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Film boiling of Freon 113, Normal Pentane, Cyclopentane, and Benzene from cylindrical surfaces at moderate pressures

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FILM BOILING OF FREON 113, NORMAL PENTANE,

CYCLOPENTANE, AND BENZENE FROM CYLINDRICAL

SURFACES AT MODERATE PRESSURES

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ABSTRACT

An investigation of film boiling heat transfer in saturated pools of liquid Freon 113, Normal Pentane, Cyclopentane, and Benzene was made. The fluids were boiled from copper, cylindrical heat transfer surfaces, 3 inches long, and 0.55, 0.75, and 1.00 inch in diameter. The heat transfer elements were positioned horizontally in an autoclave and tested at moderate pressures of up to a pressure of 242.5 psia for Normal Pentane.

The experimental data are discussed and compared with known film boiling correlations. The known correlations were found to be inadequate in predicting heat transfer coefficients as a function of pressure, temperature difference between the heater surface and the fluid, surface diameter, and the type of fluid boiled. For instance, a correlation by Sciance (26) predicts the experimental heat transfer coefficients, h, of this investigation from within 3% error to as much as 50% error. A correlation by Chang (13) predicts values of h that vary by a factor of 3 from the experimental values of this investigation. The h values predicted by the correlations of Baumeister (2), (3), (4), Breen and Westwater (6), Pomerantz (23), Bromley (7), and Berenson (5) deviate from the experimental values by percentages between those of the Sciance and Chang correlations depending on the pressure of the system, diameter of the heater surface, and the fluid under investigation.

A correlation for film boiling is derived and discussed. The correlation

$$Q = 0.137\, T_c^{0.54} (\lambda\, P_{sys})^{0.37} (\Delta T \log_{10} T_f)^{0.73}\, d^{-0.26}$$

was found to predict the film boiling of Freon 113, Normal Pentane, and Benzene to within 10%. The correlation predicts the boiling behavior of Cyclopentane to within 20%.

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I. INTRODUCTION

This investigation studied the film boiling of Freon 113, n-Pentane, Cyclopentane, and Benzene from horizontal cylinders at moderate pressures.

In Figure 1 is shown the typical boiling curve as presented by Nukiyama (20) in 1934. The curve is a plot of the logarithm of the heat flux from the heating surface as a function of the logarithm of the temperature difference between the surface and the saturated fluid.

The curve is divided into four distinct regions. Initially, the temperature difference is small and a small heat flux is obtained. This region of small temperature difference is the convection region of the boiling curve and the heat is carried away by the convection currents in the liquid. As the temperature difference is increased, the heat flux increases to a point where bubbles form at specific sites called nuclei. The point where bubbles initially form is the beginning of the nucleate boiling region. The number of bubbles formed will increase with increasing temperature difference until point A is reached. Point A in Figure 1 is known as the burnout point and is characterized by the formation of vapor film over the heat transfer surface. At this point in the boiling curve, the very high heat transfer rate in the nucleate boiling region decreases because of the vapor formation. The third region is known as the unstable film boiling region. In this region a film is continuously forming and collapsing as the

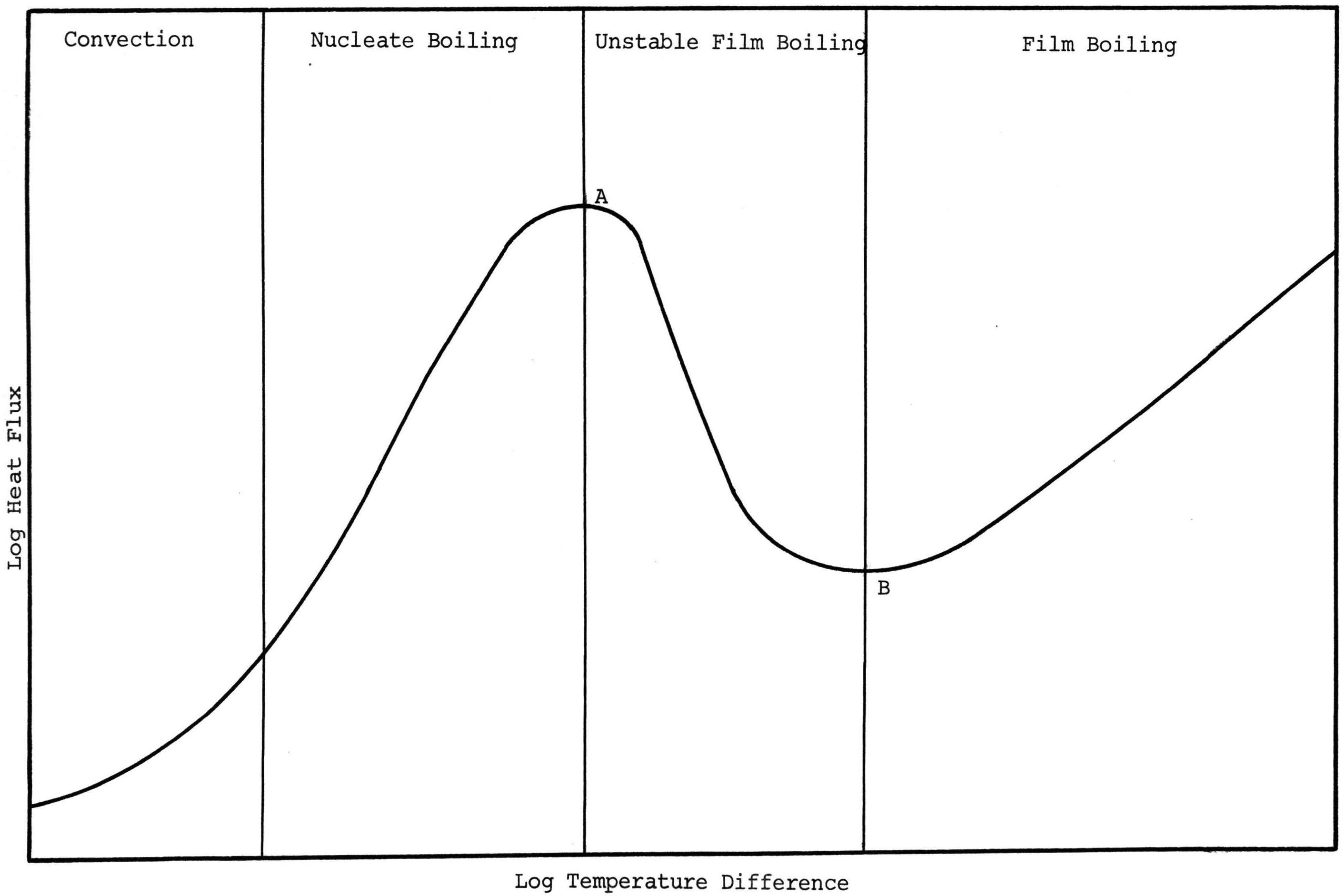


Figure 1. A Typical Boiling Heat Transfer Curve

temperature difference increases and the heat transferred decreases because of the partial vapor film. The next critical reached is the Leindenfrost Point. This point is attained when a stable film of vapor is formed over the entire surface. As the temperature difference is increased further, the fourth region is entered. This region of film boiling is investigated in the following dissertation.

II. LITERATURE REVIEW

Scorah and Farber (14) described the entire boiling curve (Figure 1) by boiling water from nickel, tungsten, chromel A, and chromel C wires. They found the boiling curve to depend on the pressure of the system and the metal used for the heat transfer element.

Bromley (7) suggested an analysis for film boiling similar to Nusselt's (17) development for condensation. As a result of visual observations, he assumed a mechanism in which the vapor film is in dynamic equilibrium with the surrounding liquid. As the vapor rises under the action of bouyant forces, vapor is added to the film from the surrounding liquid. The resulting equation is given below. All symbols in the following equations are given on page 70.

$$h = (\text{Constant}) \left[\frac{k_v^3 \, \rho_v (\rho_l - \rho_v) \lambda'' g}{D \, \Delta T \, \mu_v} \right]^{1/4} \tag{1}$$

The value of the constant was found experimentally to 0.62. This value is the arithmetic average value between 0.512 and 0.724, which are the values predicted by Bromley (7) by assuming the surrounding liquid is either stagnant, or moving freely with the vapor.

Bromley (7) found the heat transfer coefficient to be independent of the heater material and that the dependence of heat transfer on the pressure of the system can be calculated from the pressure effect on the physical properties of the system. Bromley's data also showed that the heat transfer coefficient varies inversely with the heater diameter in the range of 0.188 inches to 0.466 inches. Bromley (8) improved his film boiling correlation by using a λ" corrected for the sensible heat of the vapor:

$$\lambda'' = \lambda[1.0 + (0.34\ C_p\ \Delta T)/\lambda]^2 \tag{2}$$

Banchero, Barker, and Boll (1) boiled liquid oxygen with heaters of various diameters to show the limitations of Bromley's equation. They found that Bromley's equation predicts the effect of diameter when in the range of 0.069 to 0.127 inches, but fails to predict the effect of diameter when a range of 0.025 to 0.75 inches is considered. These authors present the following equation as a modification of Bromley's equation (1).

$$h = a(1.0/D + C)F \tag{3}$$

where: $C = \text{constant}(36.5\ \text{in}^{-1})$

$$F = \left[\frac{k_v^3\ \rho_v\ \lambda'(\rho_l - \rho_v)g}{\Delta T\ \mu_v}\right]^{1/4}$$

Both a and C are determined by a trial and error fit of experimental data. Their investigation showed the heat transfer coefficient to vary inversely with the diameter of the heater and to increase with increasing pressure.

Chang (13) chose to analyze film boiling by considering hydrodynamic wave formation. The vapor film will grow with increasing heat flux until the vapor breaks the vapor-liquid interface at intervals equal to the critical wavelength, l_{cr},

where:

$$l_{cr} = 2\pi \left[\frac{\sigma}{g(\rho_1 - \rho_v)} \right]^{1/2} \tag{4}$$

Chang's final equation is

$$h = 0.234 \left[\frac{k_v^2 \, \rho_v (\rho_1 - \rho_v) \lambda g}{4\pi^2 \, \mu_v \, \Delta T} \right]^{1/3} \tag{5}$$

Chang (13) concluded that the heat transfer coefficient will increase with increasing pressure and that the effect of temperature and pressure can be calculated by its effect on the physical properties of the liquid and its vapor. Also, he found that the first stage of wave motion development is governed by hydrodynamic effects. In this stage where hydrodynamic effects are important, the vapor film surrounding the heat transfer surface is very thin, but the vapor film will continue to grow. The heat being transferred will decrease as the film thickness increases. The wavelength of the standing wave at the vapor-liquid interface is longer than the critical wavelength given by equation 4. Because of the hydrodynamic forces, the interface will break and vapor bubbles will be released. The film thickness will be reduced and an equilibrium condition will be established. Since the vapor will be periodically released at the interface, an average film thickness will be maintained and the heat transfer is now governed by conduction through the vapor.

Berenson (5) used a similar analysis of hydrodynamic instability in the development of a correlation for film boiling on a horizontal surface. The final equation is

$$h = 0.425\left[\frac{k_v^3\,\rho_v(\rho_l - \rho_v)\lambda g}{\mu_v\,\Delta T(g_c\,\sigma/g(\rho_l - \rho_v))^{1/2}}\right]^{1/4} \qquad (6)$$

Equation 6 is similar to Bromley's (equation 1) in that substitution of $(g_c\,\sigma/g(\rho_l - \rho_v))^{1/2}$ for D in equation 1 will give equation 6. Berenson's equation seems to be effective only near the minimum point of the film boiling region.

Breen and Westwater (6) investigated film boiling of Freon 113 and Isopropanol from horizontal cylinders ranging in diameter from 0.185 to 1.895 inches. They attempted to develop an equation that would predict the effects of diameter in the film boiling regime based on hydrodynamics and Taylor instability. Their study suggested that there are two mechanisms controlling film boiling. These mechanisms are a function of "the most dangerous wavelength" λ_d, where:

$$\lambda_d = \sqrt{3}\ \lambda_c$$

$$\lambda_c = 2\pi (g_c\ \sigma / g(\rho_l - \rho_v))^{1/2}$$

The Breen and Westwater correlation is

$$h(\lambda_c)^{1/4}/F = 0.59 + 0.069\ \lambda_c/D \tag{7}$$

where:

$$F = \left[\frac{k_v^3\ \rho_v(\rho_l - \rho_v)\lambda'' g}{\mu_v\ \Delta T}\right]^{1/4}$$

Breen and Westwater (6) found that there was a certain regime of λ_c/D which fit Bromley's data. Accordingly, they suggested an alternative procedure involving three boiling regions.

One of the boiling regions is

$$\lambda_c/D < 0.8\ ;\ h(\lambda_c)^{1/4}/F = 0.60$$

The above condition develops when the diameter of the cylinder is very large and wave motion appears around the perimeter of the cylinder. In this region surface tension effects are important.

The next boiling region is

$$0.80 < \lambda_c/D < 8.0\ ;\ h(\lambda_c)^{1/4}/F = 0.62$$

In this region the surface tension effects are not important and the mechanism is determined by conduction through vapor in viscous flow. The wave formation is one dimensional at the top of the cylinder.

The third boiling region is

$$8.0 < \lambda_c/D \; ; \; h(\lambda_c)^{1/4}/F = 0.16(\lambda_c/D)^{0.83}$$

In this region of boiling the diameter of the cylinder is small and the boiling mechanism is governed by bubble release. Again, surface tension is important.

Park (21) showed the Breen and Westwater correlation (equation 7) to be inadequate in predicting the heat transferred in the film boiling of nitrogen and methane from a horizontal cylinder (0.8022" diameter) over a wide pressure range. He found the Breen and Westwater correlation (equation 7) to be in error by +30% and -40% in predicting heat transfer coefficients when boiling methane and nitrogen, respectively. Also, his data showed a temperature dependence at high temperature differences that is not predicted by the Breen and Westwater correlation. Park's data revealed a decrease in the heat flux as the critical pressure is approached. The effect was noticed at reduced pressures greater than 0.90.

Sciance (26), who continued Park's work, did not observe the same decrease in heat transfer at reduced pressures up to 0.90. Sciance, Colver and Sliepcevich (26) fitted their methane data with equation 8 given below.

$$\frac{h\sqrt{\dfrac{g_c\,\sigma}{g(\rho_l - \rho_v)}}}{k_v} = 0.346\left[\frac{\left[\dfrac{g_c\,\sigma}{g(\rho_l - \rho_v)}\right]^{3/2} \rho_v(\rho_l - \rho_v)\lambda' g}{\mu_v\,\Delta T\,k_v\,T_r^2}\right]^{0.276} \tag{8}$$

There is no diameter term in the expression above; therefore, it is unlikely that this expression will fit data which are for diameters that are removed from the diameter used by Sciance (0.811 inch).

Baumeister and co-workers (2), (3), (4) postulated a model which consists of a thin tubular vapor film between the heat transfer surface and the boiling liquid. Analysis of this model yielded the following expression.

$$h = C\left[\frac{k_v^3\,\rho_v(\rho_l - \rho_v)\lambda' g}{\mu_v\,\Delta T\sqrt{\dfrac{g_c\,\sigma}{g(\rho_l - \rho_v)}}}\right]^{1/4}$$

$$\left[1.0 + \frac{9.0}{\sqrt{6.0}}\left[\frac{\sqrt{\dfrac{g_c\,\sigma}{g(\rho_l - \rho_v)}}}{D}\right] + \frac{8.0}{3\sqrt{6.0}}\left[\frac{\sqrt{\dfrac{g_c\,\sigma}{g(\rho_l - \rho_v)}}}{D}\right]^3\right]^{1/4} \tag{9}$$

The constant c was found to be 0.346; however, the constant was increased to 0.46 for nitrogen film boiling.

Pomerantz (23) in a study of the effect of gravity on film boiling suggested the following film boiling equation.

$$h = 0.62\left(\frac{1}{D}\right)^{1/4}\left(\frac{D}{\lambda_c}\right)^{0.172} F \qquad (10)$$

Frederking (16) suggested that film boiling from wires could be correlated using the following expression.

$$\frac{h\ D}{k_v} = C_2\left[\left[\frac{D^3\ \rho_v^2\ \beta\ g\ \Delta T}{\mu_v^2}\right]\left[\frac{C_p\ \mu_v}{k_v}\right]\right]^m \qquad (11)$$

where β is the coefficient of thermal expansion. The constant, C_2, and exponent, m, were found to be 2.5 and 0.11 respectively for helium. A larger constant, C_2, was suggested for nitrogen data.

Flanigan (15) found his experimental data to show the correlations of Bromley (7), and Breen and Westwater (6) to be inadequate in predicting heat fluxes from cylindrical heaters boiling in nitrogen and argon. Bromley's correlation (equation 1) and the Breen and Westwater correlation (equation 7) predicted heat transfer coefficients which were approximately 55% and 50% lower than the experimental values obtained by Flanigan (15). He used a modified form of Banchero, Barker, and Boll (1) to fit his data:

$$h = a_2(1.0/D + C)P_r^{1/4} \qquad (12)$$

where: $a_2 = b_1 + b_2 T_r + b_3 T_r^2 + b_4 T_r^3$

b_1 b_4 = constants in third order equation for "a"

$C = 36.5 \text{ in}^{-1}$

P_r = reduced pressure of the system

The use of corresponding states fluids allowed Flanigan to substitute the reduced properties of the system for the physical properties in previous correlations. He found that using this principle of corresponding states he could predict his film boiling heat transfer coefficients within ± 20% deviation.

The author in previous papers (9), (10), (11) presented an empirical equation which was restricted to corresponding states fluids. Like equation 12, the equation below is restricted to corresponding states fluids (N_2, A_r, CO).

$$h = 255.83 + 94.69(P_r) - 86.79(P_r)^2 + 21.02(P_r)^3$$
$$- 0.316(\Delta T) + 4.13 \times 10^{-4}(\Delta T)^2 - 438.02(D)$$
$$+ 286.90(D)^2 \qquad (13)$$

where: D is in inches

The values of the coefficients in equation 13 were determined by a least squares fit of Flanigan's data (15).

Equations 1 through 13 show the wide variety of correlations that have been presented in the past for film boiling heat transfer. The correlations indicate that the heat being transferred is dependent on the physical properties of the fluid (C_p, k_v, μ_v, $\cdots$) and on the diameter of the heat transfer surface. In the following sections, the experimental equipment, procedures, and data will be presented for the eventual comparison of the above correlations with experimentally determined values of film boiling heat transfer coefficients.

III. EXPERIMENTAL EQUIPMENT

The experimental equipment used in this investigation of film boiling heat transfer can be described in terms of five sub-systems: A) heat transfer elements, B) boiling vessel, C) pressure measurement and control, D) power supply, and E) temperature measurement.

A. Heat Transfer Elements

The heat transfer elements shown in Figure 2 consisted of copper cylinders heated by passing direct current through tungsten wire cemented inside the copper cylinders.

The heat transfer surface was machined from copper tubing to outside diameters of 1.00, 0.75, and 0.55 inches, a length of 3.00 inches, and a wall thickness of 0.1 inches. Four thermocouple wells were drilled axially into the walls of the cylinders to a depth of 1.0 inch with a diameter of 0.056 inches. Two of the four thermocouple wells were located at one end of the cylinder and 180^{o} apart. The remaining two thermocouple wells were located at the opposite end of the cylinder, 180^{o} apart, and rotated by 90^{o} from the other two thermocuple wells. All holes for the thermocouples were filled with silver solder having a melting point of 725 ^{o}F. An asbestos block was used to insulate the copper casing while heating the area of the thermocouple holes with a butane torch. When the solder became molten, 30 gauge, asbestos-covered, copper-constantan thermocouple wire was forced into the solder-filled holes.

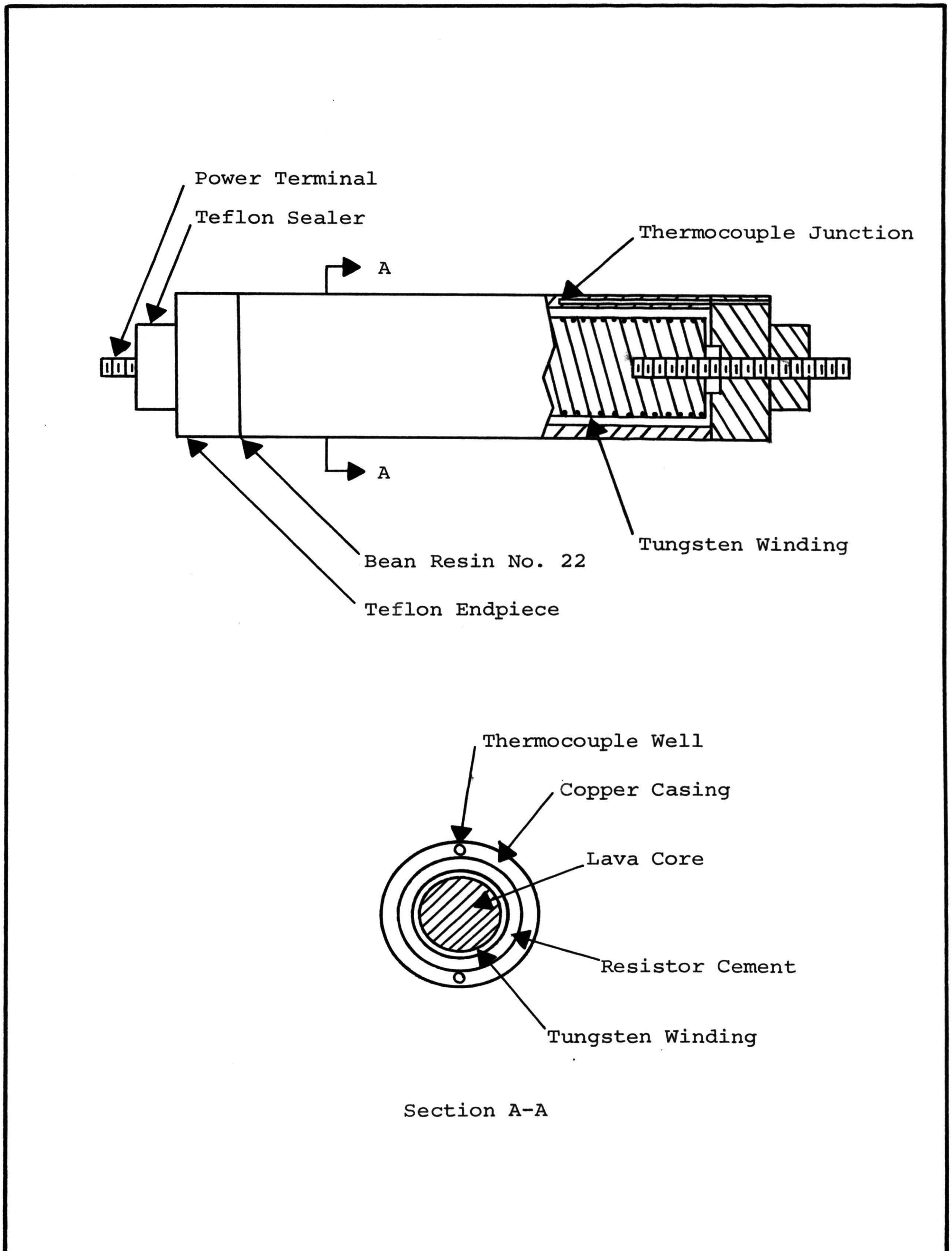


Figure 2. Heat Transfer Element

The heat to the cylindrical surfaces was supplied by passing d.c. current through tungsten wire wound on a lava core. The lava core (American Lava Corp.) were machined to a length of 2.80 inches and to diameters of 0.70, 0.45, and 0.25 inches. Reverse threads, 18 threads per inch and 0.02 inches deep, were machined on the unfired lava cores to provide a guide for winding the tungsten wire. The ends of the lava cores were drilled and tapped to provide an anchor for the tungsten wire and a power terminal. The lava was fired in a furnace at a rate of 500 ^{o}F per hour to a maximum temperature of 1900 ^{o}F.

The power terminals for the 0.70 and 0.45 inch lava cores were 10-32 machine bolts screwed 1/2 inch into each end of the lava cores which were threaded with 10-32 female threads. The power terminals for the 0.25 inch diameter cores were 4-40 bolts.

After the cores were wound with 26 gauge tungsten wire, a thin coat of Sauereisen, No. 8, high temperature cement was applied to the cores. The cores were allowed to air dry until the resistance between the power terminals and the cement was greater than 10^6 ohms. Additional layers of cement were applied to the cores until the cores fit tightly into the copper cylinders. The wound cores were cemented into the respective copper cylinders with Sauereisen, No. 8, cement. After air drying for one day, the remaining moisture was driven from the cores by the input of 1 ampere of d.c. current initially and increasing the current to 5 amperes over a 2 day period. The resistance between the power terminals and the copper cylinder for all heaters was greater than 10^6 ohms.

Teflon end plugs, 3/8 inches thick, were chemically etched for bonding purposes. Also, the ends of the copper casings were etched with Metal Etching Solution. The Teflon end plugs were bonded to the ends of the heat transfer surfaces with Bean Resin No. 22 (BR-22). The chemicals and techniques for bonding were supplied by the W. T. Bean Company. In order to form a thin glue line and to seal the power leads from the boiling fluids, an additional Teflon plug was threaded and secured on the power terminals with BR-22. The BR-22 was cured by heating the heat transfer surface to 500 ^{o}F for 2 hours. A Winchester 2514 P connector was soft soldered to each thermocouple lead which came from the copper casings.

The heat losses from the heat transfer surfaces were estimated to be less than 7% for the 1.00 inch diameter surface. Temperature measurements across the Teflon end plugs were made during tests boiling n-Pentane and Cyclopentane. Temperature differences between the Teflon surface and the boiling fluids were 2 ^{o}F and 5 ^{o}F at the edge of the end plug and at 0.10 inches from the heater surface, respectively. Estimating the heat lost by conduction through the Teflon end plugs and by using a convection coefficient from the work of Carr (12) of 1000 Btu/hr ft^2, the heat losses for a 1.00 inch diameter heater were calculated to be 2.1% and 2.7% of the energy input. The conduction of heat from the power leads was calculated to be less than 4% of the total energy input.

