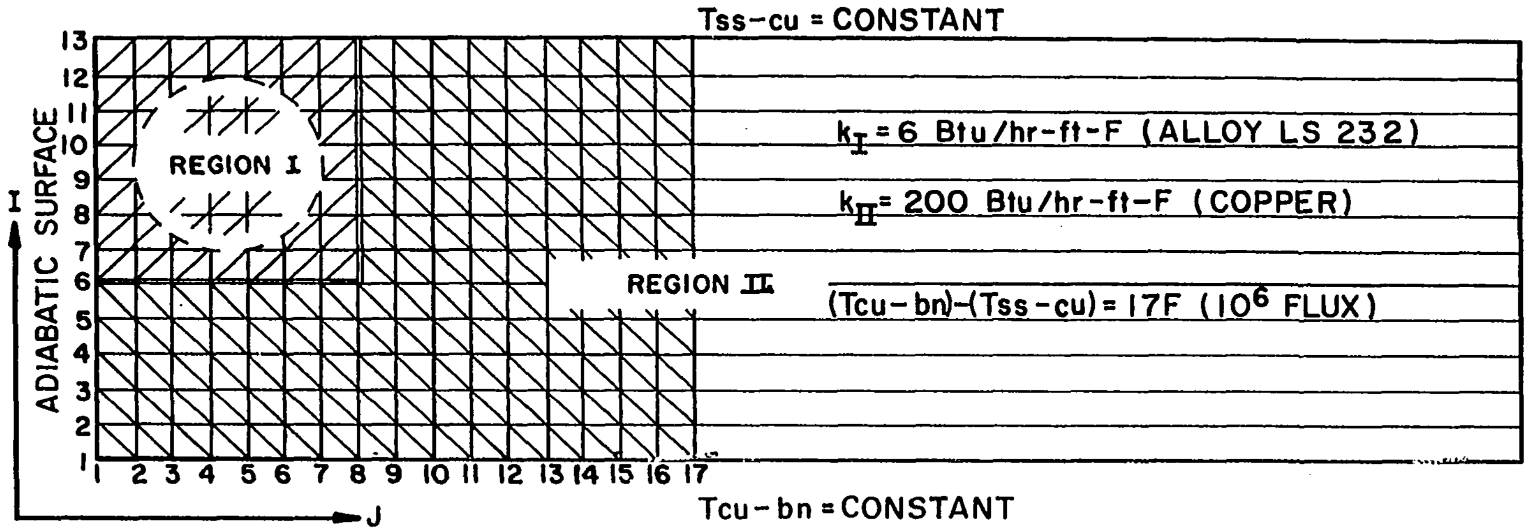

FIGURE E-1. RELAXATION GRID FOR A COMPOSITE SLAB.

than 10 degrees F and proportionately less at lower fluxes. This amounted to about 3.3 percent error for ΔT's measured at the exceedingly high flux of 10^6 Btu/hr-ft^2.

Random error due to visually averaging fluctuations occurring during vigorous boiling are not easily estimated but lack of scatter of the data indicated it was not significant. It is felt that error in calculated ΔT's did not exceed ±10 percent.

Pressure measurement.--Measurements made with the mercury manometer were accurate to ±0.02 inches of mercury. Accuracy of the cartesian-diver vacuum gauge was ±0.05 mm of mercury. Pressures measured with the 0-200 psig gauge were accurate within ±1 psi.

Power measurement.--Voltage and amperage readings were made with calibrated Simpson meters which were found accurate to better than 1/2 percent full scale. Because of possible reading error, power measurements were considered accurate within ±1 percent.

Heat Losses

Total power input was used to calculate an average flux based on the surface area (not including the ends) of each heater. To estimate an upper bound on the possible error involved in this procedure, one may simply compare the area of the two ends of the heater to the total area. This would assume that fluxes out each end of the heater were equivalent to the radial flux at the periphery. For a 3/8 inch diameter cylinder 3 inches long, we have

$$\frac{A_e}{A_t} = \frac{2\pi r^2}{2\pi rL + 2\pi r^2} = \frac{1}{1 + \frac{L}{r}} = \frac{1}{17} \qquad \text{(E-4)}$$

This gives an upper bound of 6 percent heat loss. A more sophisticated analysis (such as that performed by Colver (33) for a much shorter heater) indicates only about 3 percent heat loss. It can be shown in a manner similar to that of Sciance (110) that even a 10 percent heat loss will have no effect on temperature measurements made at the central portion of the heater.

APPENDIX F

NOMENCLATURE

ENGLISH SYMBOLS

A	Heater surface area, ft^2.
a	Acceleration, ft/sec^2.
B	Laplace reference length, ft.
C	Constant.
C_p	Specific heat, Btu/lb_m.
D	Tube diameter, ft; bubble departure diameter, ft.
D_b	Bubble diameter, ft.
F	Degrees Fahrenheit.
f	Bubble departure frequency, sec^{-1}.
Gr	Grashof number, $D^3\rho^2 g\epsilon\Delta T/\mu^2$, dimensionless.
g	Local gravitational acceleration, ft/sec^2.
g_c	Gravitational constant, 32.174 $ft\text{-}lb_m/lb_f\text{-}sec^2$.
g/l	Concentration units, gram/liter.
h	Heat transfer coefficient, $Btu/hr\text{-}ft^2\text{-}F$.
I	Counter for relaxation grid.
J	Counter for relaxation grid.
K	Empirical constant.
k	Thermal conductivity, Btu/hr-ft-F.
L	Heater length, inches.
ℓn	Natural logarithm.
Nu	Nusselt number, dimensionless.
P	Pressure, lb_f/in^2.

ΔP	Pressure difference corresponding to ΔT, lb_f/in^2.
P_c	Critical pressure, lb_f/in^2.
P_r	Reduced pressure, P/P_c.
Pr	Prandtl number, $C_p\mu/k$, dimensionless.
q/A	Heat flux, Btu/hr-ft^2.
R_{cf}	Most favorable cavity radius, ft.
Re	Reynolds number, dimensionless.
r	Tube radius, inches.
T	Temperature, F.
T_r	Reduced temperature, F.
T_{sat}	Saturation temperature, F.
T_w	Heater surface temperature, F.
ΔT	Temperature difference, $T_w - T_{sat}$, F.
t	Tube wall thickness, ft.
x	Horizontal dimension, ft.
y	Vertical dimension, ft.

GREEK SYMBOLS

α	Thermal diffusivity, $k/\rho C_p$, ft^2/sec.
β	Contact angle, degrees.
γ	Constant.
Δ	Denotes difference.
δ	Function used in data reduction, F^2.
ϵ	Volume expansion coefficient, F^{-1}.

λ	Latent heat of vaporization, Btu/lb_m.
λ'	Modified latent heat of vaporization, Btu/lb_m.
μ	Viscosity, lb_m/ft-hr.
π	Constant, 3.14159.....
ρ	Density, lb_m/ft^3.
σ	Surface tension, lb_f/ft.

SUBSCRIPTS

1c	First critical.
2c	Second critical.
b	Bubble.
c	Critical.
f	Film.
ℓ	Liquid.
ℓs	Liquid-solid.
m	Mean.
r	Reduced.
v	Vapor.
vl	Vapor-liquid.
vs	Vapor-solid.
w	Wall.