Other heater designs were attempted during this investigation. For instance, the recommended design of Wafer (27) utilizes a recessed heater core. However, the recession of the heater core greater than 0.1 inches caused instability in the film boiling behavior of the organic fluids and resulted in the loss of stable film boiling. Unless the heater winding extends to the edge of the copper heat transfer surface, nucleate boiling will form at the edge and spread to the center of the surface destroying the film boiling regime.

Another heater design which did not maintain stable film boiling utilized metal end plugs and a mechanical seal on the power leads. Axial heat losses for this heater were of the same magnitude as the heat transfer element with Teflon end plugs which verifies the low axial thermal gradients. In the design, the heater core was recessed 1/2 inches from the ends of the heater. Even though the end plugs were copper, there was not enough heat being transferred axially to maintain film boiling. Visual observation showed only nucleate boiling from the end plugs.

Other heater designs were employed in an attempt to attain heater temperatures greater than 600 ^{o}F. Fired lava end plugs in conjunction with the latest epoxies and resins were employed, but thermal expansion of the copper casing cracked the lava.

B. Boiling Vessel

The boiling vessel was a one gallon, 304 stainless steel autoclave, 5 inches I. D., 12 inches deep, and was manufactured by

High Pressure Equipment Company. The autoclave was sealed with a 304 stainless steel cap and plug with a Teflon O-ring. The sealing plug was fitted with 5, 1/4 inch coned fittings for a fill line, level indication, pressure tap, and inlet-outlet ports for a condensing coil. The sealing plug also had 3, 3/4 inch, NPT fittings. One of the 3/4 inch ports was used in conjunction with a Conax (PL) power lead, with Teflon sealant. Six Teflon insulated, silver plated, 12 gauge copper wires were fed through the Conax fitting to supply power to the heater inside the autoclave. Another 3/4 inch port was fitted with a Conax (MHM) Multi-Hole (Metal Follower) with 10, 0.062 inch holes. Five Teflon coated copper-constantan thermocouple wires (Leeds and Northrup Co., #20-55-27, 20 gauge, type T solid) were led through this fitting for temperature measurement inside the autoclave. The remaining 3/4 inch port was fitted with a 3/4 inch plug which had an open hook on the opposite end. The hook was used for raising and lowering the sealing plug and associated apparatus.

The boiling vessel was wrapped with an asbestos tape heating element for auxiliary heating of the autoclave. The autoclave was mounted on a one square foot steel platform inside a 9 inch steel pipe mounted vertically on the platform. The purpose of the platform was to provide accessibility while servicing the autoclave.

C. Pressure Measurement and Control

The pressure in the autoclave was controlled by regulating the flow of cooling oil (Union Carbide, UCON Heat Transfer Fluid No. 30) through 20 feet of internal, stainless steel cooling coil contained inside the autoclave. The oil flow was regulated by a Research Controls Inc., ATO, 3-15 psi diaphram, type J trim control valve in conjunction with a 3/8 inch Whitey valve for manual control. The air signal to the control valve was supplied by the output of a Honeywell (PI) air operated stack controller. The air signal to the controller was supplied by a Taylor differential pressure cell (d/p) with an operating pressure of 1500 psi and a range of 0 to 100 inches of water. The low pressure side of the d/p cell was connected by 1/4 inch O. D. thick wall stainless steel tubing to the system pressure inside the autoclave. The high pressure side of the d/p cell was connected to a nitrogen, high pressure cylinder with a Victor high pressure regulator. The pressure in the autoclave was measured with a Heise Bourdon tube pressure gauge (Model CMM) which had a 16 inch dial, a range from 0 to 2000 psi in 1 psi increments and an accuracy of less than 0.1% full scale. The system pressure was read to the nearest 0.5 psi. During tests there were fluctuations in the system pressure of $\pm$ 0.25 psi as measured from the d/p cell output by means of a Honeywell, 3-15 psi pressure gauge. The system pressure fluctuations of $\pm$ 0.25 psi correspond to temperature fluctuations of the boiling fluid of $\pm$ 0.5 ^{o}F (See Appendix A).

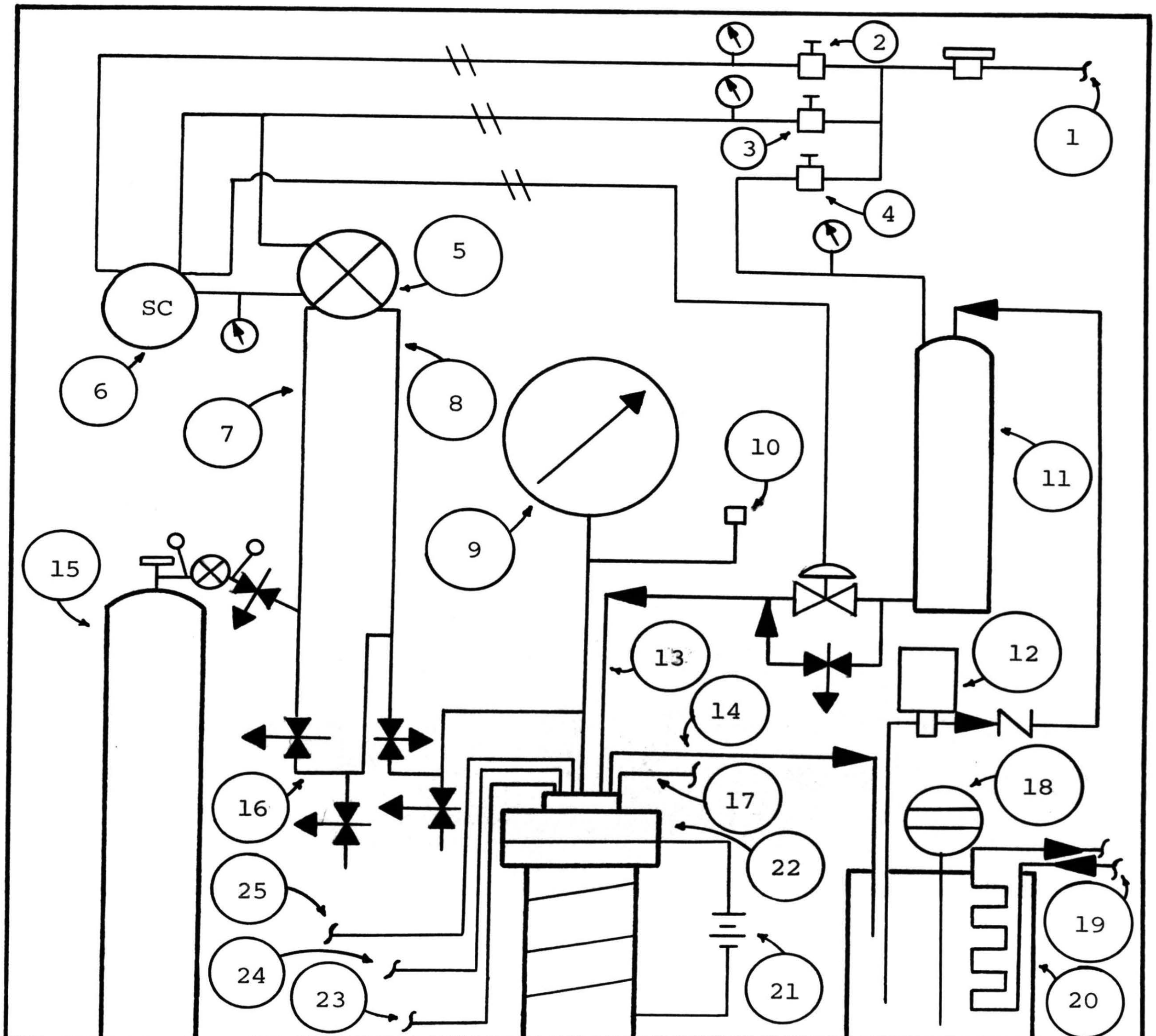
The supply of cooling oil to the autoclave was contained in a 5 gallon steel reservoir. The oil was forced from the reservoir by laboratory instrument air at 60 psig. After passing through the control valve and autoclave cooling coil, the oil flowed to a 5 gallon oil cooler where the oil was returned to ambient temperature by means of water-cooled, copper coil. The level in the oil cooler was controlled by a Mercoid Corporation, Mercoid Control level switch which operated a Flotec Inc., 1/4 hp motor (See Figure 3).

D. Power Supply

The power was supplied by a Nobatron, DCR 60-40 A, 60 volt, 40 amp, Sorensen D. C. Power Supply, and was measured with a Weston, Type PX-4, d.c. ammeter which could be read to ± 0.1 ampere and a United Systems Corporation, Model 211 Digital d.c. voltmeter which could be read to ± 0.01 volts. The accuracy of this voltmeter was 0.1% of the 100 volt full scale. All power leads from the power supply to the autoclave were 10 gauge copper wire.

E. Temperature Measurement

Asbestos-coated, 24 gauge, copper-constantan thermocouple wires were connected to the Teflon coated thermocouple leads from the autoclave cap and to a Leeds and Northrup thermocouple switch. The temperatures were read in millivolts using a United Systems Corporation, Model 268 Digital D. C. Millivoltmeter. Accuracy of the millivoltmeter was ± 0.01% of the 0 to 20 millivolt range. In addition, a Honeywell E Electronik 19 strip chart recorder was used in order to establish steady state conditions of the system during operation. The temperature readings were referenced to 32 ^{o}F with a West Instrument Corporation, Model AC-II thermocouple reference box. The temperatures during tests were read to within ± 0.004



1. Instrument air supply
2. Set point air regulator
3. Instrument air regulator
4. Oil reservoir air regulator
5. Pressure difference transmitter
6. Stack controller
7. Low pressure side of transmitter
8. High pressure side of transmitter
9. System pressure gauge
10. Rupture disk
11. Oil reservoir
12. Pump
13. Oil coolant inlet
14. Oil coolant outlet
15. Helium cylinder
16. Vent system
17. Level indicator
18. Level switch
19. Cooling water inlet
20. Oil cooling tank
21. Auxiliary heater
22. Autoclave
23. Fill line
24. Thermocouple leads
25. Power leads to heater

Figure 3. Schematic Diagram of Experimental Apparatus

millivolts or $\pm$ 0.15 ^{o}F.

At the minimum values of voltage (9 volts) and amperage (12 amps), the maximum error in the experimentally determined heat flux was approximately 1%. In view of the accuracy of temperature measurements and pressure control of the system and taking into consideration the heat losses of 7% for a 1 inch diameter heater, a conservative estimate of the total error in the heat flux introduced by experimental limitations was 8%.

IV. EXPERIMENTAL PROCEDURE

The experimental procedure during this investigation is discussed in terms of three phases: A) Startup, B) Data Collection, and C) Shutdown.

A. Startup

The cylindrical heat transfer element was horizontally suspended from the autoclave plug by the entering power leads. The level of the heater in the autoclave was adjusted to allow a 3 inch liquid level above the heater surface. A 1/16 inch stainless steel tube was positioned through the autoclave cap to indicate when the vessel was filled to the proper level in the vessel. All the power leads and themocouple connectors were wrapped with Teflon tape.

The autoclave cap and plug were lowered to the boiling chamber and tightened. The apparatus was rolled into position on the autoclave platform, and the pressure tap, fill line, and oil lines were connected. The voltmeters and power source were turned on and allowed to stabilize. The oil reservoir was pressurized to 60 psig with instrument air and the cooling water to the oil cooling tank was turned on. Instrument air was regulated to 20 psig to the controller and the d/p cell, and to 9 psig to the controller set point.

After the metering systems had stabilized, the power to the heat transfer element was turned on. The power was supplied in step increases of one volt every 5 minutes. When the heat transfer surface attained a temperature of approximately 500 ^{o}F, the fluid to be tested was forced through the fill line with instrument air. As the fluid reached the level of the heater surface, additional power was supplied to the element to maintain the surface temperature at 500 ^{o}F. When the level of the liquid was shown by the level indicator to be 3 inches above the heater surface, the fill line and level indicator ports were capped. This procedure of pouring the liquid on the heated surface was adopted to avoid the necessity of going through the burnout point. The possibility of destruction of the heating element was decreased by avoiding the critical heat flux. Auxiliary power to the autoclave was turned on to bring the fluid in the boiling vessel to the desired saturation temperature and pressure.

B. Data Collection

The fluids boiled during this investigation were Freon 113, n-Pentane, Cyclopentane, and Benzene. The fluids were boiled from cylindrical heaters, 3 inches long, and having diameters of 1.00, 0.75, and 0.55 inches. The purity of the fluids was greater than 99%.

In general, the saturation pressure of the system was first set at a reduced pressure of 0.04. The temperatures of the heater surface were monitored with the strip chart recorder until there was no change in temperature with time. With a 1 volt increase or decrease in the voltage input, steady state was attained after approximately 10 minutes. The four temperatures on the circumference of the heater surface were then recorded along with the saturation temperature of the fluid, and the voltage and amperage supplied to the heat transfer element. The next temperature level was attained after an approximate 0.5 volt increase or decrease in the voltage to the heater. Every test consisted of a sequence of increasing voltage, followed by a sequence of decreasing voltage with occasional reverse steps.

The power level required to avoid slipping into the nucleate boiling region, for any particular heater, produced a temperature difference of approximately 200 ^{o}F between the heater surface and the saturated liquid. The lower temperature limits were determined by the fluids ability to remain in film boiling. For instance, n-Pentane will remain in film boiling below a temperature difference (ΔT) of 200 ^{o}F, and, indeed, there were data taken for n-Pentane at a ΔT lower than 200 ^{o}F.

The upper limit for the power level was attained when the surface temperature was approximately 550 ^{o}F. This upper limit was dictated by the temperature at which Teflon begins to soften. There were instances when the surface temperature was taken beyond 550 ^{o}F and the heaters were ultimately destroyed. Also, surface temperatures were taken beyond 550 ^{o}F when boiling Benzene on a 1.00 inch diameter surface. These heaters were fabricated using lava end plugs, but the heaters were eventually destroyed during testing.

The next step in the procedure was to increase the system pressure to a higher value by closing the cooling coil valves to the autoclave and increasing the delivery pressure from the nitrogen cylinder to the high pressure side of the d/p cell. Normally, the pressure was increased by an amount to increase the reduced pressure of the system by 0.02. Some intermediate pressure tests were made and are reported in the Appendix A.

The highest system pressure attained was for n-Pentane at 242.5 psia for a 1.00 inch diameter surface. Since the saturation temperature for n-Pentane at 242.5 psia is 306 ^{o}F, the limitation of a ΔT of 200 ^{o}F and a maximum surface temperature of 550 ^{o}F restricted the pressure to 242.5 psia. Other fluids with higher boiling points than n-Pentane at equivalent reduced pressures were restricted to even lower reduced pressures. For instance, the boiling point of Cyclopentane at a reduced pressure of 0.10 is 223 ^{o}F. A temperature difference of 200 ^{o}F results in a surface temperature of 423 ^{o}F. Therefore, there was a surface temperature range of 127 ^{o}F at a reduced pressure of 0.10.

C. Shutdown

The shutdown of the system began with closing the high and low pressure side valves to the d/p cell. The valves on the venting manifold were opened. The power supply to the heating element was turned off and the by-pass valve for the cooling coil was opened. The auxiliary power to the autoclave and the power to the metering systems were shut off. The oil remaining in the oil reservoir and the cooling coil were drained into the oil cooling tank. Instrument air to the pressure controls was shut off. The autoclave was allowed to cool until the system pressure returned to atmospheric pressure.

The servicing ports to the autoclave were removed, and the cap to the autoclave was lifted with a block and tackle. The fluid in the boiling vessel was removed and the autoclave was prepared for another test.

The procedures detailed above for the collection of data resulted in data within the experimental equipment limitations of 8% error. In the following section the data shows that, in general, the reproducibility of the data was approximately 3%.

V. RESULTS AND DISCUSSION

The results and discussion of this investigation of film boiling are presented in three sections: A) Data Presentation, B) Comparison of Existing Film Boiling Correlations, and C) Development of a New Correlation.

A. Data Presentation

The calculated results for the film boiling of Freon 113, n-Pentane, Cyclopentane, and Benzene are presented in tabular form in Appendix A. The heat flux from the heater surface was determined by the electrical power input to the heat transfer element and divided by the surface area of the copper surface. The surface temperatures 1, 2, 3, along the circumference of the heater surface were arithmetically averaged to obtain the average surface temperature. The temperature gradient along the circumference was less than 8 ^{o}F for all tests. The saturation temperature of the fluid was recorded for each data point. The temperature difference, $T_{sur}-T_{sat}$, was calculated by subtracting the saturation temperature from the average surface temperature, and the heat transfer coefficient was determined by dividing the heat flux by the temperature difference.

The calculated results are also presented in graphical form in Figures 4 through 12. For any fluid and diameter above 200 ^{o}F ΔT, the heat flux increases as the temperature difference and pressure increase.

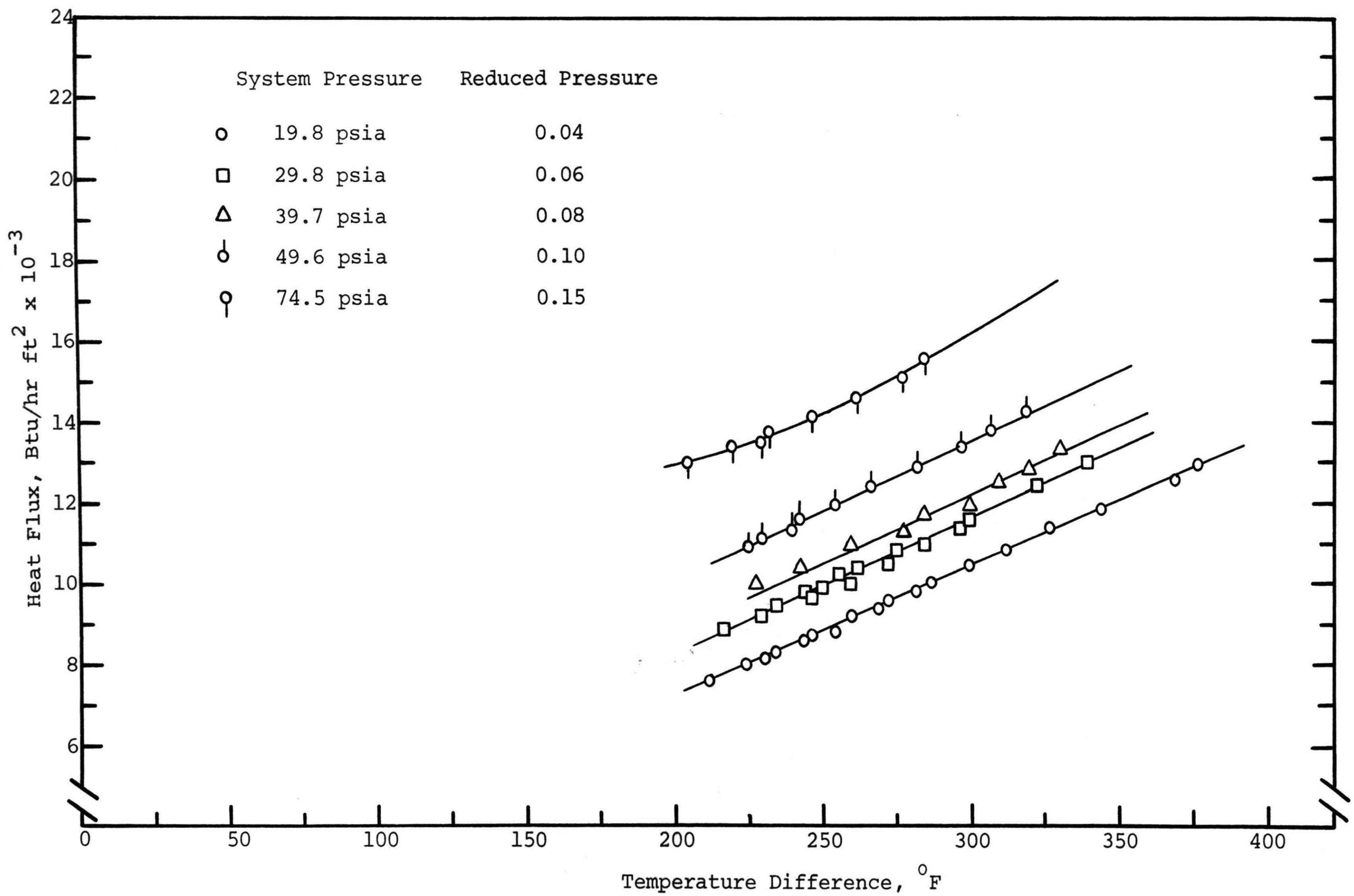


Figure 4. Film Boiling Results of Freon 113, 1.00 Inch Surface

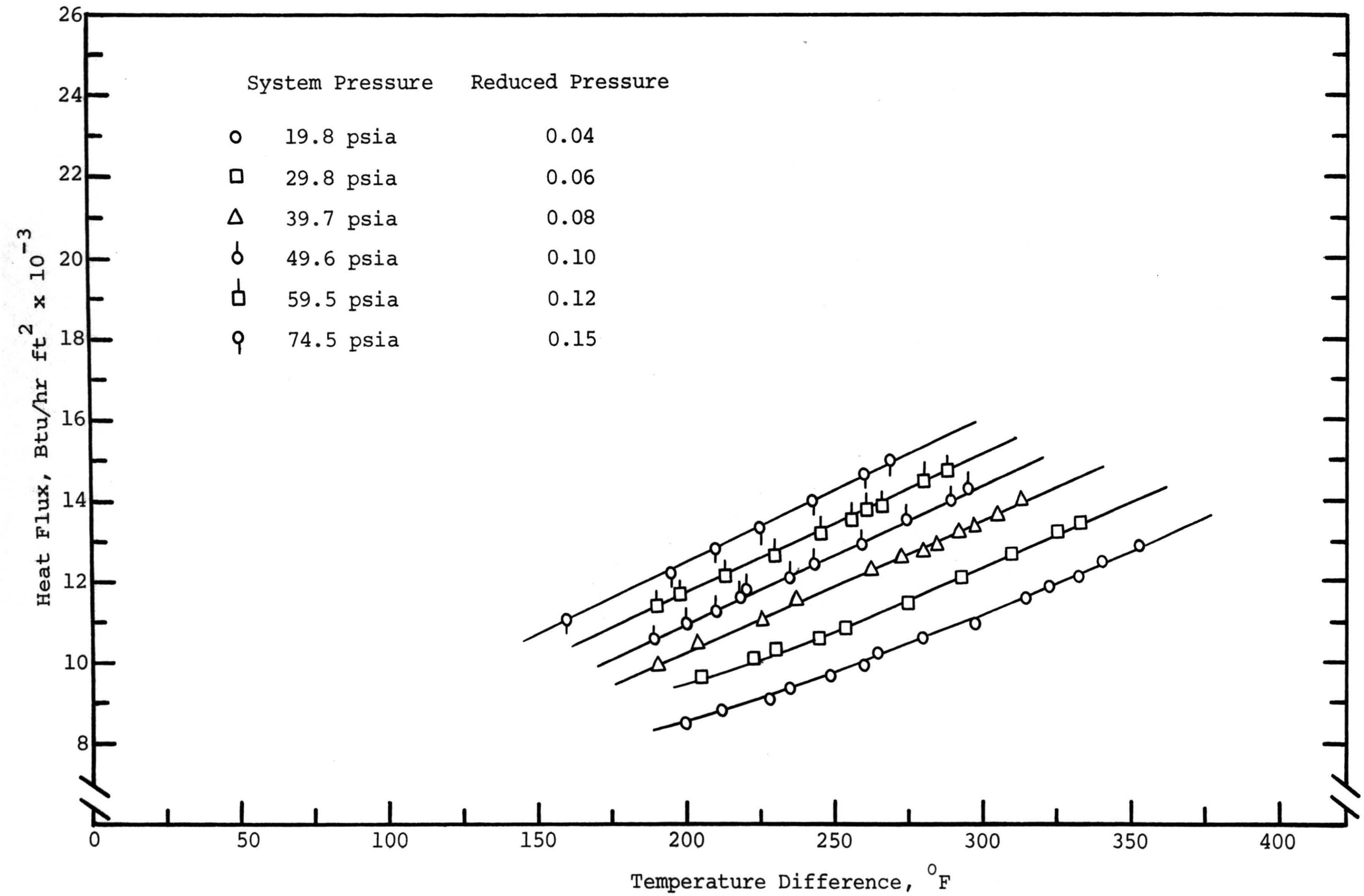


Figure 5. Film Boiling Results for Freon 113, 0.75 Inch Surface

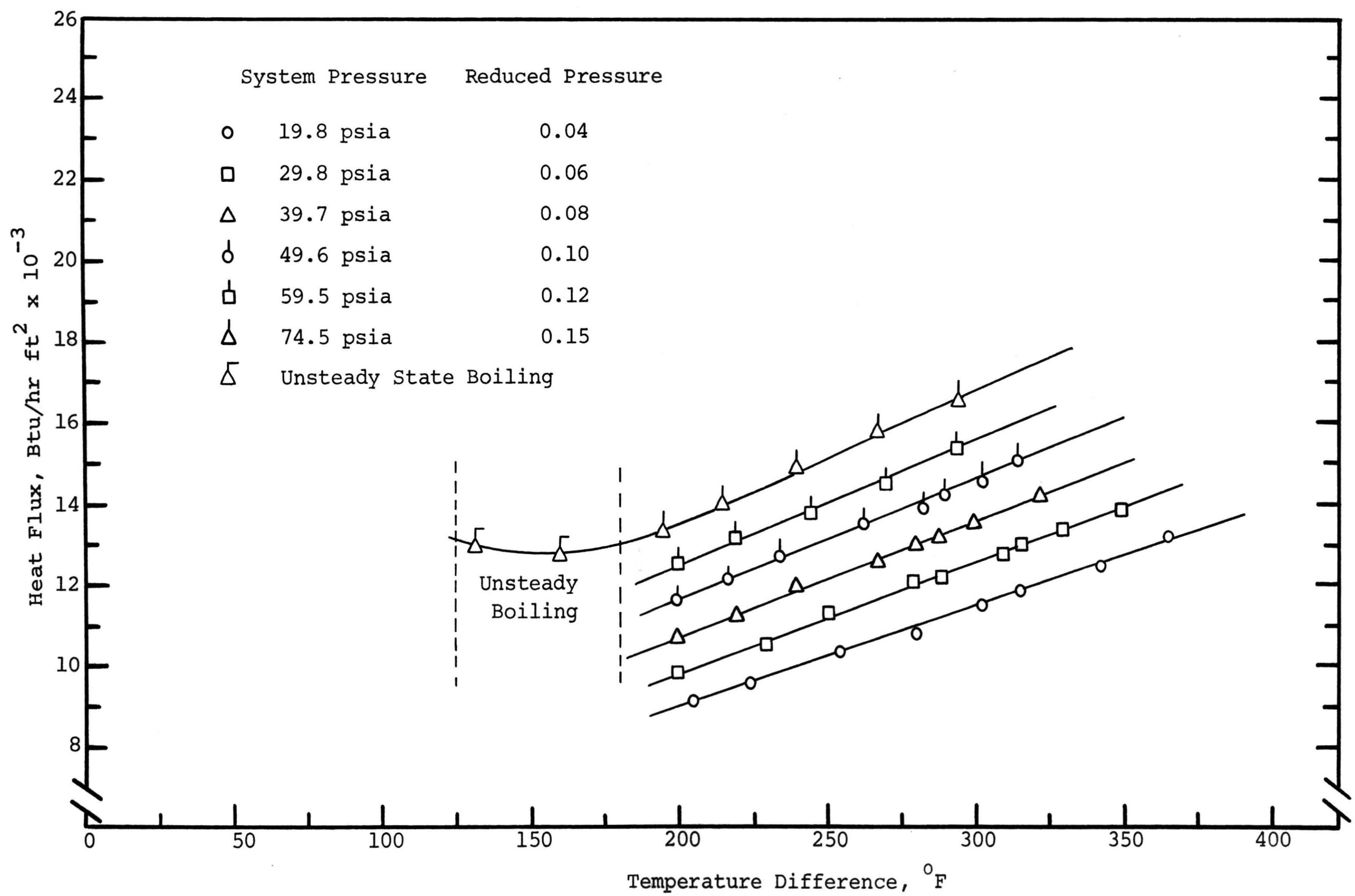


Figure 6. Film Boiling Results for Freon 113, 0.55 Inch Surface

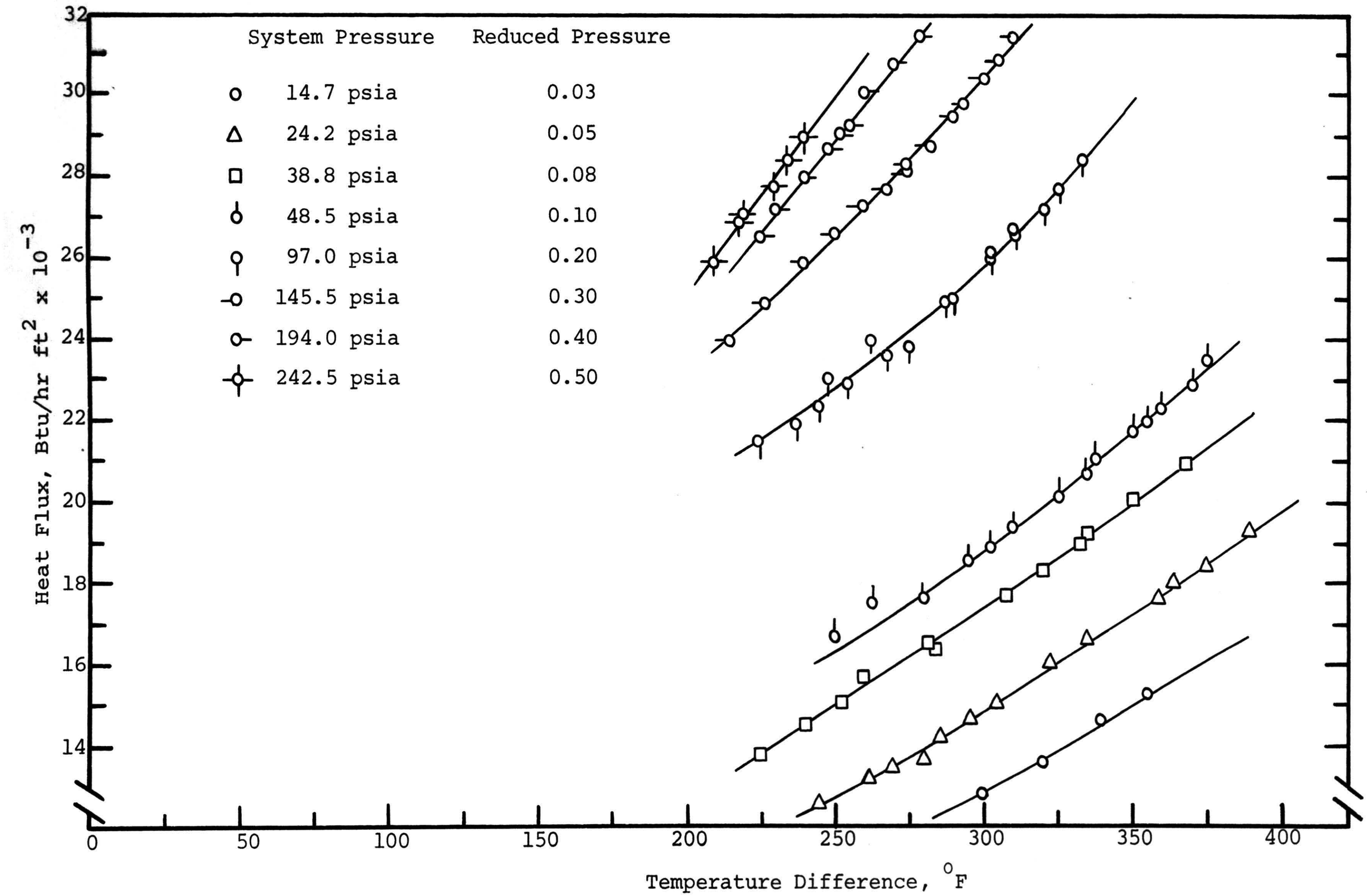


Figure 7. Film Boiling Results for n-Pentane, 1.00 Inch Surface

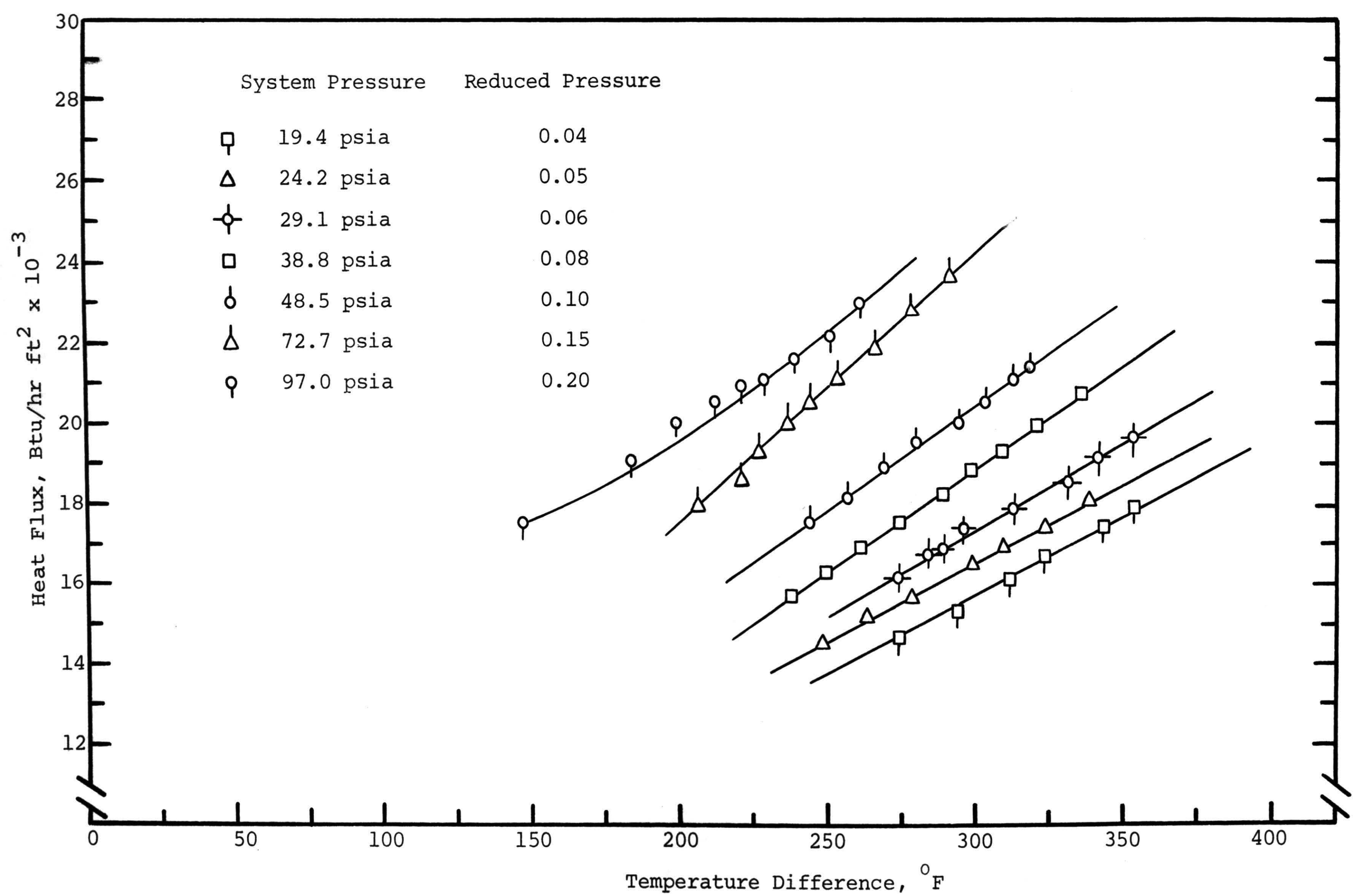


Figure 8. Film Boiling Results for n-Pentane, 0.75 Inch Surface

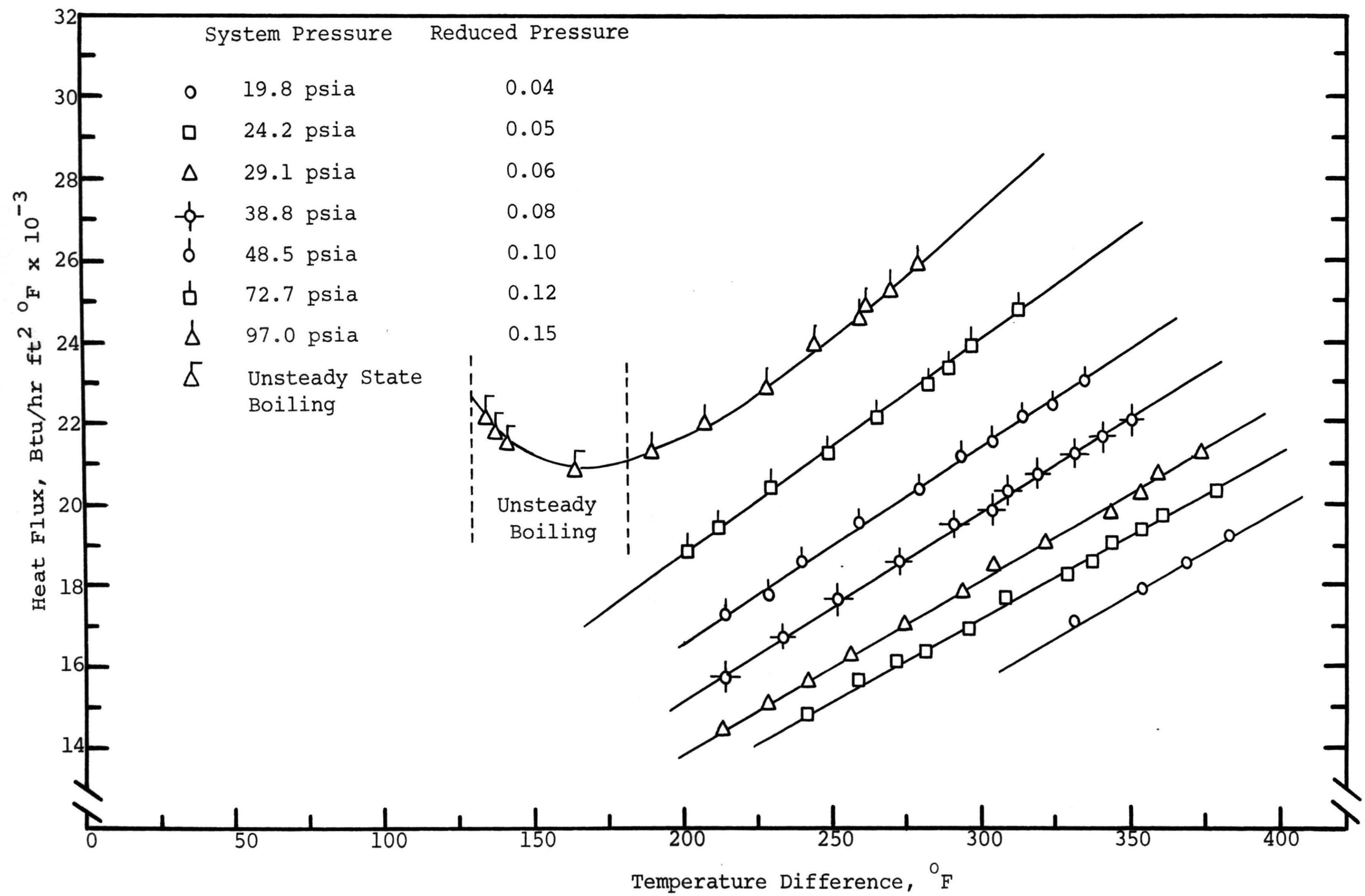


Figure 9. Film Boiling Results for n-Pentane, 0.55 Inch Surface

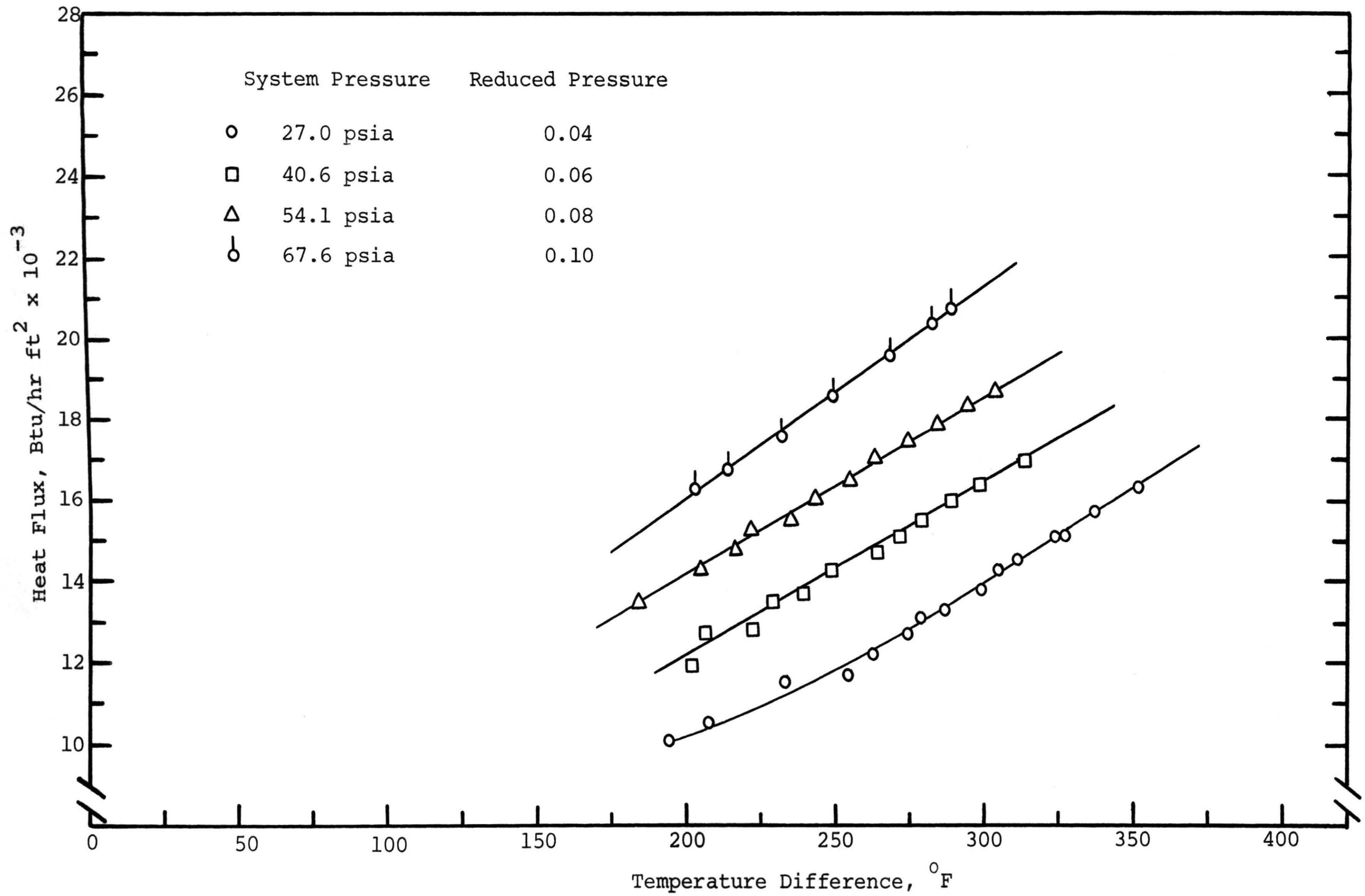


Figure 10. Film Boiling Results for Cyclopentane, 1.00 Inch Surface

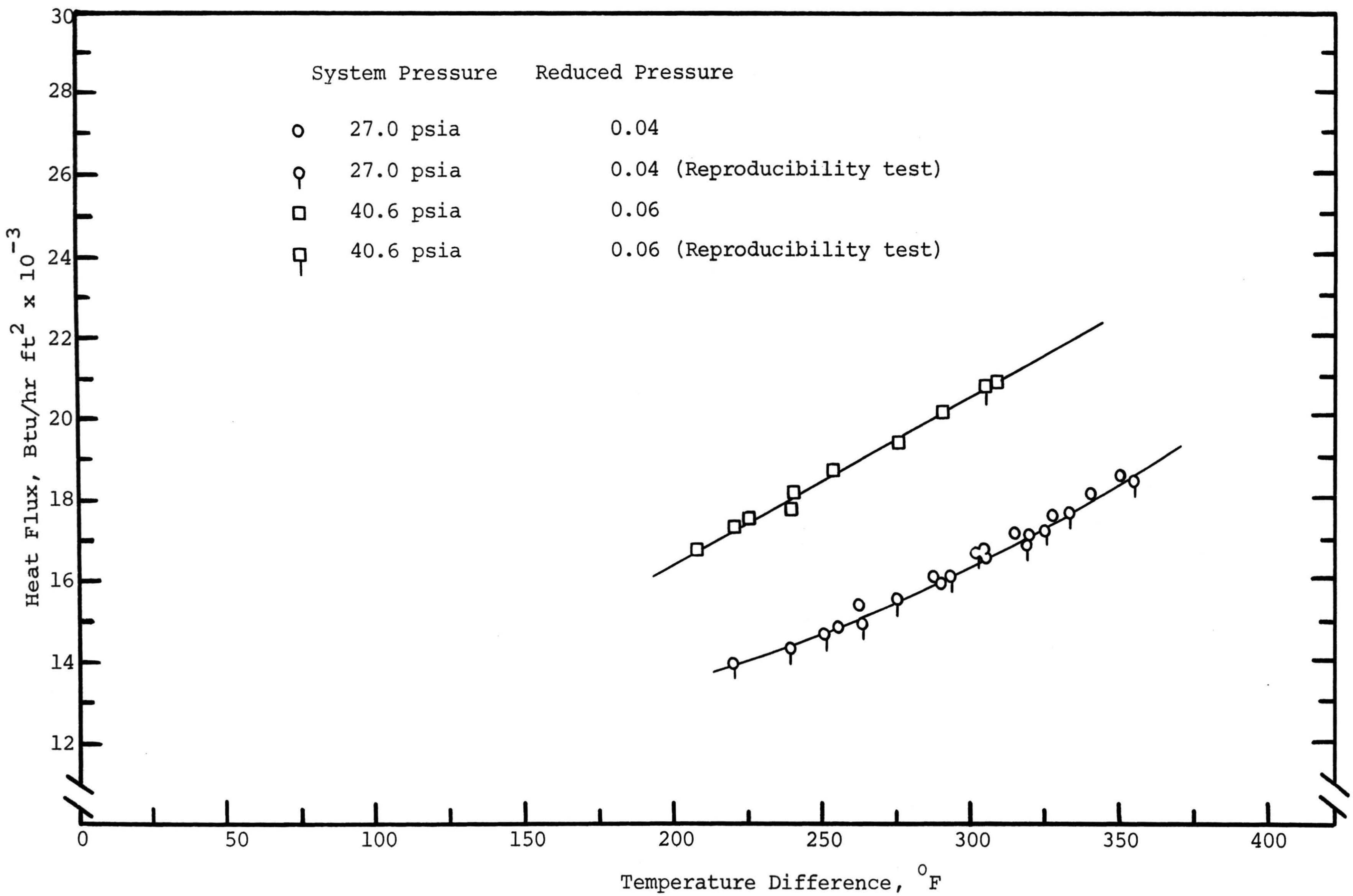


Figure 11. Film Boiling Results for Cyclopentane, 0.75 Inch Surface

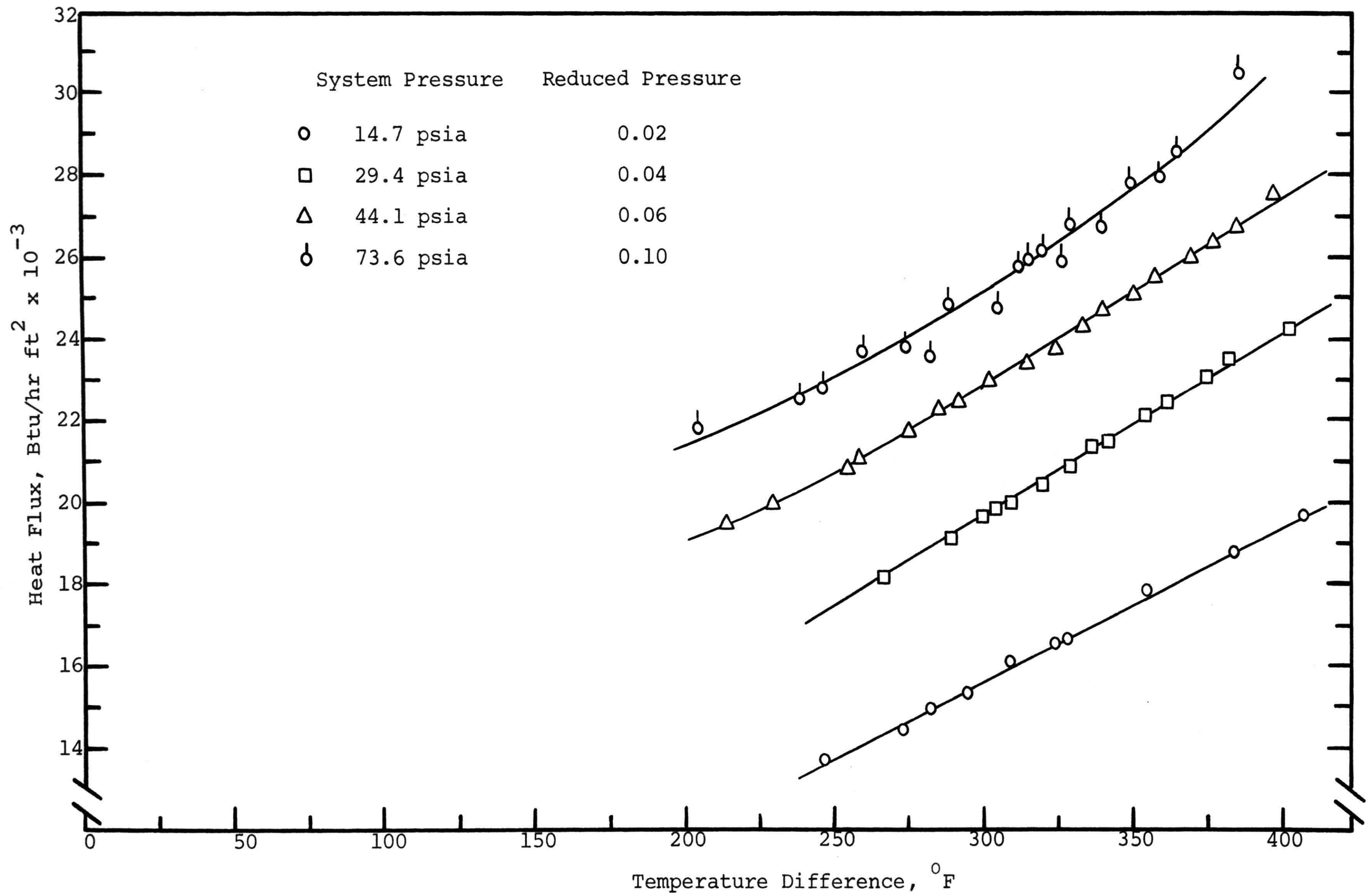


Figure 12. Film Boiling Results for Benzene, 1.00 Inch Surface

Below 200 ^{o}F ΔT, the heat flux may increase with decreasing ΔT as shown in Figures 6 and 9. Figure 9 shows a minimum for n-Pentane at a pressure of 97.0 psia and a diameter of 0.55 inches. All the data points at the minimum and to the left are unsteady state values and were obtained by increasing the power supply as the heater temperature decreased. The surface temperatures were recorded when the maximum surface temperature of the heater was attained after a step increase in the power level.

Tests showing the reproducibility of the data are shown in Figures 11 and 12 for Cyclopentane and Benzene, respectively. The scatter in the data shown in Figure 11 for the Cyclopentane boiling from a 0.75 diameter heater is less than 3%. The Benzene reproducibility shown in Figure 12 was within 6%. The increased scatter for the Benzene was caused by the increased difficulty in maintaining a stable film. At any particular temperature difference, system pressure, and surface diameter, the required heat flux increased in the following order: Freon 113, n-Pentane, Cyclopentane, and Benzene. In general, the trend of the boiling behavior is an increase of the heat flux with an increase in the latent heat of vaporization.

Since the saturation temperature is dependent on the system pressure, a plot of heat flux as a function of wall temperature could be more informative than a plot of heat flux as a function of ΔT. Figure 13 is a plot of heat flux as a function of the surface temperature. As shown, the heat flux at a given surface temperature

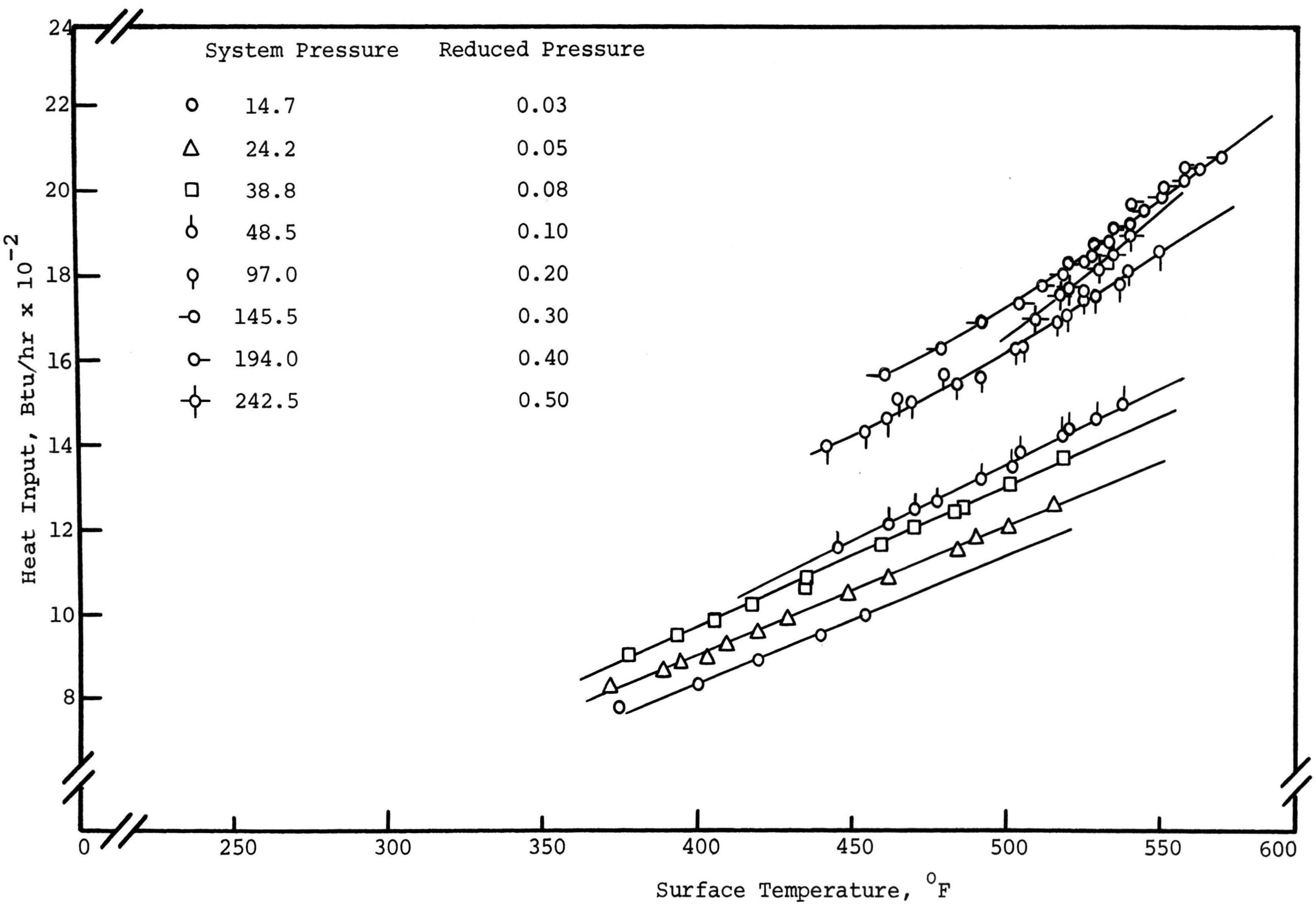


Figure 13. Film Boiling of n-Pentane as a Function of Surface Temperature, 1.00 Inch Surface

from a pressure of 194 psia to 242 psia decreases slightly. Fluids other than n-Pentane were tested at pressured below reduced pressures of 0.20 and show an increase in heat flux with an increase in pressure as shown for the lower pressures for n-Pentane.

Capone (9) suggested that similar fluids when compared at the same reduced temperature and pressure will behave in a similar manner when in film boiling. Figure 14 shows a plot of heat flux as a function of the reduced temperature difference at a reduced pressure of 0.06 for a 1.00 inch diameter surface. As shown, the heat flux is not the same for all fluids even though the Z_c values for all the fluids are approximately 0.27. On a molecular scale the structure and inter-molecular forces of the fluids are different and different heat flux requirements should be expected when in film boiling. It is interesting to note that the lines appear to be almost parallel when the data are plotted in this manner.

Figures 15 and 16 show the heat input per foot of heater surface as a function of heater diameter. Although the figures are presented for Freon 113, similar trends are shown by n-Pentane. The figures were presented in this form in order to show more clearly the dependence of the heat input on the diameter. For example, Wafer (27) plotted heat flux and heat transfer coefficients as a function of diameter and an explanation of the resulting graphs was not readily apparent for liquid nitrogen. However, plotting Wafer's data as the heat input as a function of surface diameter, similar trends as those shown in Figures 15 and 16 were observed. Freon 113 at a pressure of

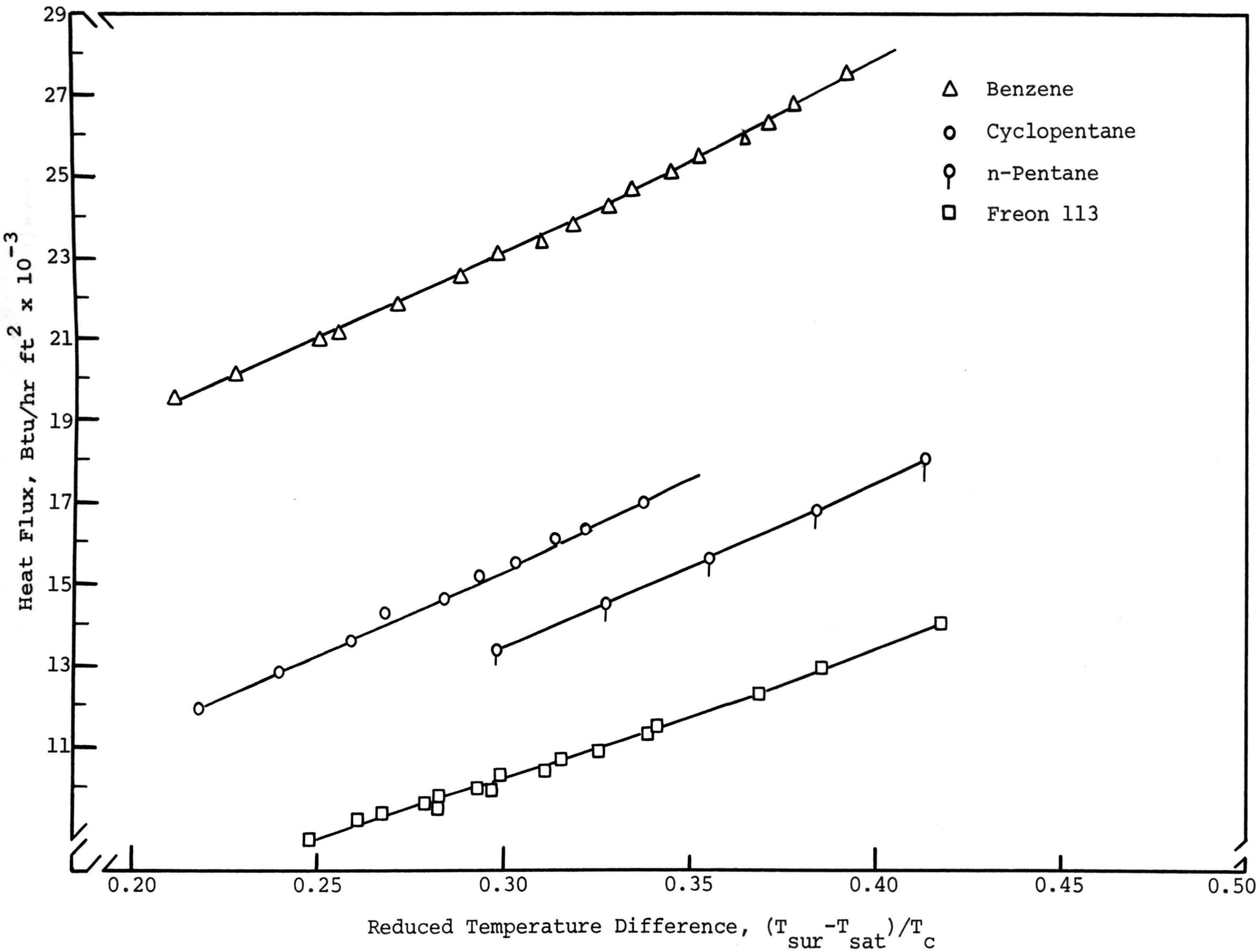


Figure 14. Film Boiling as a Function of Reduced Temperature Difference, 1.00 Inch Surface, 0.06 Reduced Pressure

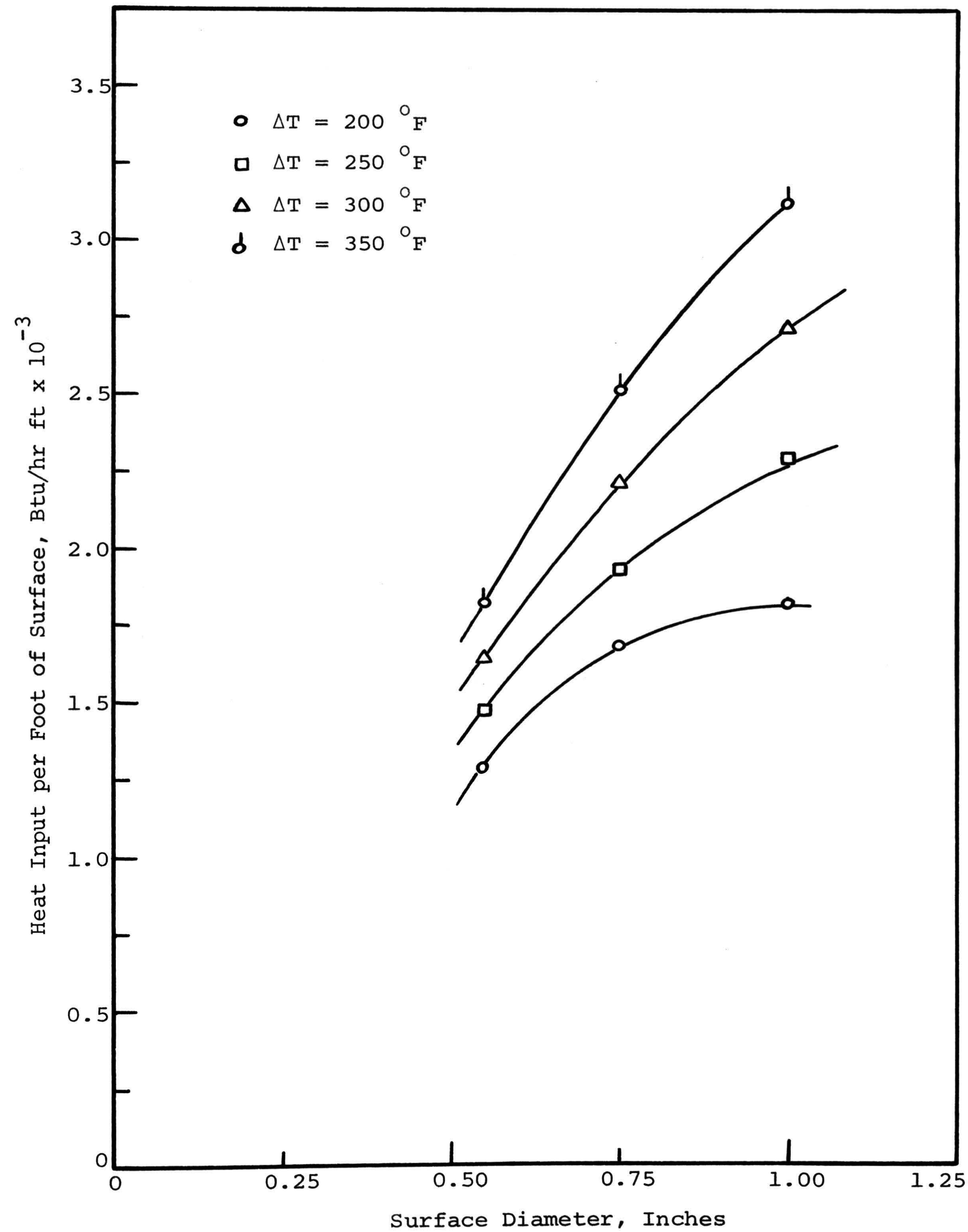


Figure 15. Film Boiling as a Function of Surface Diameter, Freon 113 at 19.8 psia

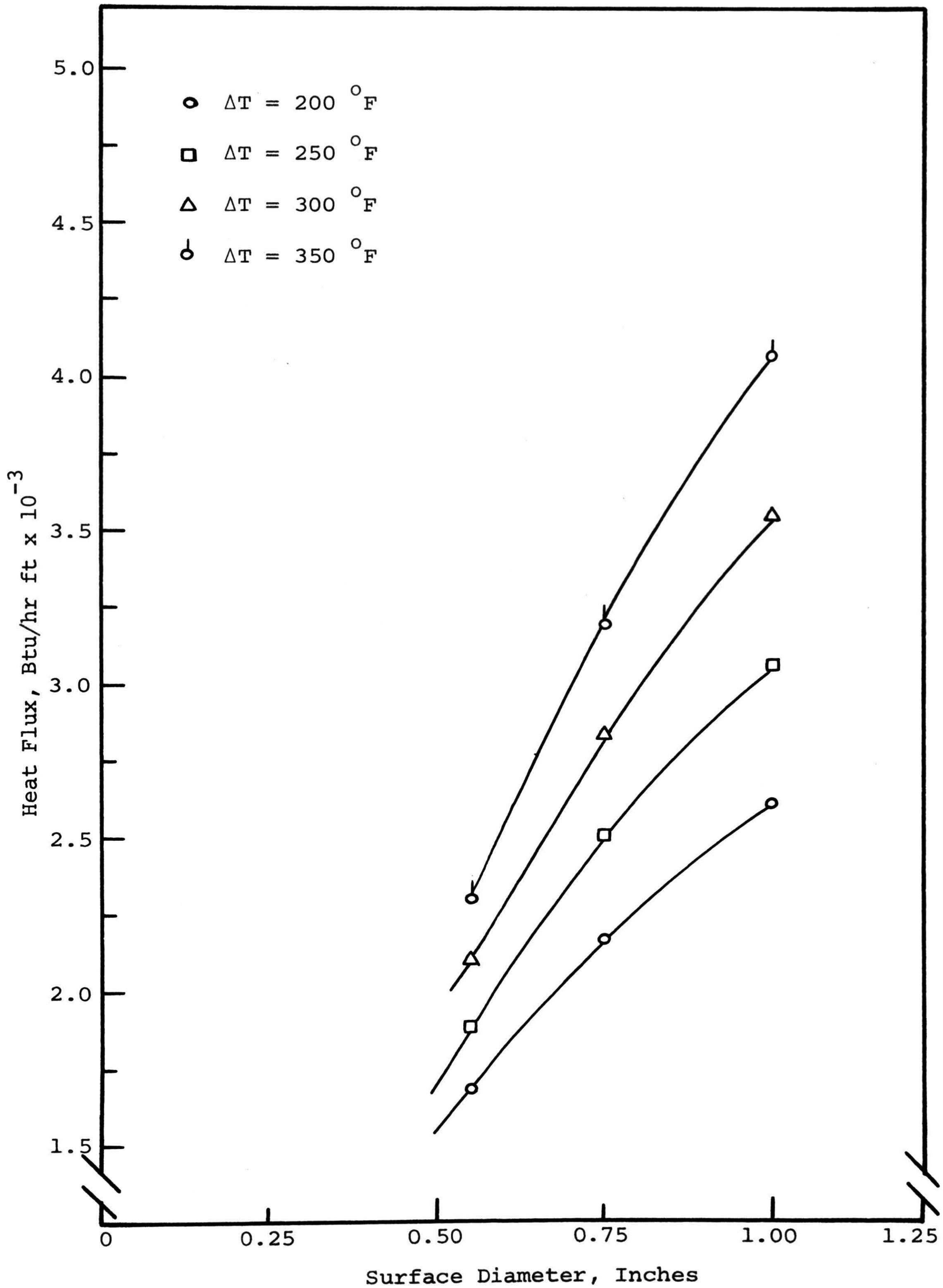


Figure 16. Film Boiling as a Function of Surface Diameter, Freon 113 at 49.6 psia

19.8 psia shows almost a linear relationship for the heat per foot as a function diameter at a temperature difference of 350 ^{o}F. The functional relationship becomes more non-linear as the temperature difference approaches 200 ^{o}F. Figure 16 shows that the diameter effect at the lower temperature differences becomes linear at the higher pressure of 49.6 psia.

As the diameter approaches zero, the heat required to maintain film boiling should approach zero. However, the extrapolation to a value of zero was not attempted since a stable film may not be attainable at the temperature differences shown in Figures 15 and 16. An example of the relationship between the diameter and temperature difference required for stable film boiling was observed when boiling Benzene. Only data for a 1.00 inch surface could be obtained. No stable film boiling was observed for Benzene from surfaces of 0.75 and 0.55 inch diameters with surface temperatures of 450 ^{o}F. More dramatic behavior was observed when boiling Cyclopentane (Figure 11). When testing a surface of 0.75 inch diameter, Cyclopentane remained in stable film boiling conditions up to and including a pressure of 40.6 psia. Increasing the pressure to 54.1 psia and holding the surface temperature at 500 ^{o}F resulted in the loss of stable film boiling conditions and the slippage into nucleate boiling. Stable film boiling of Cyclopentane from a 0.55 inch surface could not be attained for surface temperatures of 450 ^{o}F. Consequently, stable film boiling is a strong function of the type of fluid, system pressure, surface temperature, and surface diameter.

B. Comparison of Existing Film Boiling Correlations

The comparison of the experimental data with the existing correlations are presented in Figures 17 through 24. The graphs represent the heat transfer coefficient as a function of temperature difference.

Figure 17 shows that the Sciance correlation (equation 8) for n-Pentane from a 1.00 inch surface and at 48.5 psia predicts values within a few per cent of the experimental values. The other correlations presented in Figure 17 agree with the experimental values to a lesser extent to a maximum of approximately 60% for the Chang correlation. As shown in Figure 18, there is a lack of response of the correlations to an increase in pressure to 242.5 psia. The Sciance correlation is approximately 20% lower than the experimental values of the Chang correlation is approximately 70% lower than the experimental values at 242.5 psia.

Figures 19 through 24 present similar comparisons of the experimental values with existing correlations. The correlations show insufficient response to changing pressures, fluids, and diameters. With the wide variations in the ability of the correlations to accurately predict experimental values, no previous correlation can be recommended with an acceptable (± 20%) degree of reliability.

Many of the correlations presented in Section B were developed in a manner similar to the development of the correlation of

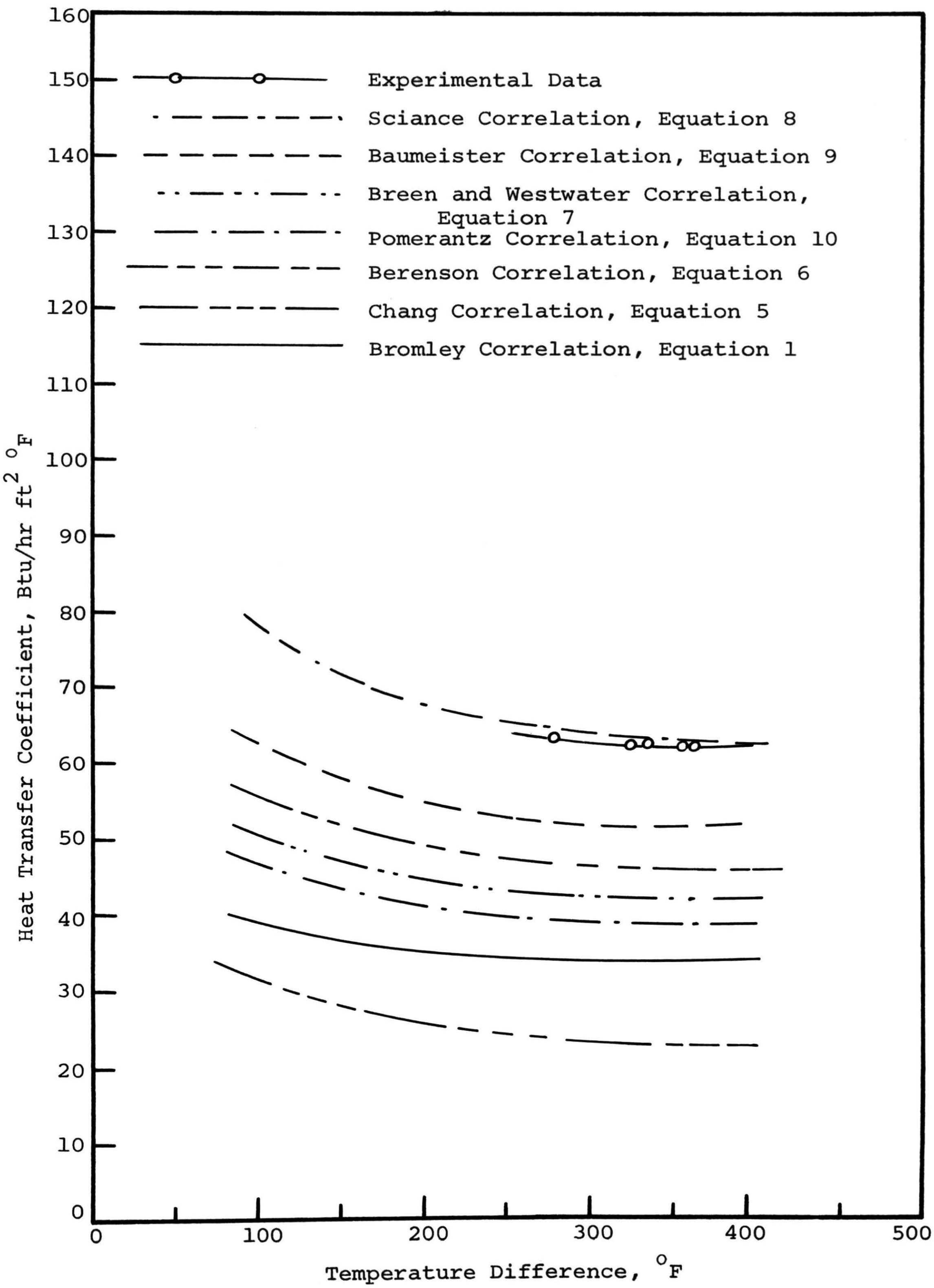


Figure 17. Comparison of Film Boiling Correlations, n-Pentane, 48.5 psia, 1.00 Inch Surface

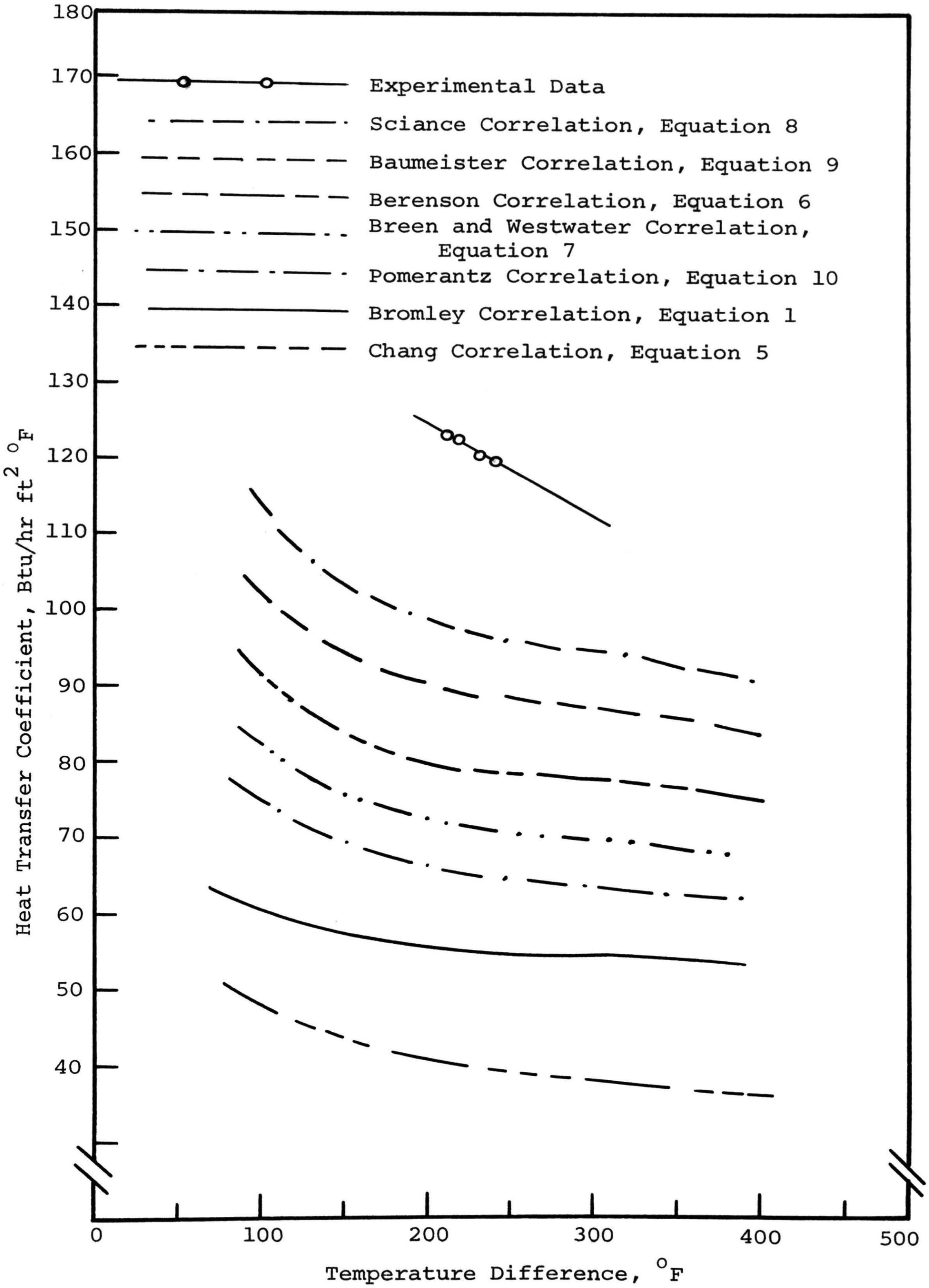


Figure 18. Comparison of Film Boiling Correlations, n-Pentane, 242.5 psia, 1.00 Inch Surface

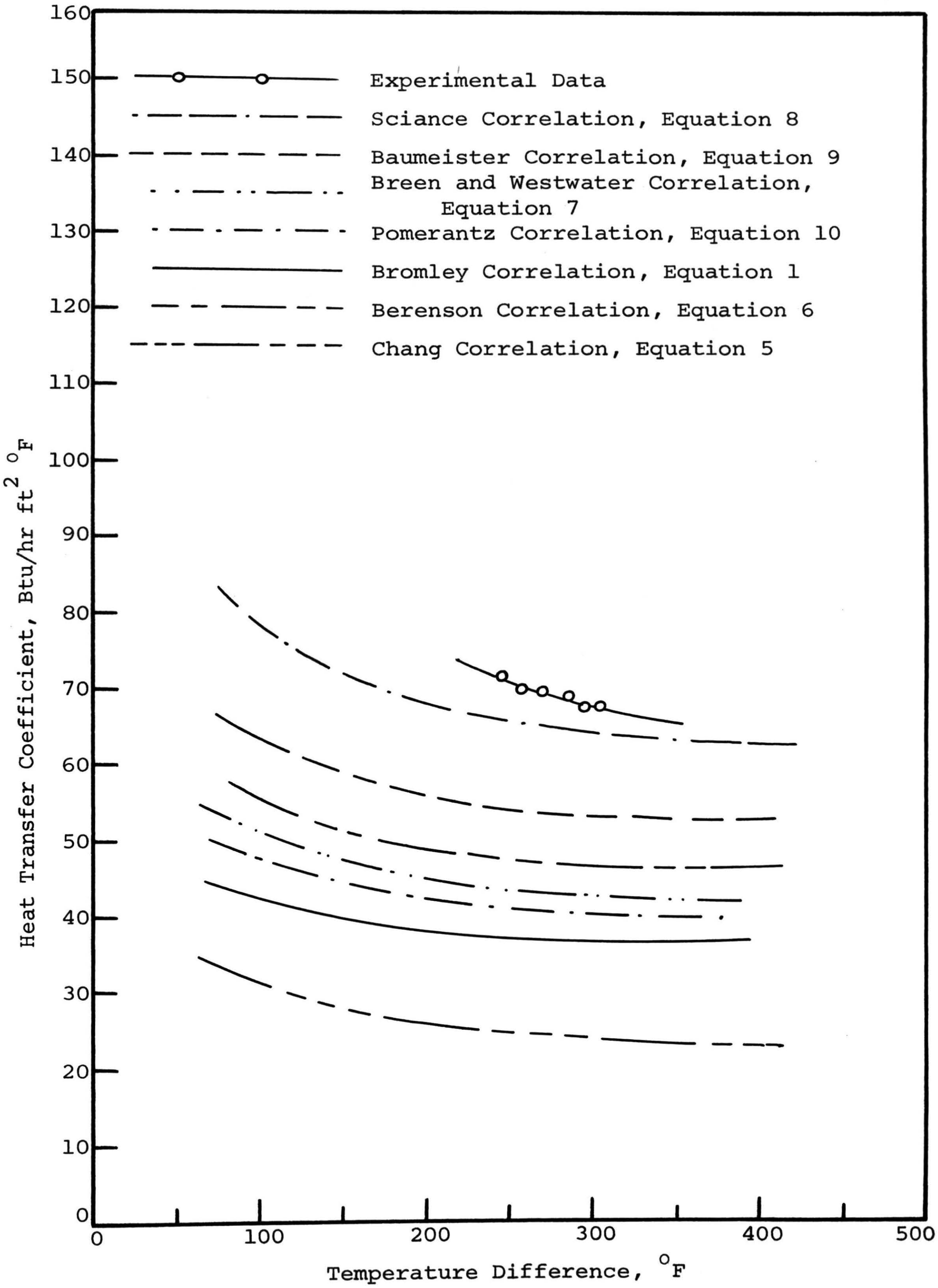


Figure 19. Comparison of Film Boiling Correlations, n-Pentane, 48.5 psia, 0.75 Inch Surface

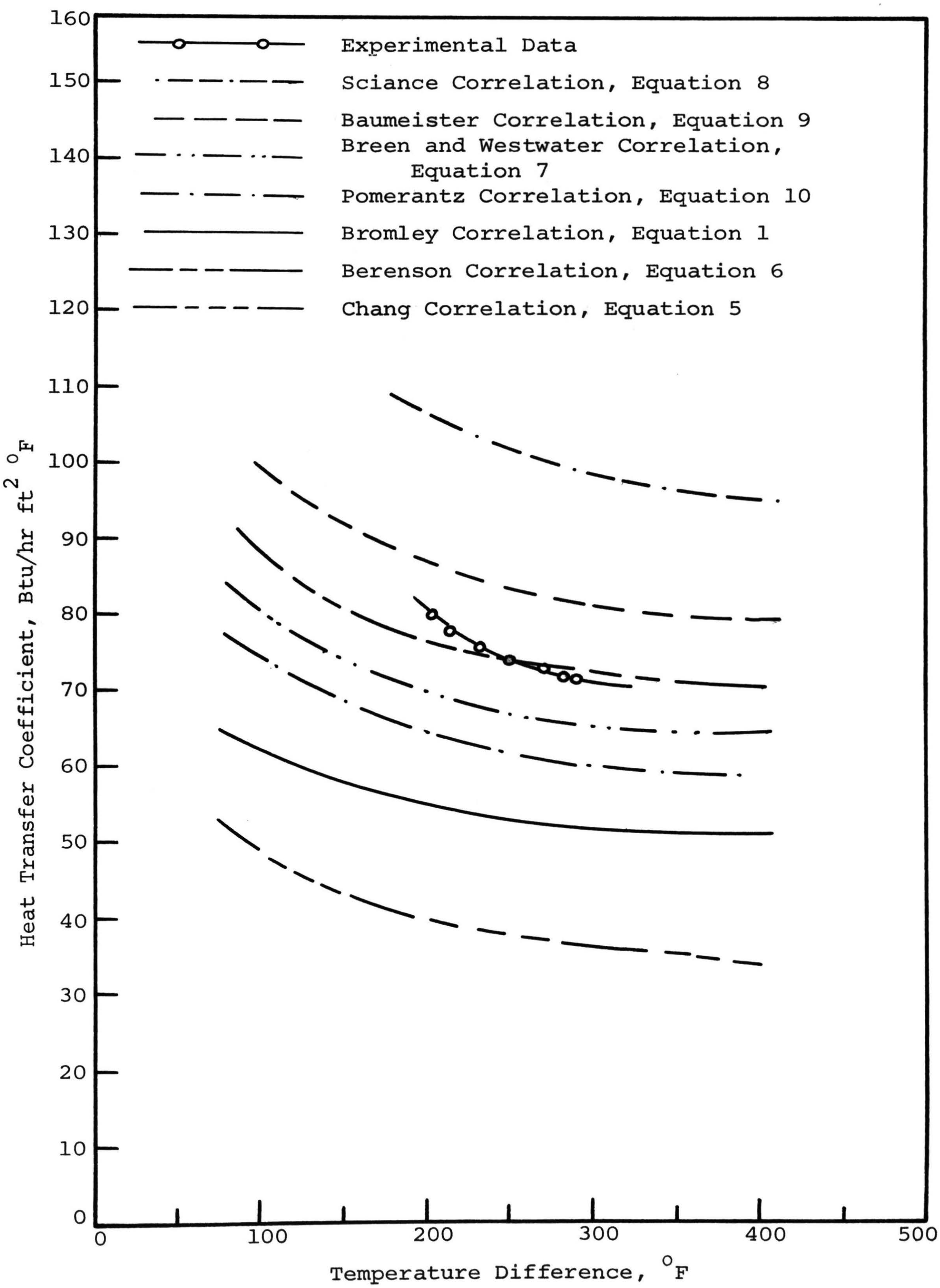


Figure 20. Comparison of Film Boiling Correlations, Cyclopentane, 67.6 psia, 1.00 Inch Surface

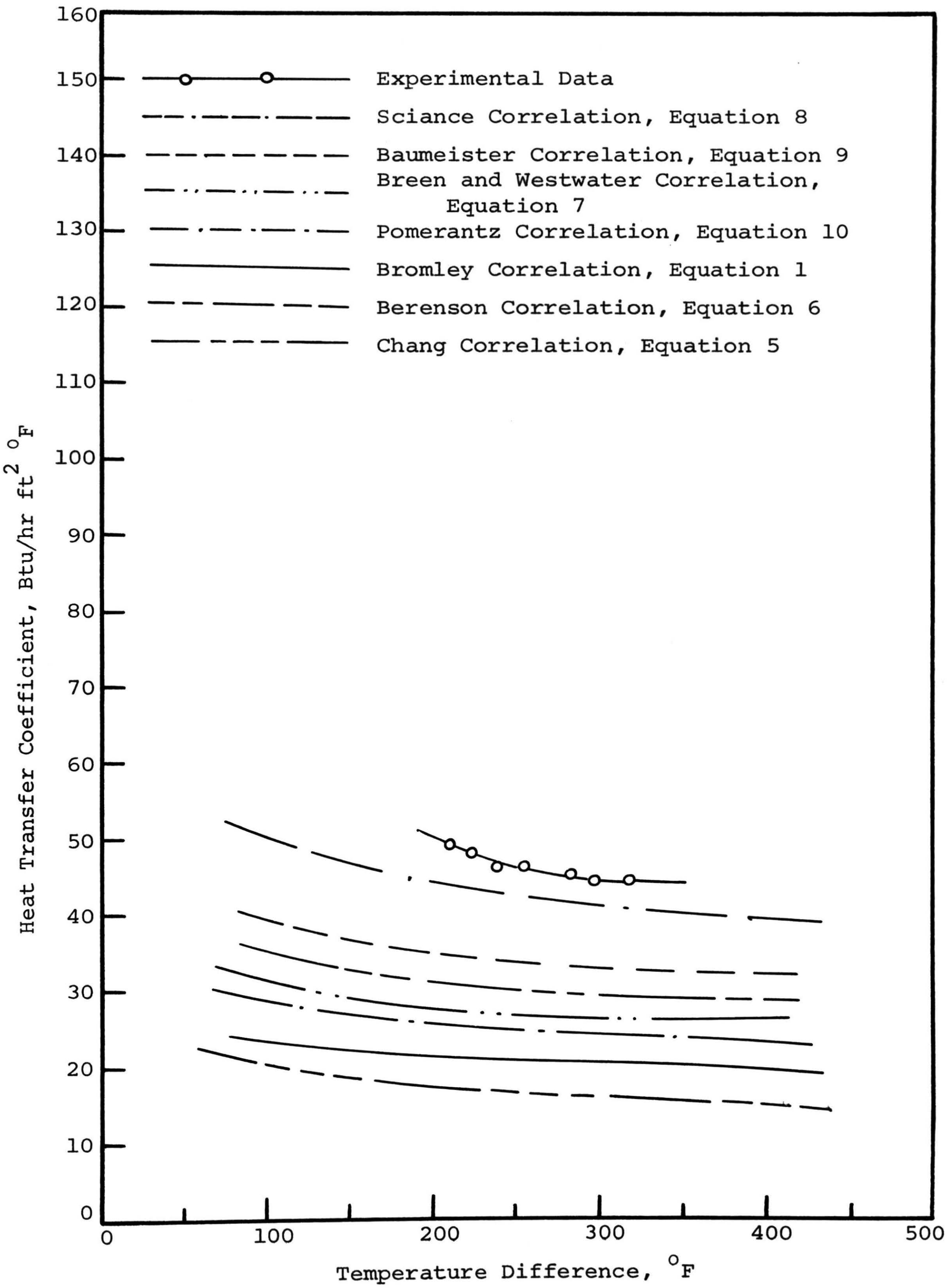


Figure 21. Comparison of Film Boiling Correlations, Freon 113, 49.5 psia, 1.00 Inch Surface

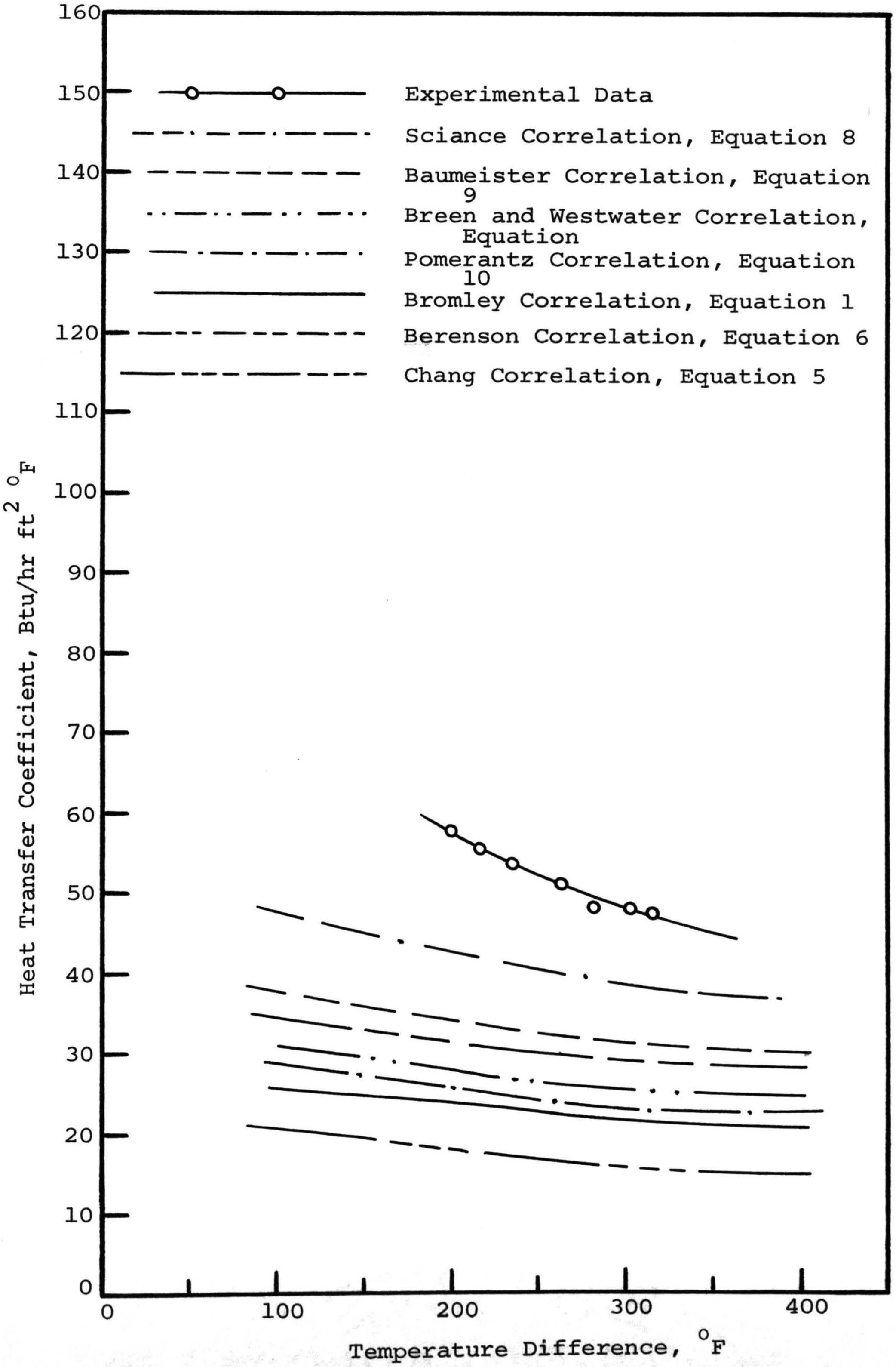


Figure 22. Comparison of Film Boiling Correlations, Freon 113, 49.5 psia, 0.55 Inch Surface

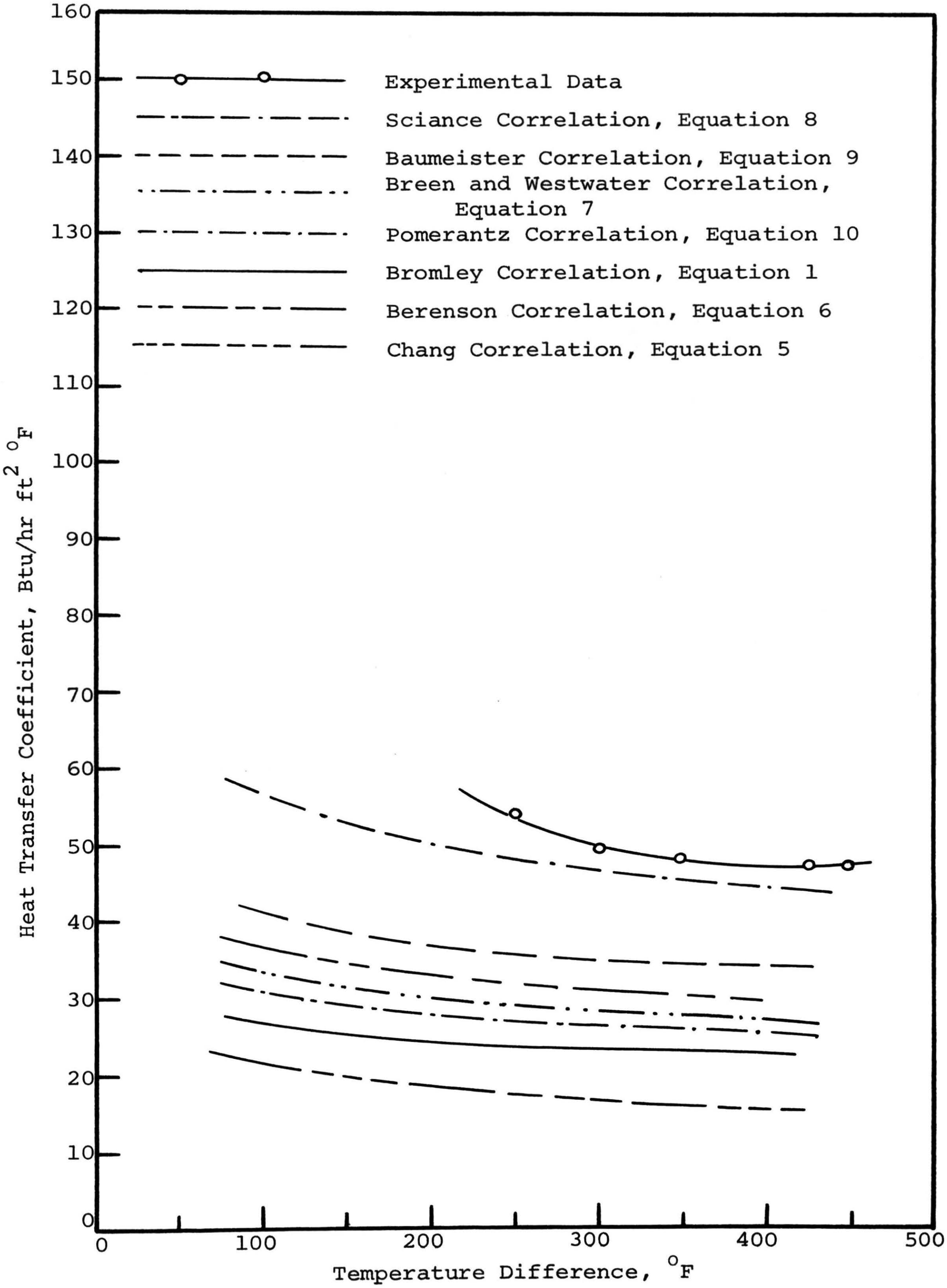


Figure 23. Comparison of Film Boiling Correlations, Benzene, 14.7 psia, 1.00 Inch Surface

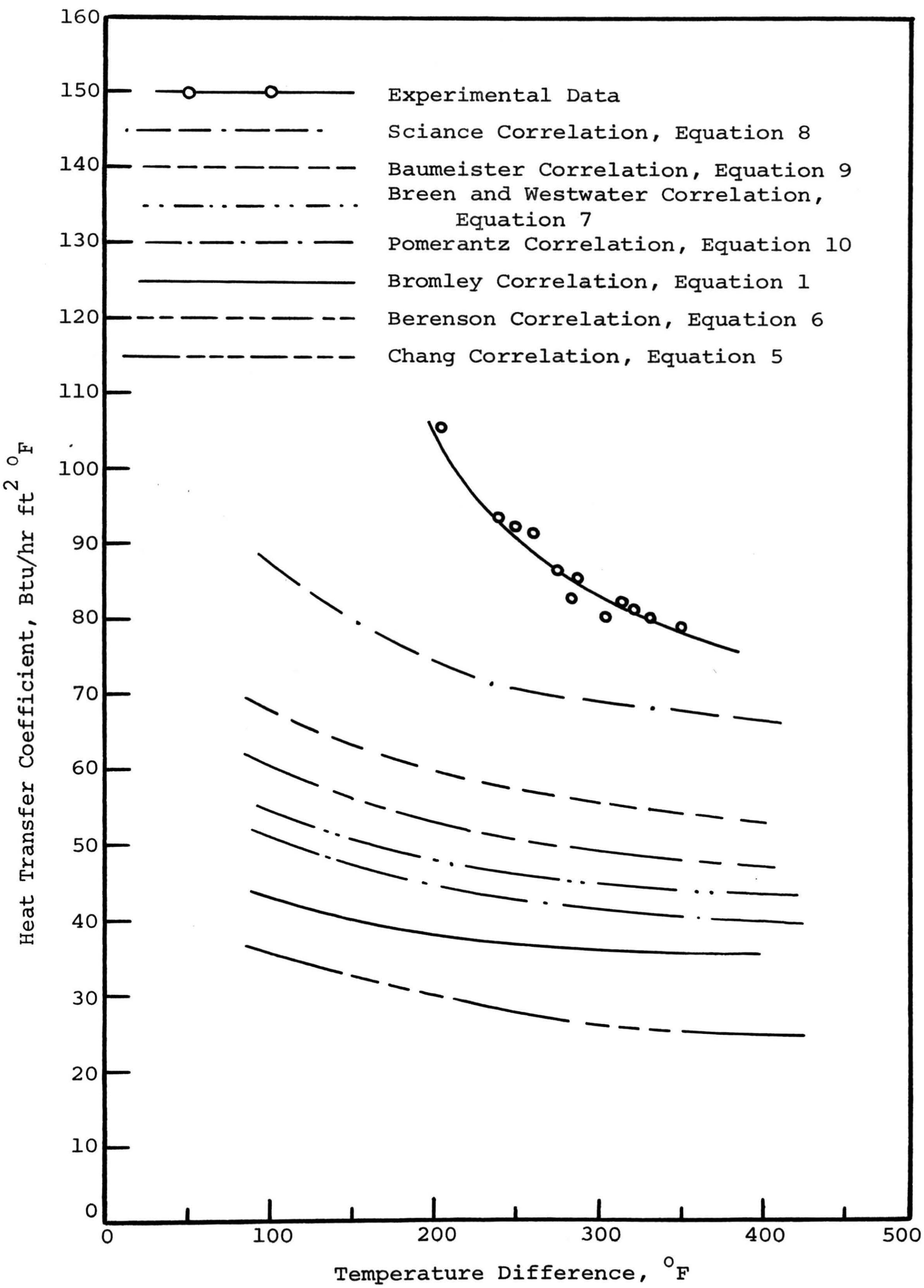


Figure 24. Comparison of Film Boiling Correlations, Benzene, 73.6 psia, 1.00 Inch Surface

Bromley (7). An energy balance within the vapor flow surrounding the heat transfer element was the starting point for the Bromley development. The F factor in the Bromley correlation (equation 1) is included in many of the other correlations presented in Section II on the previous work in film boiling heat transfer. For example, Chang (13) obtains the same fluid property group, F, but raised to the 1/3 power instead of the 1/4 power. The effect of the fluid properties suggested by the F factor can be studied by calculating F without the D and ΔT terms. When considering just the fluid property dependent part of F, comparisons of F with the experimental data at constant ΔT and D were made for n-Pentane at 14.7 psia, 48.5 psia, and 242.5 psia, and for Freon 113 at 39.7 psia and 49.6 psia. The change in the F factor, without the diameter and temperature difference terms, was found to deviate by as much as 20% from the experimental data when the system pressure was increased by a factor of 3 for n-Pentane. At vapor film temperatures below 300 ^{o}F the F factor increased with an increase in the system pressure for n-Pentane. However, at vapor film temperatures above 350 ^{o}F for pressure increases from 14.7 to 48.5 psia and from 48.5 to 242.5 psia, the F factors as a function of the film temperature decreased with the increase in the system pressure. The decrease in F with an increase in the system pressure is the wrong trend since the heat flux increases with an increase in the system pressure. Also, F deviated by a factor of 2 from the experimental data when the system fluid was changed from Freon 113 to n-Pentane. It is apparent that the grouping of physical properties as defined by F does not respond correctly to changes in the system pressure or fluid properties.

Other comparisons were made with experimental data from other investigations. The heat transfer coefficient of this investigation for n-Pentane at 14.7 psia and a diameter of 0.55 inches is approximately 50 Btu/hr ft^2 $^\circ$F. Breen and Westwater (6) present heat transfer coefficients of Bromley from 30 to 50 Btu/hr ft^2 $^\circ$F for n-Pentane at 14.7 psia, a diameter of 0.468 inches, and temperature differences of 600 to 1500 $^\circ$F. Other data presented by Breen and Westwater (6) show values which are 30% lower than the values of h for this investigation when boiling Freon 113 from 0.55 to 1.00 inch diameter surfaces. However, the energy balances for the steam-heated, heat transfer surfaces show deviations of 52% for the Freon 113 data of Breen and Westwater.

C. Presentation of a New Correlation

As shown in Section B, there is a need for an equation that will predict the effects of pressure and fluid behavior in film boiling heat transfer. Because a better theory for film boiling than those already presented is not available at this time, an empirical equation was developed from the experimental data of this investigation and is given below:

$$Q = 0.137\, T_c^{0.54} (\lambda P)^{0.37} (\Delta T \log_{10} T_f)^{0.73}\, d^{-0.26} \tag{14}$$

The constants in equation 14 were determined by least squares approximation of the experimental data covering the entire ranges of temperatures, pressures, fluids, and diameters on 67 data points.

Equation 14 is plotted along with a portion of the data from this investigation in Figures 25 through 33. Equation 14 predicts the experimental data to within 10% for n-Pentane at pressures from 14.7 psia to 48.5 psia. Above a reduced pressure of 0.10, the predicted values fall short of the experimental values to a maximum of approximately 20% at $P_r = 0.50$.

Figures 28 through 30 show that equation 14 predicts heat flux values for Freon 113 to within 10% at reduced pressures from 0.04 to 0.10. The largest deviations of 10% occur at the smallest diameter of 0.55 inches. Figure 31 shows that equation 14 predicts values of heat flux for Benzene within 10%. The largest deviations of up to 20% occur for Cyclopentane at reduced pressures of 0.04 and 0.08 (See Figure 32). In general, the prediction of film boiling heat transfer by equation 14 for the boiling of Benzene, n-Pentane, Freon 113, and Cyclopentane for diameters of 0.55, 0.75, and 1.00 inch at moderate pressures is within $\pm$ 10% with the sole exception of 20% for Cyclopentane at 1.00 inch diameter surface for temperature differences between 200 and 400 ^{o}F.

Beyond the data of this investigation, equation 14 predicts h values which are low by a factor of 1.4 when compared to the experimental data of Flanigan (15), Wafer (27), and Capone (9) for

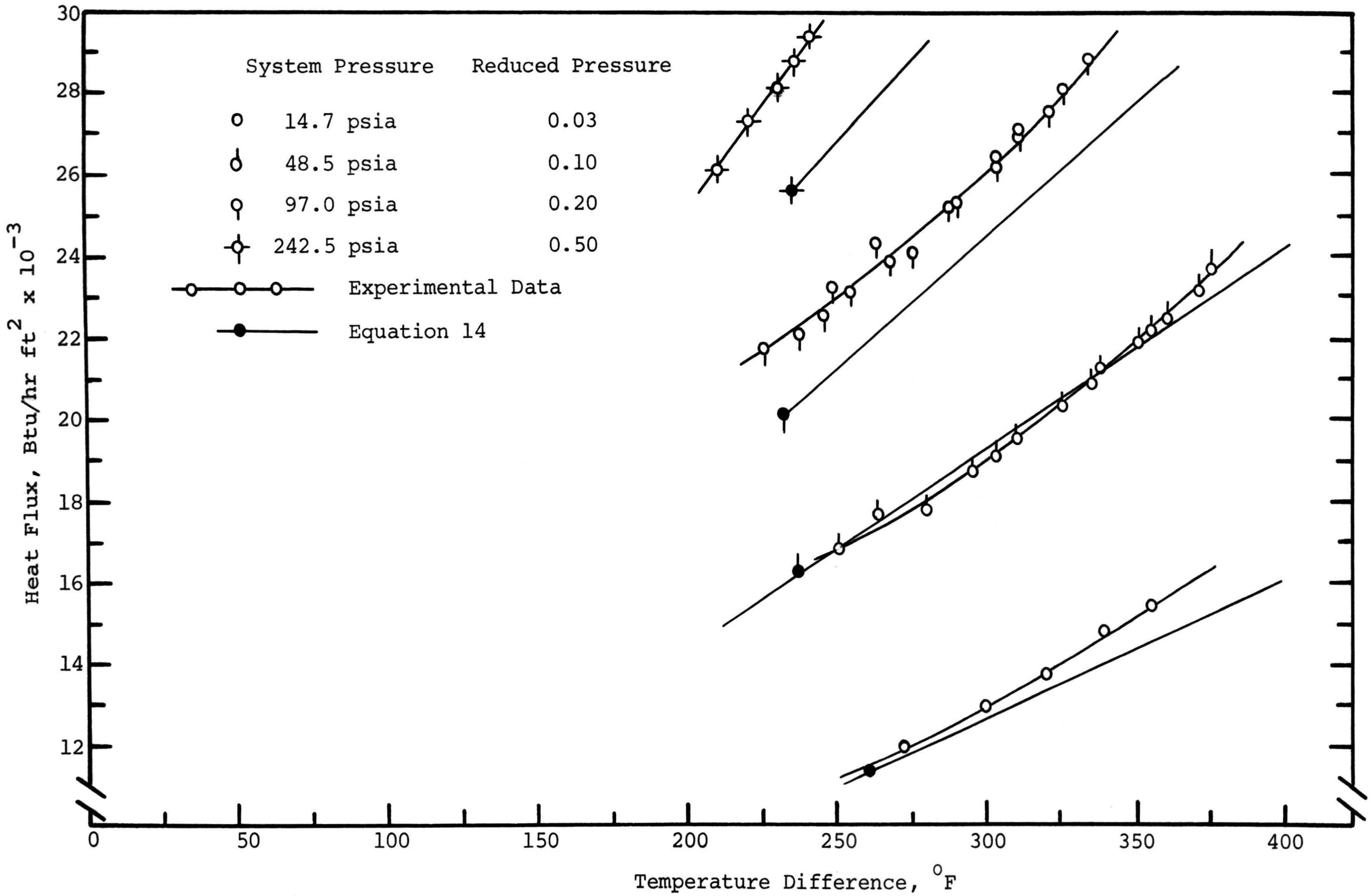


Figure 25. Film Boiling Comparison with Equation 14, n-Pentane, 1.00 Inch Surface

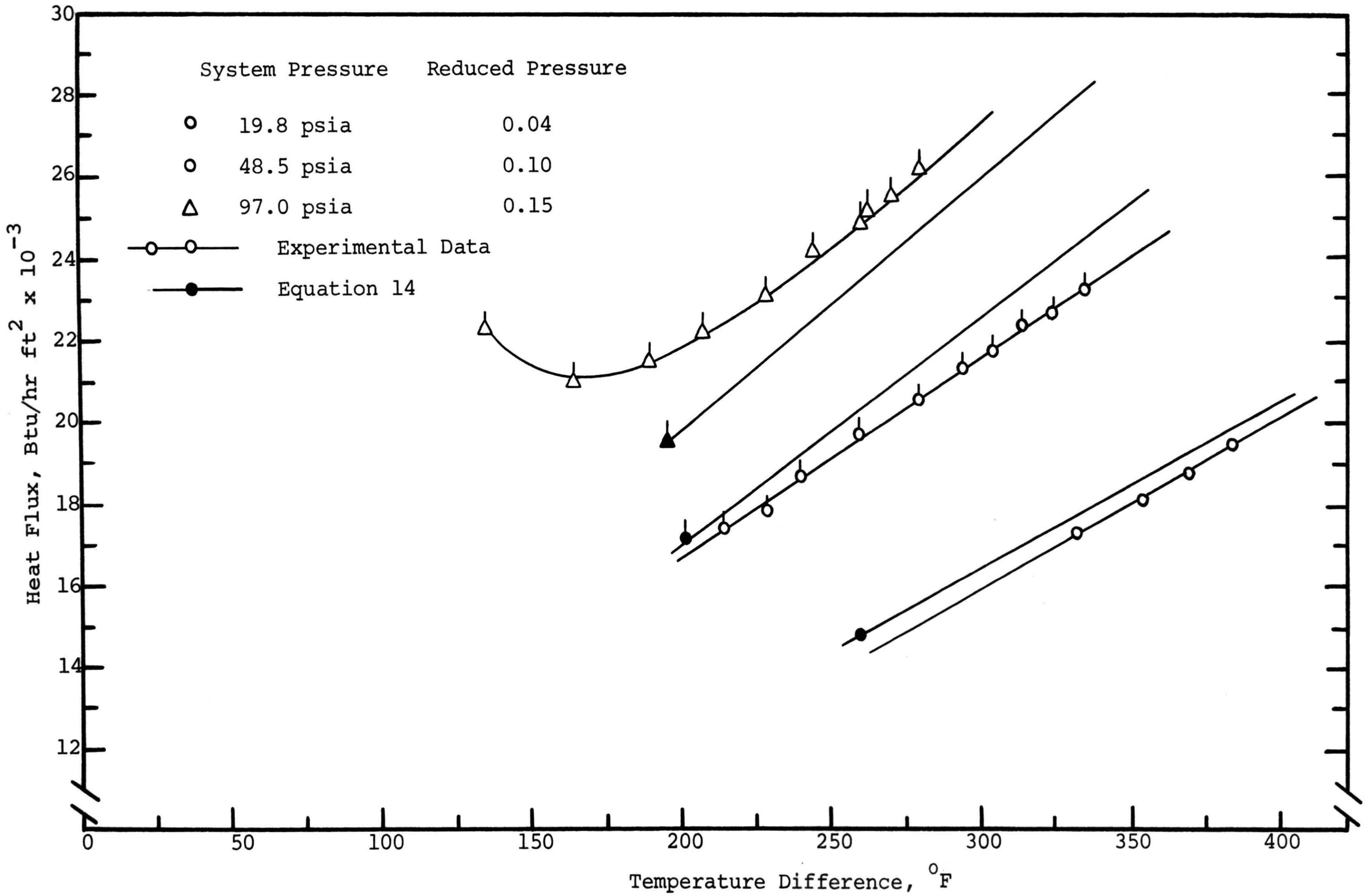


Figure 26. Film Boiling Comparison with Equation 14, n-Pentane, 0.55 Inch Surface

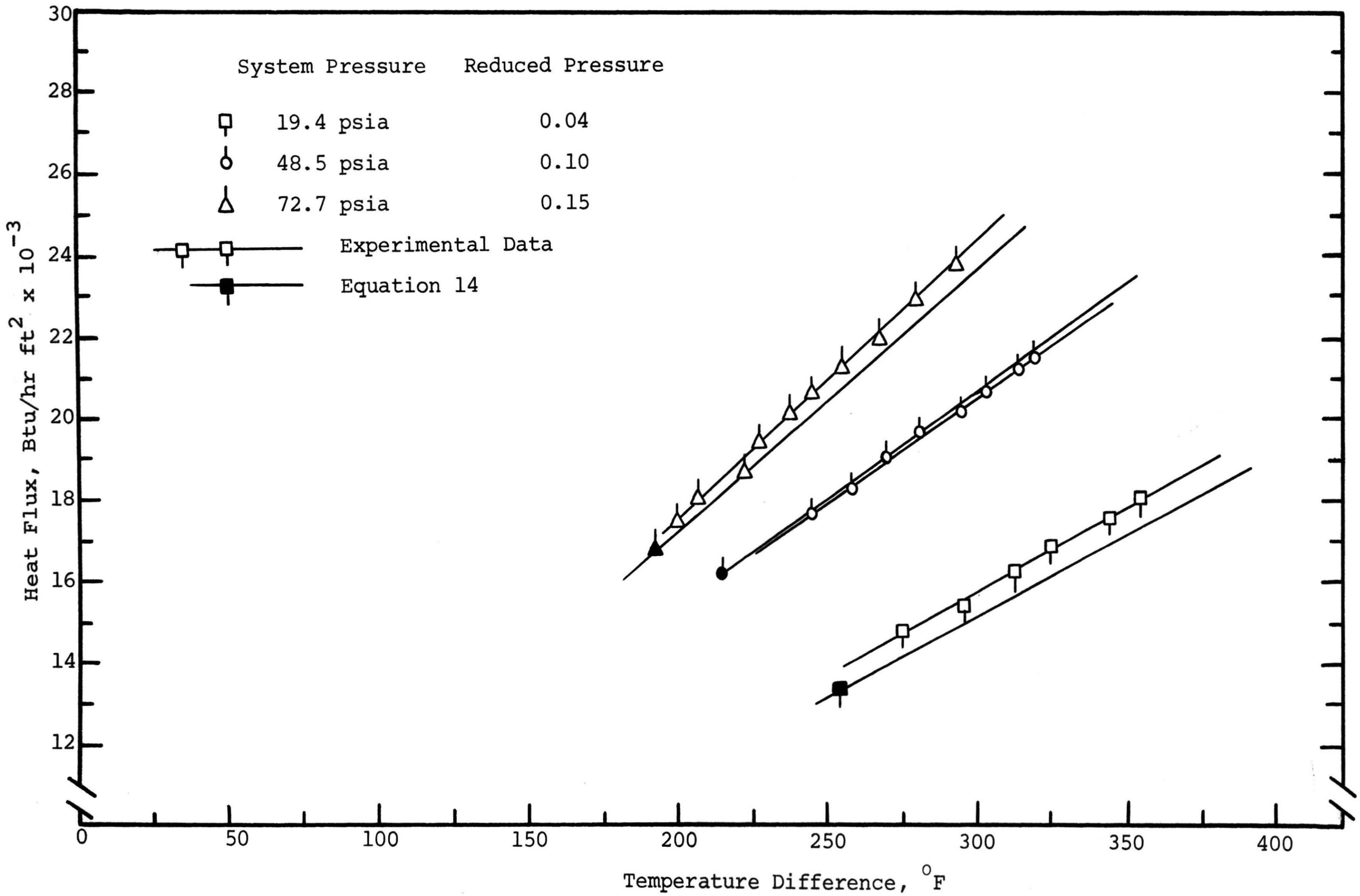


Figure 27. Film Boiling Comparison with Equation 14, n-Pentane, 0.75 Inch Surface

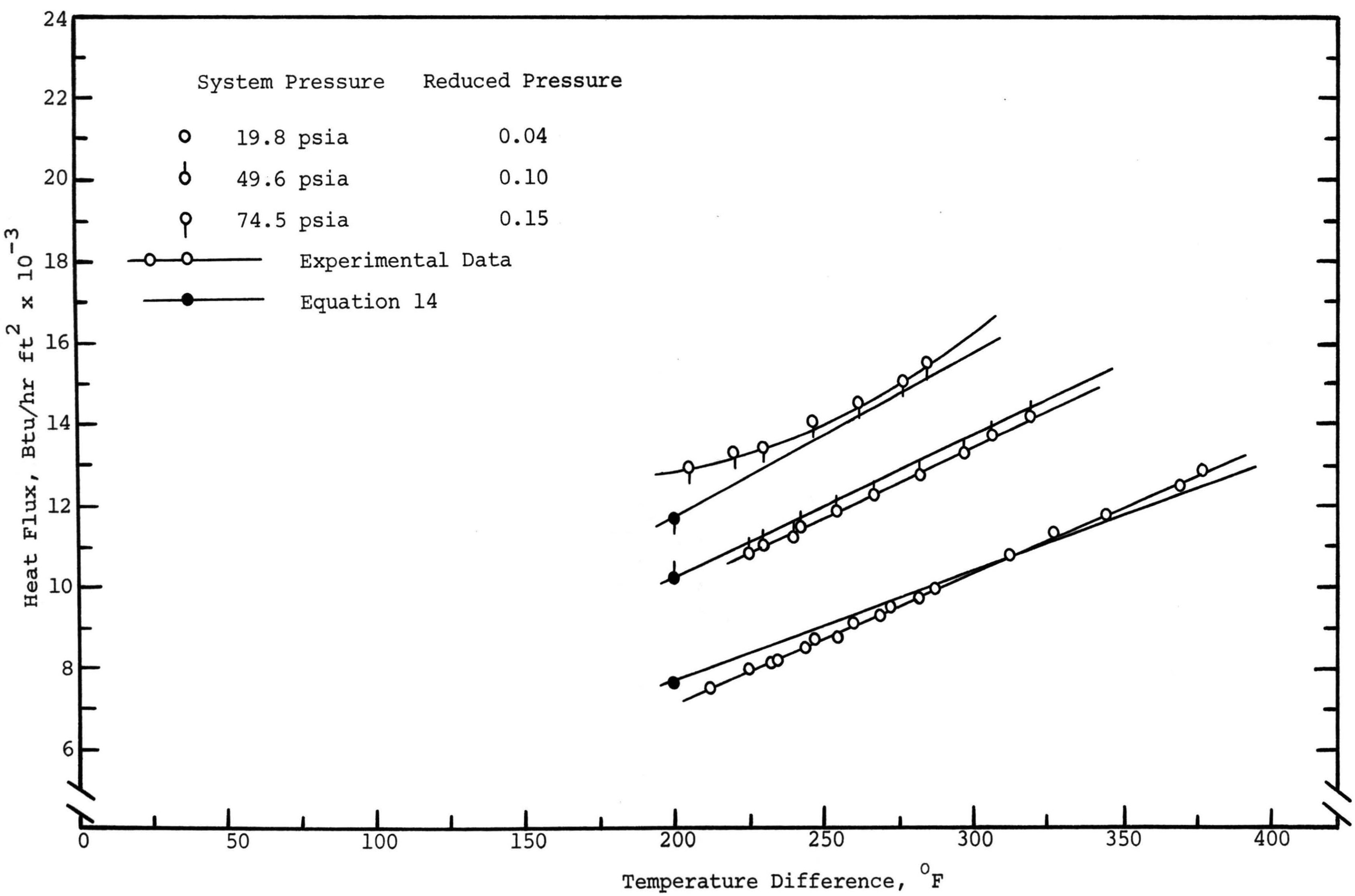


Figure 28. Film Boiling Comparison with Equation 14, Freon 113, 1.00 Inch Surface

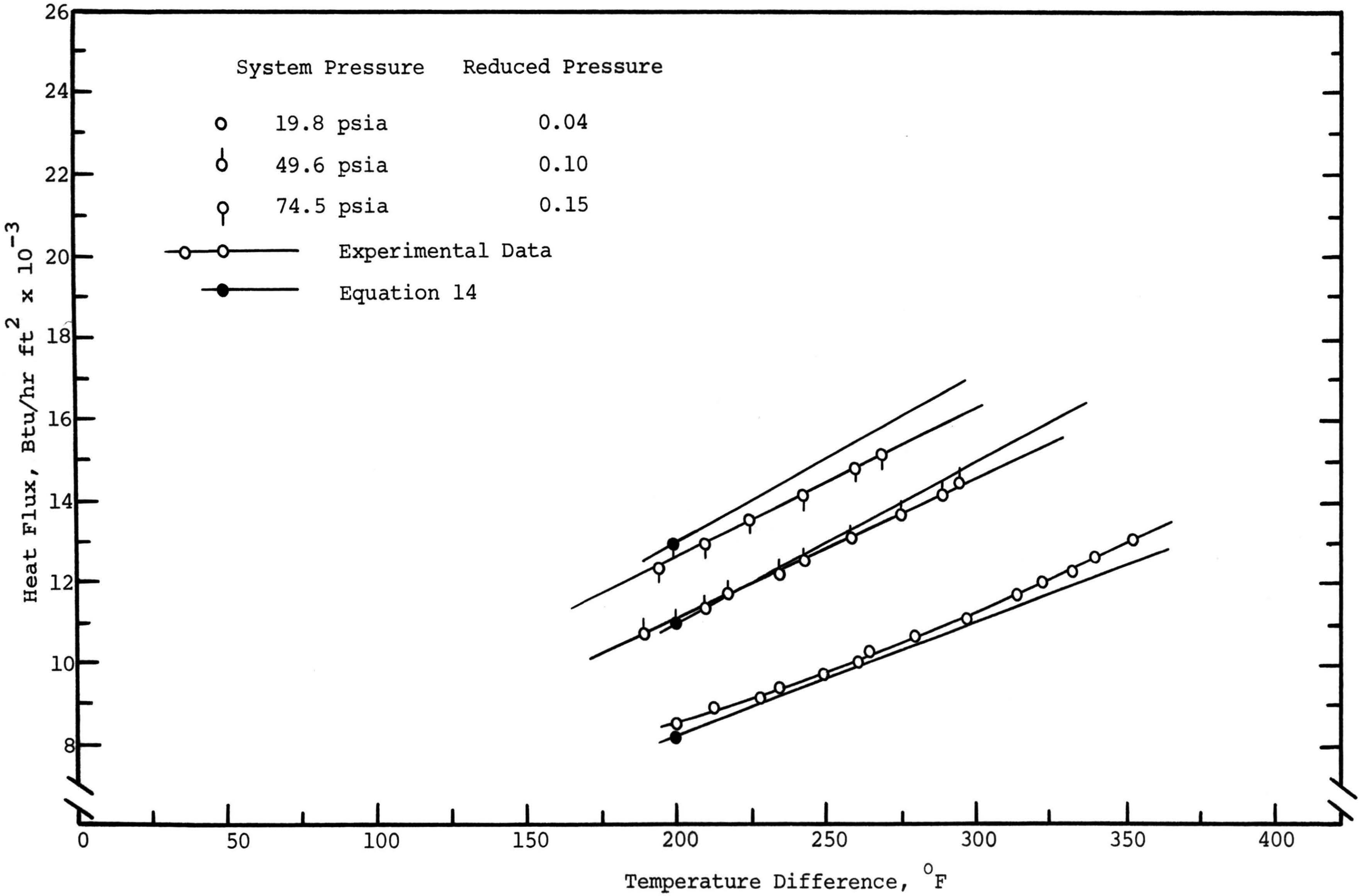


Figure 29. Film Boiling Comparison with Equation 14, Freon 113, 0.75 Inch Surface

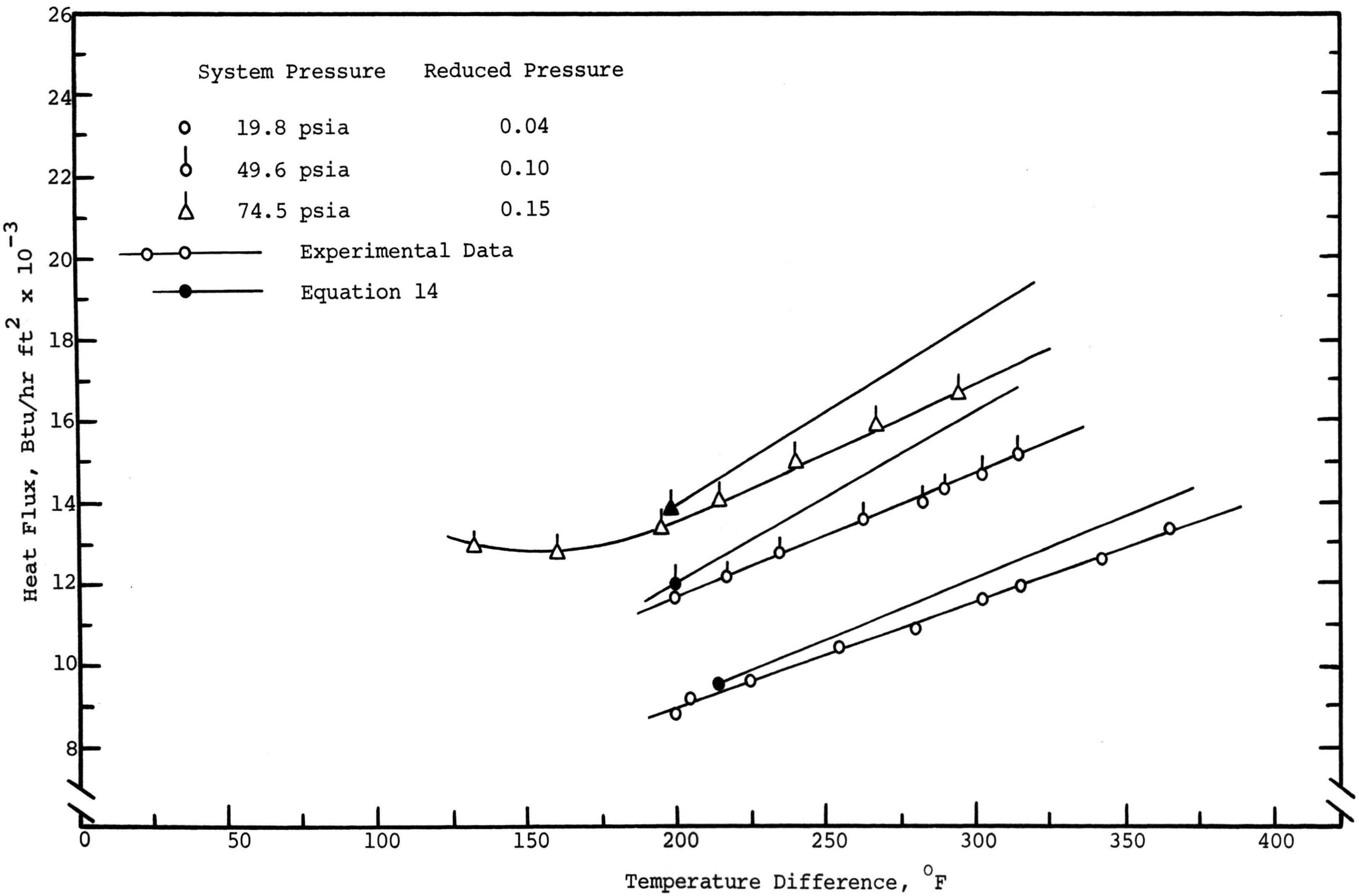


Figure 30. Film Boiling Comparison with Equation 14, Freon 113, 0.55 Inch Surface

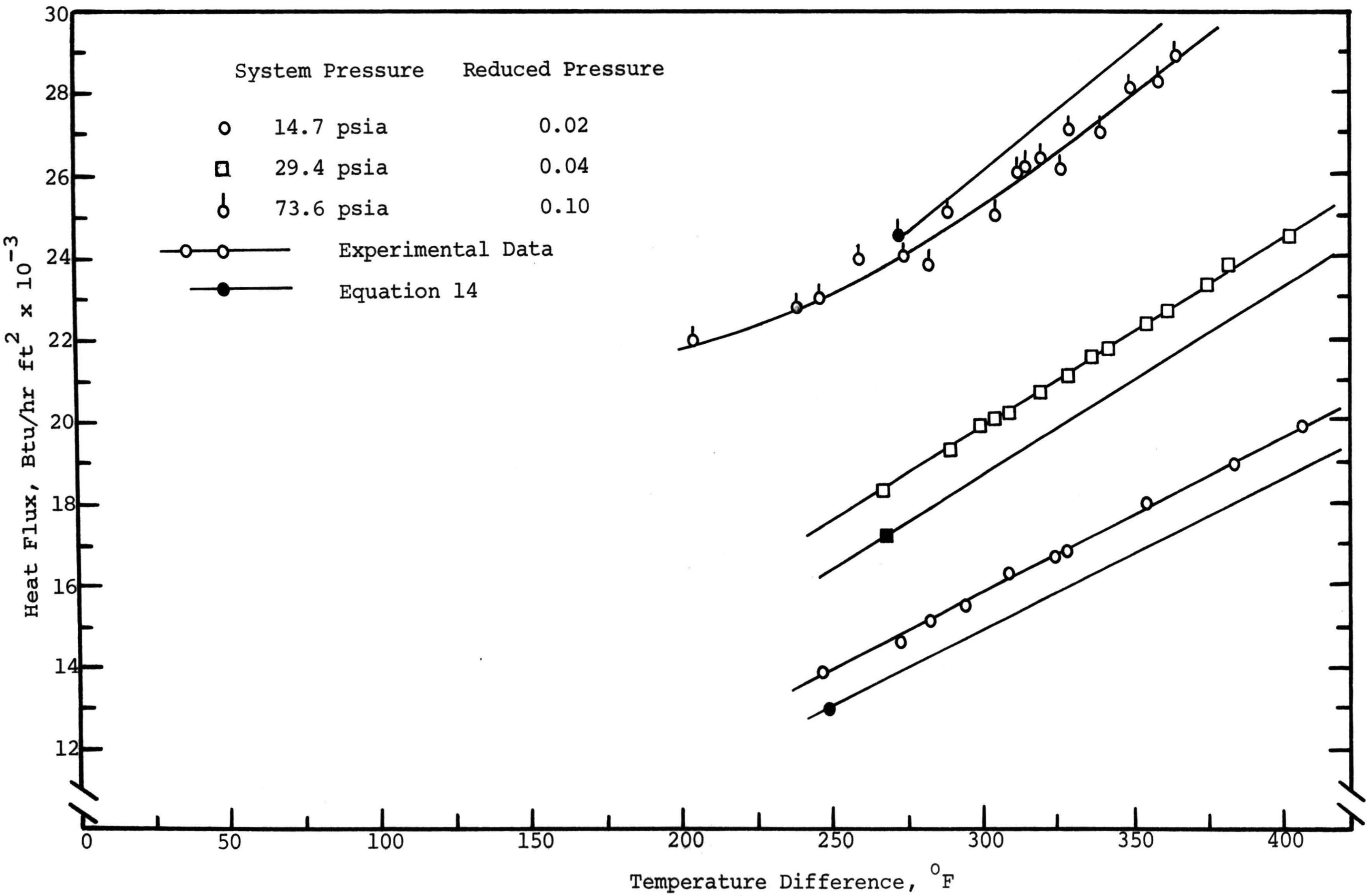


Figure 31. Film Boiling Comparison with Equation 14, Benzene, 1.00 Inch Surface

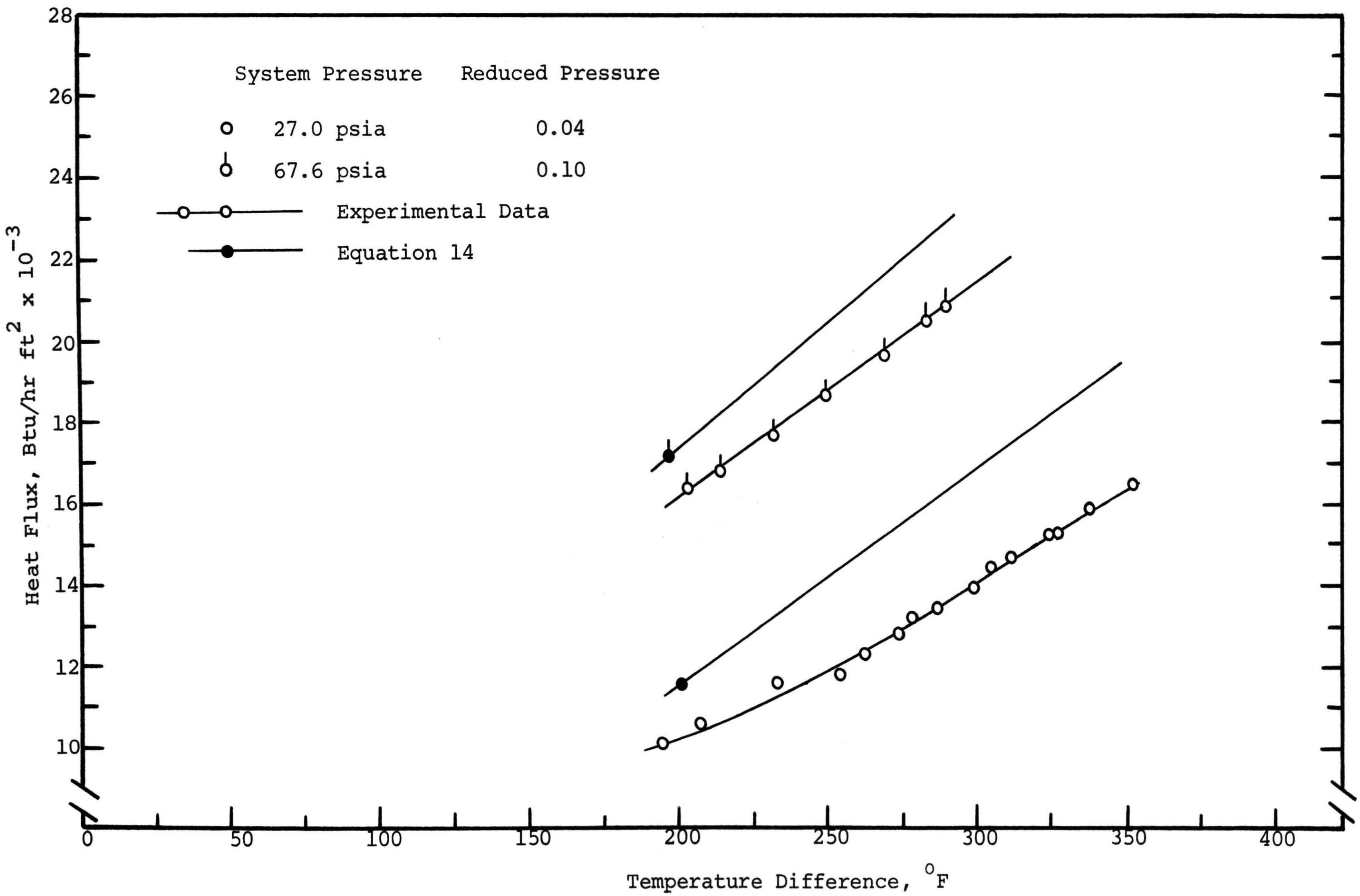


Figure 32. Film Boiling Comparison with Equation 14, Cyclopentane, 1.00 Inch Surface

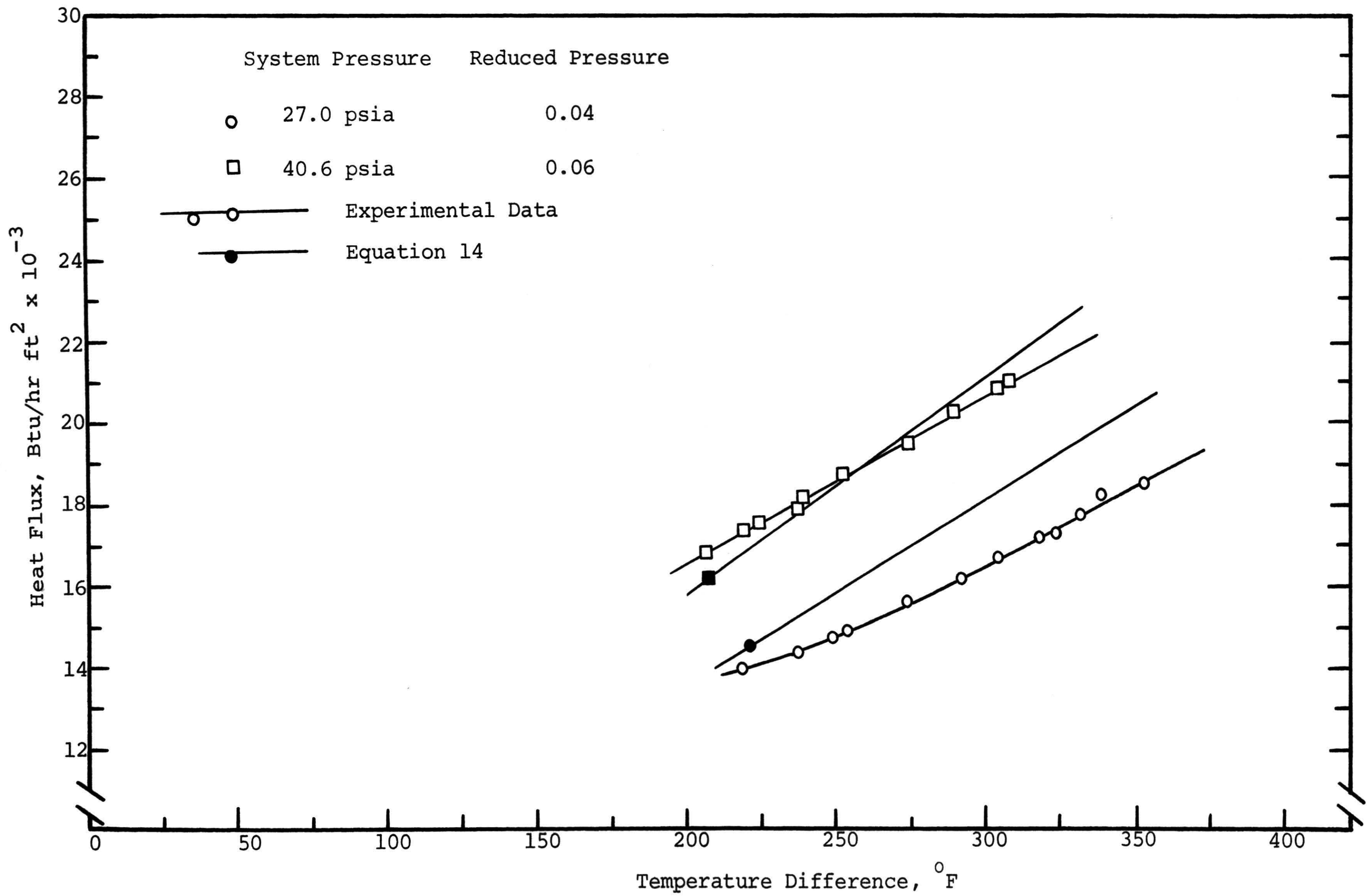


Figure 33. Film Boiling Comparison with Equation 14, Cyclopentane, 0.75 Inch Surface

the film boiling of liquid nitrogen. However, equation 14 predicts h values to within 10% for the film boiling data of Bromley (6) at 14.7 psia and a surface diameter of 0.350 inches. Equation 14 was found to predict values of Sciance (26) to within 20% for the film boiling of liquid methane from a 0.811 inch diameter surface at 14.7 psia and 114 psia.

VI. CONCLUSIONS

1. In general, the film boiling heat flux as a function of temperature difference, $T_{sur}-T_{sat}$, increases as the temperature difference and system pressure increase at the moderate temperature differences and pressures of this investigation.

2. The heat flow, as a function of vapor film temperature, decreases between a reduced pressure of 0.40 and 0.50 for n-Pentane boiling from a 1.00 inch diameter surface.

3. Comparison among organic liquids, having critical compressibility factors of 0.27, at the same reduced pressure and reduced temperature difference, shows that the heat flux increases by a factor of 2 from Freon 113 to Benzene.

4. The heat transfer per foot of heater surface is a non-linear function of surface diameter.

5. The heat flux required to maintain stable film boiling increases as the latent heat of vaporization for the boiling fluid increases as found for Freon 113, n-Pentane, Cyclopentane, and Benzene, respectively.

6. Previous correlations do not adequately (± 20%) predict the film boiling behavior of Freon 113, n-Pentane, Cyclopentane, and Benzene at moderate temperature differences and pressures, and at surface diameters of 0.55, 0.75, and 1.00 inches. The difference between the correlations and experimental data are 3% to 40% for the Sciance correlation (equation 8) and up to a factor of 3 for the Chang correlation (equation 5).

7. Equation 14:

$$Q = 0.137\ T_c^{0.54} (\lambda P)^{0.37} (\Delta T \log_{10} T_f)^{0.73}\ d^{-0.26}$$

predicts a) film boiling heat transfer for Freon 113 and n-Pentane from 0.55, 0.75, and 1.00 inch diameter, cylindrical surfaces at moderate pressures and temperature differences to within 10%, b) the film boiling heat transfer for Cyclopentane to within 20% for surface diameters of 0.75 and 1.00 inch at moderate pressures, and c) the film boiling behavior of Benzene from a 1.00 inch surface at moderate temperature differences and pressures to within 10%.

NOMENCLATURE

A	Area, ft^2
C	Constant in equation 3, $inches^{-1}$
c_p	Heat Capacity, $Btu/lb_m\ {}^oF$
D	Diameter, ft
d	Diameter, inches
F	$(k_v^3\ \rho_v(\rho_l - \rho_v)g\lambda'/\Delta T\ \mu_v)^{1/4}$, $Btu/hr\ ft^2\ {}^oF$
g	Acceleration due to gravity, ft/sec^2
g_c	Gravitational constant, $lb_m\ ft/lb_f\ sec^2$
H	Enthalpy, Btu/lb_m
h	Heat transfer Coefficient, $Btu/hr\ ft^2\ {}^oF$
k	Thermal conductivity, $Btu/hr\ ft^2\ {}^oF/ft$
m	Mass flow rate, lb_m/hr
P	Pressure, psi
P_r	Reduced pressure, P/P_c
T	Temperature, ${}^oR$
ΔT	Temperature difference, $T_{sur} - T_{sat}$, ${}^oF$ or ${}^oR$
Q	Heat flux, $Btu/hr\ ft^2\ {}^oF$
σ	Surface tension, lb_m/ft
λ_c	$2\pi[\sigma\ g_c/g(\rho_l - \rho_v)]^{1/2}$, ft
μ	Viscosity, $lb_m/ft\ hr$
ρ	Density, lb_m/ft^3
γ	Kinematic viscosity, ft^2/hr
λ	Latent heat of vaporization, Btu/lb_m
λ'	Latent heat of vaporization plus average sensible heat content of vapor, Btu/lb_m

SUBSCRIPTS

c	refers to the critical point
i	refers to flow into system
l	refers to the liquid
o	refers to flow out of system
r	refers to reduced property, (T/T_c, etc.)
sat	refers to saturation conditions
sen	refers to sensible heat
sur	refers to heat transfer surface
sys	refers to the system

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VITA

Gary Joseph Capone, son of Mr. and Mrs. Marion J. Capone, was born at St. Elizabeth Hospital in Belleville, Illinois on August 20, 1945.

He attended Belleville Township High School and graduated in June, 1963. He was admitted to the University of Missouri-Rolla (UMR) in September of 1963 and received his Bachelor of Science degree in Chemical Engineering in May of 1967 and his Master of Science degree in Chemical Engineering in June of 1969.

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Since September of 1972, he has been employed by the University of Missouri-Rolla in the Chemical Engineering Department as a graduate assistant.

APPENDIX A

CALCULATED FILM BOILING DATA

A copy of the original data is in the possession of Dr. E. L. Park, Jr., Chemical Engineering Department, University of Missouri-Rolla.

TABLE I

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch Diameter Surface at 19.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
13159	496.10	492.14	498.27	495.50	128.92	366.58	35.9
12400	468.01	464.26	469.91	467.39	129.33	338.06	36.7
11825	445.88	442.07	448.01	445.32	129.33	315.98	37.4
11501	432.78	431.74	435.31	433.27	129.33	303.94	37.8
10798	410.87	409.44	412.91	411.07	129.33	281.74	38.3
10242	383.42	381.81	385.56	383.59	129.33	254.26	40.3
9568	353.38	351.79	355.18	353.45	128.92	224.53	42.6
9065	334.61	333.21	336.52	334.78	128.92	205.86	44.0

TABLE II

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch Diameter Surface at 29.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^{o}F}$
12068	445.88	443.91	448.39	446.06	157.25	288.81	41.8
12726	466.72	465.04	469.01	466.92	157.25	309.67	41.1
13365	486.49	485.65	488.62	486.92	156.44	330.48	40.4
13873	506.39	505.01	509.27	506.89	156.84	350.05	39.6
12984	471.84	470.17	473.97	471.99	156.44	315.55	41.1
12032	436.52	434.64	438.47	436.54	156.44	280.10	43.0
11233	407.77	405.42	409.64	407.61	156.04	251.57	44.7
10580	385.14	382.97	387.32	385.14	156.04	229.10	46.2
9807	355.97	354.18	358.00	356.05	156.04	200.01	49.0

TABLE III

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch Diameter Surface at 39.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
12899	457.17	454.65	459.23	457.02	176.12	280.89	45.9
13474	477.04	475.85	479.23	477.37	176.12	301.25	44.7
14092	498.27	497.68	500.43	498.79	176.12	322.67	43.7
13244	463.62	461.77	466.01	463.80	175.72	288.08	46.0
12523	443.20	441.13	445.23	443.19	175.72	267.47	46.8
11949	416.84	413.91	418.71	416.48	175.72	240.76	49.6
11245	396.04	393.34	397.87	395.75	175.72	220.03	51.1
10783	376.59	374.87	378.32	376.59	175.72	200.87	53.7

TABLE IV

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch

Diameter Surface at 49.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
13870	474.88	472.84	477.26	474.99	191.52	283.47	48.9
14571	494.65	492.85	496.94	494.81	191.12	303.69	48.0
15035	506.56	505.43	509.43	507.14	191.12	316.01	47.6
14163	481.59	479.20	483.68	481.49	191.12	290.37	48.8
13463	454.23	451.81	456.54	454.19	191.12	263.07	51.2
12625	426.21	423.81	428.64	426.22	191.12	235.09	53.7
12068	408.24	405.97	410.21	408.14	191.12	217.02	55.6
11487	390.94	389.07	393.04	391.02	190.72	200.29	57.4

TABLE V

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch Diameter Surface at 59.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
14404	474.30	471.57	476.68	474.18	204.39	269.80	53.4
15287	498.68	496.20	500.85	498.58	204.39	294.19	52.0
13765	447.34	444.94	449.87	447.38	202.85	244.54	56.3
13093	424.74	422.61	427.27	424.87	204.39	220.49	59.4
12406	405.94	403.81	407.57	405.77	204.39	201.38	61.6

TABLE VI

Calculated Film Boiling Data for Freon 113 on a 0.55 Inch Diameter Surface at 74.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperature 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
16556	519.20	510.56	519.65	516.47	221.70	294.77	56.2
15708	491.68	482.20	491.85	488.58	221.70	266.88	58.9
14864	466.01	456.21	465.31	462.51	221.70	240.81	61.7
13988	439.97	430.97	438.87	436.61	221.70	214.91	65.1
13320	419.84	410.54	418.47	416.28	221.70	194.59	68.5
12610	386.61	377.01	385.42	383.01	221.70	161.31	78.2
12957	355.94	350.40	357.07	354.47	221.70	132.77	97.6

TABLE VII

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 19.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
11907	456.94	455.07	454.43	455.48	132.67	322.81	36.9
12518	474.36	472.59	471.71	472.88	132.25	340.63	36.7
12899	487.39	485.59	484.88	485.95	132.67	353.28	36.5
12156	465.84	464.68	463.75	464.76	132.25	332.51	36.6
11607	447.37	446.21	445.46	446.35	132.25	314.09	37.0
11041	430.17	429.37	428.57	429.37	132.25	297.12	37.2
10635	413.87	413.54	412.91	413.44	132.67	280.77	37.9
10225	399.67	399.51	398.80	399.33	132.67	266.66	38.3
9745	380.25	382.18	381.61	381.34	132.67	248.68	39.2
9405	366.28	367.21	366.80	366.76	132.25	234.51	40.1
9960	393.37	393.71	393.17	393.42	132.25	261.17	38.1
9117	360.18	360.52	360.18	360.29	132.25	228.04	40.0
8877	344.21	344.87	344.42	344.50	132.25	212.25	41.8
8499	332.25	332.68	332.36	332.43	132.25	200.18	42.5

TABLE VIII

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 29.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
10615	404.74	403.37	402.94	403.68	157.25	246.43	43.1
10130	381.71	380.90	380.35	380.99	157.25	223.73	45.3
9684	363.21	363.07	362.56	362.95	157.25	205.70	47.1
10357	389.66	388.97	388.74	389.12	157.25	231.87	44.7
10889	411.04	410.17	409.57	410.26	157.25	253.01	43.0
11548	433.37	431.57	431.31	432.08	157.67	274.42	42.1
12171	450.84	449.14	448.52	449.50	157.25	292.25	41.6
12706	469.01	467.14	466.49	467.55	157.25	310.29	40.9
13249	484.30	481.94	481.30	482.51	157.25	325.26	40.7
13452	493.14	490.56	489.75	491.15	157.25	333.89	40.3

TABLE IX

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 39.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
12601	451.01	448.88	448.30	449.39	176.52	272.87	46.2
12984	464.81	462.49	462.07	463.12	176.52	286.60	45.3
13371	476.65	473.75	473.01	474.47	176.52	297.95	44.9
13638	484.43	481.68	481.10	482.40	176.52	305.88	44.6
13996	491.49	488.94	488.43	489.62	176.52	313.10	44.7
13282	470.49	468.62	468.14	469.08	176.52	292.56	45.4
12860	456.54	455.46	455.01	455.67	176.52	279.15	46.1
12347	439.30	438.87	438.01	438.72	176.52	262.20	47.1
11599	415.14	414.27	413.97	414.46	176.52	237.94	48.7
11106	404.34	403.37	402.77	403.49	176.92	226.57	49.0
10477	381.04	380.94	380.45	380.81	176.92	203.89	51.4
10090	368.01	367.52	367.11	367.55	176.92	190.62	52.9

TABLE X

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 49.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
12075	429.64	427.71	427.34	428.23	191.92	236.31	51.1
11616	411.94	410.21	409.57	410.57	191.92	218.65	53.1
10962	393.34	392.04	391.70	392.36	191.92	200.44	54.7
10628	381.94	380.42	380.01	380.79	191.92	188.87	56.3
11266	402.47	401.18	400.67	401.44	191.92	209.52	53.8
11849	414.31	413.07	412.61	413.33	191.92	221.41	53.5
12426	436.84	435.21	434.57	435.54	191.92	243.62	51.0
12922	451.94	449.61	448.94	450.16	191.92	258.24	50.0
13504	470.55	468.14	467.84	468.84	191.92	276.92	48.8
14049	485.78	482.97	482.59	483.78	191.92	291.86	48.1
14330	489.81	486.62	486.10	487.51	191.92	295.59	48.5

TABLE XI

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 59.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
13601	463.30	460.23	459.84	461.12	204.39	256.74	53.0
13987	473.17	469.59	468.78	470.51	204.00	266.51	52.5
14459	486.68	483.23	482.46	484.12	204.00	280.12	51.6
14780	493.78	490.59	490.17	491.51	204.00	287.51	51.4
13833	467.97	465.14	464.68	465.93	204.39	261.54	52.9
13260	450.97	449.04	448.52	449.51	204.39	245.12	54.1
12730	434.71	432.75	432.39	433.28	204.00	229.28	55.5
12171	418.07	416.41	415.74	416.74	204.00	212.74	57.2
11663	403.04	400.81	400.34	401.39	203.62	197.78	59.0
11379	395.37	393.14	393.07	393.86	203.62	190.24	59.8

TABLE XII

Calculated Film Boiling Data for Freon 113 on a 0.75 Inch Diameter Surface at 74.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
14726	484.07	482.52	481.20	482.60	220.93	261.67	56.3
15013	490.85	488.94	487.17	488.99	220.93	268.06	56.0
14055	464.52	462.91	462.17	463.20	220.54	242.66	57.9
13426	449.04	447.07	446.71	447.61	221.70	225.91	59.4
12838	433.54	431.51	430.84	431.96	221.70	210.27	61.1
12205	417.47	415.41	414.87	415.92	220.93	194.99	62.6
11101	381.54	379.87	380.01	380.47	220.54	159.93	69.4

TABLE XIII

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch

Diameter Surface at 19.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures 1	2	3	Temperatures, ^{o}F Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^{o}F}$
9639	411.91	416.97	415.07	414.65	132.25	282.40	34.1
9230	400.51	405.28	403.54	403.11	132.25	270.86	34.1
8799	386.71	391.07	389.52	389.10	132.67	256.43	34.3
8448	374.83	378.90	377.45	377.06	132.67	244.39	34.6
8220	366.56	370.30	369.04	368.63	132.67	235.97	34.8
7938	355.73	359.25	358.00	357.66	132.67	224.99	35.3
7594	343.63	346.73	345.63	345.33	132.67	212.66	35.7
8179	363.94	367.80	366.42	366.05	132.67	233.38	35.0
8658	378.21	382.42	380.94	380.52	132.67	247.85	34.9
9008	389.25	393.87	392.14	391.75	132.67	259.09	34.8
9449	403.24	408.21	406.41	405.95	132.67	273.28	34.6
9933	417.57	423.04	420.94	420.52	132.67	287.85	34.5
10339	429.64	435.47	433.07	432.73	132.67	300.06	34.5
10762	442.37	448.43	446.01	445.60	132.67	312.93	34.4
11246	456.61	463.07	460.39	460.02	132.67	327.36	34.4
11759	474.14	481.20	478.52	477.95	132.67	345.28	34.1
12423	500.52	507.59	504.29	504.13	132.67	371.47	33.4
12801	507.17	514.38	511.10	510.88	132.67	378.22	33.8

TABLE XIV

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch Diameter Surface at 19.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
				(Replicate Test)			
9504	399.77	401.52	404.54	401.94	130.58	271.36	35.0
8778	378.42	380.14	382.90	380.49	132.25	248.24	35.4
8439	367.69	369.01	371.73	369.48	132.25	237.23	35.6
7992	353.14	354.14	357.11	354.80	132.67	222.13	36.0
7761	344.04	344.90	347.47	345.47	132.67	212.80	36.5
8204	356.87	357.87	360.63	358.45	133.08	225.37	36.4
8656	370.20	371.66	374.69	372.19	133.08	239.10	36.2
9296	390.14	392.01	395.27	392.47	133.08	259.39	35.8
9858	406.54	408.87	412.17	409.19	133.08	276.11	35.7
10206	415.91	418.41	421.77	418.69	133.08	285.61	35.7
10554	427.11	429.57	433.04	429.91	133.50	296.40	35.6
10883	436.68	439.36	442.97	439.67	133.50	306.17	35.5
11379	451.07	454.36	458.14	454.52	133.08	321.44	35.4
11760	465.57	469.10	473.04	469.24	133.08	336.15	35.0
12110	476.39	479.88	484.07	480.11	133.08	347.03	34.9
12720	493.78	498.20	502.41	498.13	133.08	365.05	34.8

TABLE XV

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch Diameter Surface at 29.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
10837	440.44	445.78	443.43	443.21	156.84	286.37	37.8
11302	451.74	457.62	455.23	454.86	157.25	297.61	38.0
10406	427.54	432.78	430.71	430.34	157.67	272.67	38.2
9933	416.07	421.01	419.01	418.69	157.67	261.03	38.1
9532	403.81	408.34	406.41	406.18	157.67	248.51	38.4
10106	411.91	416.81	415.07	414.59	157.25	257.34	39.3
9690	399.34	404.04	402.41	401.93	156.84	245.09	39.5
9204	384.44	388.44	386.97	386.62	157.25	229.36	40.1
8840	372.66	376.32	375.01	374.66	157.25	217.41	40.7
9418	389.59	393.91	392.45	391.98	157.25	234.73	40.1
9824	402.57	407.41	405.66	405.21	156.84	248.37	39.6
10351	416.24	421.44	419.64	419.11	156.84	262.26	39.5
10747	430.07	435.71	433.54	433.11	156.44	276.66	38.8
11528	452.46	458.84	456.04	455.78	156.84	298.94	38.6
12382	476.68	484.01	480.97	480.55	156.84	323.71	38.2
12887	491.68	498.81	495.69	495.40	156.44	338.96	38.0
10803	425.34	431.11	429.17	428.54	156.84	271.70	39.8

TABLE XVI

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch

Diameter Surface at 19.8 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, $^\circ$F Surface Temperature 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 $^\circ$F
				(Replicate Test)			
9504	399.77	401.52	404.54	401.94	130.58	271.36	35.0
8779	378.42	380.14	382.90	380.49	132.25	248.24	35.4
8440	367.69	369.01	371.73	369.48	132.25	237.23	35.6
7993	353.14	354.14	357.11	354.80	132.67	222.13	36.0
7762	344.04	344.90	347.47	345.47	132.67	212.80	36.5
8204	356.87	357.87	360.63	358.45	133.08	225.37	36.4
8656	370.20	371.66	374.69	372.19	133.08	239.10	36.2
9297	390.14	392.01	395.27	392.47	133.08	259.39	35.8
9859	406.54	408.87	412.17	409.19	133.08	276.11	35.7
10207	415.91	418.41	421.77	418.69	133.08	285.61	35.7
10555	427.11	429.57	433.04	429.91	133.50	296.40	35.6
10884	436.68	439.36	442.97	439.61	133.50	306.17	35.5
11380	451.07	454.36	458.14	454.52	133.08	321.44	35.4
11761	465.57	469.10	473.04	469.24	133.08	336.15	35.0
12110	476.39	479.88	484.07	480.11	133.08	347.03	34.9
12721	493.78	498.20	502.41	498.13	133.08	365.05	34.8

TABLE XVII

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch Diameter Surface at 39.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
10560	441.04	433.74	438.41	437.73	175.72	262.01	40.3
11147	457.14	449.34	454.59	453.69	176.12	277.56	40.2
11871	479.75	471.21	477.10	476.02	176.12	299.90	39.6
12328	490.23	481.49	487.17	486.30	176.12	310.17	39.7
12753	500.39	491.52	497.46	496.46	175.72	320.74	39.8
13208	510.17	501.04	507.04	506.08	175.72	330.36	40.0
11680	463.68	455.81	461.31	460.27	175.72	284.55	41.0
10883	440.81	433.67	438.44	437.64	175.72	261.92	41.6
10300	420.57	414.34	418.77	417.89	175.72	242.17	42.5
9902	405.45	399.77	404.01	403.08	175.72	227.36	43.6

TABLE XVIII

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch Diameter Surface at 49.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
11154	433.71	427.27	432.10	431.03	190.32	240.70	46.3
10816	418.31	412.74	417.07	416.04	191.12	224.92	48.1
10504	406.14	400.94	404.84	403.97	191.12	212.85	49.3
11041	424.07	418.14	422.54	421.58	191.12	230.46	47.9
11428	436.13	429.64	434.41	433.39	191.12	242.27	47.2
11831	448.91	442.04	447.17	446.04	191.12	254.92	46.4
12286	462.81	455.10	460.52	549.48	190.72	268.76	45.7
12765	477.38	469.36	474.94	473.89	190.72	283.17	45.1
13273	491.68	483.07	488.56	487.77	190.72	297.05	44.7
13706	502.41	493.56	499.26	498.41	190.72	307.69	44.5
14170	512.91	503.97	509.78	508.89	190.72	318.17	44.5

TABLE XIX

Calculated Film Boiling Data for Freon 113 on a 1.00 Inch Diameter Surface at 74.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
13424	453.84	447.37	452.20	451.14	220.93	230.21	58.3
13256	445.26	439.36	443.97	442.87	220.93	221.94	59.7
12930	429.74	424.51	428.64	427.63	220.93	206.70	62.6
13621	455.91	449.51	454.33	453.25	220.93	232.32	58.6
14025	471.54	464.65	469.78	468.66	221.31	247.35	56.7
14537	487.49	480.17	485.46	484.37	221.31	263.06	55.3
15067	503.36	495.23	500.75	499.78	221.31	278.47	54.1
15418	510.72	502.69	508.16	507.19	220.93	286.27	53.9

TABLE XX

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 19.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
17065	441.07	440.14	444.37	441.86	110.39	331.47	51.5
17917	465.34	465.21	469.36	466.64	109.96	356.68	50.2
18597	480.10	480.85	483.75	481.57	110.39	371.17	50.1
19257	494.52	495.01	498.20	495.91	110.39	385.52	50.0

TABLE XXI

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 24.2 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
18247	450.97	451.61	454.91	452.50	122.63	329.87	55.3
19062	466.62	466.91	470.36	467.96	122.63	345.34	55.2
19731	487.01	487.97	490.85	488.61	121.79	366.82	53.8
20306	501.78	502.38	505.62	503.26	121.79	381.47	53.2
19418	475.26	475.33	479.26	476.62	121.79	354.83	54.7
18610	458.34	458.87	462.39	459.87	121.79	338.08	55.0
17741	430.54	429.57	433.91	431.34	121.79	309.55	57.3
16980	418.74	419.07	422.64	420.15	121.79	298.36	56.9
16422	403.14	402.61	406.54	404.09	121.79	282.30	58.2
15677	381.17	380.01	384.37	381.85	121.79	260.06	60.3
14823	363.69	362.66	366.80	364.38	121.79	242.59	61.1
16089	394.80	393.81	398.42	395.67	121.79	273.88	58.7

TABLE XXII

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 29.1 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
19862	477.35	476.46	481.36	478.39	133.08	345.31	57.5
20340	486.52	486.39	490.14	487.68	133.08	354.60	57.4
21257	506.72	506.39	511.32	508.14	133.08	375.06	56.7
20779	491.65	492.49	495.73	493.29	133.08	360.20	57.7
19062	455.55	455.07	458.87	456.50	133.08	323.41	58.9
18469	438.87	438.34	442.87	440.03	133.08	306.94	60.2
17826	427.94	427.27	431.57	428.93	133.08	295.84	60.3
17064	407.27	406.57	410.54	408.13	132.67	275.46	61.9
16311	389.07	387.80	392.25	389.71	132.67	257.04	63.5
15677	375.67	374.56	379.17	376.47	133.08	243.38	64.4
15049	361.94	361.14	365.18	362.75	132.67	230.08	65.4
14430	347.47	346.56	350.68	348.24	132.67	215.57	66.9

TABLE XXIII

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 38.8 psia Pressure

Heat Flux $\frac{\text{Btu}}{\text{hr ft}^2}$	Temperatures, ^{o}F: Surface Temperatures 1	Surface Temperatures 2	Surface Temperatures 3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{\text{Btu}}{\text{hr ft}^2\ ^{o}F}$
19893	455.75	455.23	459.64	456.88	151.58	305.29	65.2
20695	472.20	471.37	476.39	473.32	151.58	321.74	64.3
21748	492.85	492.49	497.33	494.22	151.58	342.64	63.5
22103	503.04	502.94	507.20	504.39	151.58	352.81	62.6
21285	483.65	483.10	488.10	484.95	151.58	333.37	63.8
20345	462.52	461.61	466.36	463.50	151.58	311.91	65.2
19531	442.47	442.14	446.74	443.78	151.58	292.20	66.8
18602	424.04	423.74	428.27	425.35	151.58	273.76	67.9
17739	404.04	403.51	408.24	405.26	151.58	253.68	69.9
16745	385.94	385.32	389.38	386.88	151.58	235.29	71.2
15785	367.07	366.14	370.87	368.03	151.58	216.44	72.9

TABLE XXIV

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 48.5 psia Pressure

Heat Flux $\frac{\text{Btu}}{\text{hr ft}^2}$	Temperatures, $^{\circ}F$ Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{\text{Btu}}{\text{hr ft}^2\ ^{\circ}F}$
21452	470.23	469.72	474.30	471.41	166.92	304.49	70.5
22349	490.17	489.81	494.10	491.36	167.32	324.04	69.0
22986	501.30	500.85	505.91	502.68	167.32	335.36	68.5
22111	479.91	479.78	485.36	481.68	167.32	314.36	70.3
21186	461.47	460.94	465.51	462.64	167.32	295.32	71.7
20374	445.78	445.36	450.65	447.26	167.32	279.94	72.8
19541	426.07	425.34	430.41	427.27	167.32	259.95	75.2
18509	407.57	407.07	411.57	408.74	167.32	241.42	76.7
17640	395.31	394.97	399.51	396.59	167.32	229.27	76.9
17213	382.38	381.67	386.14	383.40	167.32	216.08	79.7

TABLE XXV

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 72.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
22928	477.29	477.51	482.65	479.15	195.44	283.71	80.8
23865	491.85	491.85	496.23	493.31	195.84	297.47	80.2
24736	507.85	508.26	513.52	509.88	196.23	313.64	78.9
23323	483.78	483.72	488.36	485.29	195.84	289.44	80.6
22076	459.81	459.33	464.52	461.22	195.04	266.18	82.9
21203	443.36	443.43	448.20	444.99	195.04	249.95	84.8
20309	425.07	425.01	428.74	426.27	195.04	231.23	87.8
19360	407.41	407.71	411.31	408.81	195.04	213.76	90.6
18782	396.14	396.97	400.04	397.72	195.04	202.67	92.7

TABLE XXVI

Calculated Film Boiling Data for Normal Pentane on a 0.55 Inch Diameter Surface at 97.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
24583	476.72	479.52	482.04	479.43	217.87	261.55	94.0
25209	487.01	490.07	492.49	489.86	218.23	271.62	92.8
25819	494.36	497.52	500.33	497.40	217.87	279.53	92.4
24849	476.88	480.23	482.55	479.89	217.87	262.01	94.8
23952	461.44	465.17	466.75	464.45	218.23	246.22	97.3
22831	442.71	447.04	448.52	446.09	217.87	228.22	100.0
21957	422.81	427.41	428.41	426.21	218.23	207.97	105.6
21244	404.81	411.17	410.87	408.95	218.23	190.72	111.4
20818	382.90	382.90	382.90	382.90	218.23	164.67	126.4
21454	361.66	361.66	361.66	361.66	218.23	143.43	149.6
21704	356.49	356.49	356.49	356.49	218.23	138.25	157.0
22040	353.73	353.73	353.73	353.73	218.23	135.50	162.7

TABLE XXVII

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 19.4 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
14665	385.87	385.97	382.38	384.74	109.13	275.62	53.2
15384	407.47	407.87	403.87	406.41	110.39	296.01	52.0
16196	423.57	423.91	419.54	422.34	110.39	311.95	51.9
16778	438.24	438.67	434.51	437.14	110.39	326.75	51.3
17426	457.17	457.33	453.24	455.91	111.67	344.24	50.6
17896	469.59	469.84	464.84	468.09	112.09	356.00	50.3

TABLE XXVIII

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 24.2 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^{0}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^{0}F}$
18021	464.52	464.46	460.10	463.03	123.04	339.98	53.0
17426	451.21	451.41	447.71	450.11	123.88	326.23	53.4
16935	435.37	435.67	432.20	434.41	124.29	310.12	54.6
16459	425.41	425.74	422.24	424.46	123.88	300.59	54.8
15663	405.66	405.90	402.54	404.70	123.88	280.82	55.8
15209	391.90	391.52	388.34	390.59	123.88	266.71	57.0
14459	377.11	377.18	373.18	375.82	123.88	251.95	57.4

TABLE XXIX

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 29.1 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
16760	422.07	422.11	418.11	420.76	133.92	286.84	58.4
17272	434.04	434.34	429.71	432.69	133.92	298.78	57.8
17871	448.94	448.97	443.91	447.27	133.92	313.36	57.0
18586	468.88	469.07	464.33	467.43	134.75	332.67	55.9
19186	479.43	479.10	474.78	477.77	133.92	343.85	55.8
19660	489.75	489.85	485.55	488.38	133.92	354.47	55.5
18811	471.47	471.24	467.14	469.95	133.92	336.03	56.0
18167	453.61	453.27	448.36	451.75	133.92	317.83	57.2
16821	424.57	424.94	420.71	423.41	133.50	289.90	58.0
16184	409.21	409.07	404.84	407.71	133.50	274.20	59.0

TABLE XXX

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 38.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
17554	427.57	427.24	423.07	425.96	151.17	274.79	63.9
16937	414.84	414.91	410.41	413.38	151.17	262.21	64.6
16296	401.52	401.70	397.47	400.23	151.17	249.06	65.4
15743	392.04	391.97	387.63	390.55	151.58	238.96	65.9
16652	408.07	408.04	403.54	406.55	151.58	254.96	65.3
17554	427.51	427.81	423.01	426.11	151.17	274.94	63.8
18219	442.11	441.46	436.84	440.14	149.96	290.18	62.8
18882	453.17	452.88	447.44	451.16	151.17	299.99	62.9
19289	463.84	463.84	458.21	461.97	151.17	310.80	62.1
19964	476.81	476.39	471.04	474.75	150.76	323.99	61.6
20688	491.04	490.56	485.33	488.97	151.17	337.81	61.2

TABLE XXXI

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch

Diameter Surface at 48.5 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^oF
19927	463.07	462.59	458.04	461.23	166.52	294.71	67.6
20452	472.84	472.20	467.21	470.75	166.92	303.83	67.3
21035	482.33	482.01	477.13	480.49	166.92	313.57	67.1
21281	488.68	487.97	482.49	486.38	166.92	319.46	66.6
19558	449.84	449.64	444.57	448.02	166.92	281.10	69.6
18954	440.31	440.17	435.77	438.75	166.92	271.83	69.7
18152	427.17	426.87	422.41	425.48	166.52	258.96	70.1
17471	413.41	412.87	408.64	411.64	166.52	245.12	71.3

TABLE XXXII

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 72.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^{o}F}$
18525	419.84	419.21	413.94	417.66	195.04	222.62	83.2
17901	404.34	403.71	398.07	402.04	195.04	207.00	86.5
19260	424.61	424.07	418.54	422.41	195.04	227.36	84.7
19943	433.47	433.34	427.01	431.27	194.66	236.62	84.3
20406	442.57	442.07	436.01	440.22	194.66	245.56	83.1
21070	454.01	453.47	447.81	451.76	195.04	256.72	82.1
21772	465.17	464.52	458.31	462.67	195.04	267.62	81.4
22680	478.10	477.47	471.14	475.57	195.04	280.53	80.8
23546	489.26	488.78	482.33	486.79	194.66	292.14	80.6

TABLE XXXIII

Calculated Film Boiling Data for Normal Pentane on a 0.75 Inch Diameter Surface at 97.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
22967	481.04	480.55	473.81	478.47	215.96	262.50	87.5
24425	489.26	488.49	482.14	486.63	216.87	269.76	90.5
22153	472.81	472.36	466.10	470.43	217.55	252.87	87.6
21527	460.81	459.84	453.61	458.09	218.23	239.85	89.8
21074	448.81	448.30	441.75	446.29	217.87	228.41	92.3
20900	443.39	443.10	436.84	441.11	218.62	222.49	93.9
20494	434.04	433.61	426.94	431.53	218.62	212.91	96.3
20004	421.74	421.31	414.74	419.26	218.62	200.64	99.7
19026	405.21	404.71	398.32	402.74	218.62	184.13	103.3
17495	369.76	369.52	363.28	367.52	218.62	148.90	117.5

TABLE XXXIV

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 14.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperature 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
12803	398.83	398.49	403.21	400.18	98.83	301.35	42.5
13624	418.91	418.57	419.24	418.91	98.83	320.08	42.6
14636	439.49	438.51	442.11	440.03	99.26	340.77	42.9
15311	454.59	454.26	454.91	454.59	100.13	354.46	43.2
11944	374.73	374.04	375.07	374.61	101.00	273.61	43.7
				(Replicate Test)			
13408	398.83	400.84	398.14	399.27	96.67	302.60	44.3

TABLE XXXV

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 24.2 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
14668	412.57	421.57	421.91	421.68	124.71	296.97	49.4
13733	403.54	403.54	403.87	403.65	124.71	278.94	49.2
13332	388.67	388.34	390.71	389.24	124.71	264.53	50.4
12638	372.32	371.63	372.32	372.09	125.54	246.54	51.3
13532	395.81	395.81	396.14	395.92	125.54	270.37	50.0
14248	409.24	408.91	411.24	309.79	125.54	284.25	50.1
15147	429.57	429.57	429.57	429.57	125.54	304.03	49.8
16059	449.67	449.01	449.67	449.45	125.54	323.91	49.6
16672	462.43	462.10	462.43	462.32	125.54	336.78	49.5
17640	484.43	483.78	484.43	484.21	125.54	358.67	49.2
18495	501.78	500.81	501.78	501.46	125.54	375.92	49.2
19266	516.75	516.43	516.75	516.64	125.54	391.10	49.3
18074	492.17	491.20	491.52	491.63	125.54	366.09	49.4

TABLE XXXVI

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 38.8 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
18421	472.20	471.87	471.87	471.98	151.58	320.40	57.5
19291	487.33	487.01	487.01	487.11	151.58	335.53	57.5
20058	502.41	502.41	502.41	502.41	151.58	350.83	57.2
20977	518.94	518.63	518.94	518.84	151.58	367.26	57.1
19076	484.75	484.43	484.43	484.53	151.58	332.95	57.3
17770	459.49	459.49	459.49	459.49	151.58	307.90	57.7
16549	434.87	434.54	434.87	434.76	151.58	283.18	58.4
15707	418.24	418.24	418.24	418.24	151.58	266.65	58.9
15174	405.56	405.56	405.56	405.56	151.58	253.97	59.7
14557	393.11	393.11	393.11	393.11	151.58	241.52	60.3
13828	377.11	377.11	377.11	377.11	151.58	225.52	61.3
16503	434.87	434.87	434.87	434.87	151.58	283.29	58.3

TABLE XXXVII

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 48.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
17659	446.37	446.37	446.37	446.37	167.32	279.05	63.3
18524	462.10	462.10	462.10	462.10	167.32	294.78	62.8
19393	477.35	477.35	477.35	477.35	167.32	310.03	62.6
20171	492.17	492.17	491.85	492.06	167.32	324.74	6.21
21093	504.63	504.32	504.63	504.53	167.32	337.21	62.6
21957	521.48	521.48	521.48	521.48	167.32	354.15	62.0
22891	538.51	538.51	537.26	538.09	167.32	370.77	61.7
23498	541.35	541.35	541.66	541.46	167.32	374.13	62.8
22353	528.43	528.10	529.07	528.53	167.32	361.21	61.9
21717	518.63	519.27	518.63	518.84	167.32	351.52	61.8
20673	501.78	502.10	501.78	501.89	167.32	334.57	61.8
18824	469.59	471.87	471.21	470.89	167.32	303.57	62.0
				(Replicate Test)			
16793	418.57	416.91	413.57	416.35	167.32	249.03	67.4
17537	431.91	431.91	429.24	431.02	167.32	263.69	66.5

TABLE XXXVIII

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 97.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures 1	2	3	Temperatures, ^{o}F Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^{o}F}$
23857	492.17	492.17	492.17	492.17	216.87	275.30	86.7
25013	507.20	506.88	506.88	506.99	216.87	290.12	86.2
26161	519.59	519.59	519.59	519.59	216.87	302.72	86.4
26721	528.75	528.10	528.75	528.53	216.87	311.67	85.7
27198	538.20	537.57	537.57	537.78	216.87	320.91	84.8
27766	541.35	541.35	541.35	541.35	216.87	324.48	85.6
28432	550.41	550.41	550.41	550.41	216.87	333.55	85.2
26721	528.75	528.75	528.75	528.75	216.87	311.88	85.7
25959	518.94	518.94	518.94	518.94	216.87	302.08	85.9
24958	504.32	504.32	504.32	504.32	216.87	287.45	86.8
23665	484.43	484.43	484.43	484.43	216.87	267.56	88.4
22947	471.87	471.87	471.87	471.87	216.87	255.01	90.0
22338	462.10	462.10	462.10	462.10	216.87	245.24	91.1
21988	454.26	454.26	454.26	454.26	216.87	237.40	92.6
21451	441.78	442.11	442.11	442.00	216.87	225.13	95.3
23109	464.68	464.68	464.68	464.68	216.87	247.82	93.3
24093	479.59	479.59	479.59	479.59	216.87	262.72	91.7
27043	524.01	523.69	524.63	524.11	216.87	307.24	88.0

TABLE XXXVIX

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 145.5 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
28092	524.32	526.54	526.54	525.80	251.49	274.31	102.4
28756	533.48	533.79	534.10	533.79	251.49	282.30	101.9
29388	540.72	540.39	540.72	540.61	251.49	289.12	101.6
29831	543.54	543.54	547.91	545.00	251.49	293.51	101.6
30363	550.10	550.10	553.23	551.14	251.49	299.66	101.3
30835	557.29	557.29	560.10	558.23	251.49	306.74	100.5
31294	562.60	562.60	565.10	563.43	251.49	311.95	100.3
31818	569.13	568.82	571.89	569.95	251.49	318.46	99.9
28208	526.23	526.54	526.85	526.54	251.49	275.05	102.6
27730	518.63	518.94	519.27	518.95	251.49	267.46	103.7
27282	511.35	511.66	514.19	512.40	251.49	260.92	104.6
26607	502.10	502.10	503.68	502.63	251.49	251.14	105.9
25905	491.85	492.17	494.10	492.71	251.49	241.22	107.4
24944	478.94	479.26	479.91	479.37	251.49	227.89	109.5
23968	464.36	465.01	467.31	465.56	251.49	214.07	112.0

TABLE XL

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 194.0 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^{o}F
26591	503.36	504.01	504.32	503.90	279.49	224.41	118.5
27159	509.10	509.43	511.04	509.86	279.49	230.37	117.9
27940	518.63	518.94	519.27	518.95	279.49	239.46	116.7
28619	526.23	526.23	528.75	527.07	279.49	247.58	115.6
29208	534.10	534.10	534.10	534.10	279.49	254.62	114.7
30009	541.04	541.35	541.35	541.25	279.49	261.76	114.6
30715	550.41	550.41	550.73	550.52	279.49	271.03	113.3
31412	557.60	557.60	558.54	557.91	279.49	278.43	112.8
29082	532.85	533.79	533.79	533.48	279.49	253.99	114.5

TABLE XLI

Calculated Film Boiling Data for Normal Pentane on a 1.00 Inch Diameter Surface at 242.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
28985	541.35	541.04	541.35	541.25	299.75	241.50	120.0
28311	533.79	533.79	535.69	534.42	299.75	234.68	120.6
27753	528.75	528.75	531.59	529.70	299.75	229.95	120.7
27028	519.27	519.27	521.48	520.00	299.75	220.26	122.7
26256	511.04	542.91	512.29	522.08	299.75	222.33	118.1
25855	508.79	508.79	509.10	508.89	299.75	209.15	123.6
26852	517.38	517.07	518.94	517.80	299.75	218.05	123.1

TABLE XLII

Calculated Film Boiling Data for Cyclopentane on a 0.75 Inch Diameter Surface at 27.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
15908	427.77	442.37	446.71	442.28	152.80	289.48	55.0
16588	454.52	459.49	463.65	459.22	152.80	306.42	54.1
17115	464.62	469.65	474.04	469.44	152.80	316.63	54.1
18039	488.91	493.94	498.75	493.87	152.80	341.07	52.9
18517	497.10	501.78	506.52	501.80	152.80	349.00	53.1
17540	475.14	480.26	485.07	480.16	152.80	327.36	53.6
16723	453.71	459.04	463.17	458.64	152.80	305.84	54.7
16024	434.94	440.11	444.24	439.76	152.80	286.96	55.8
15360	415.47	420.91	424.84	420.41	152.80	267.60	57.4
14836	403.71	408.61	412.37	408.23	152.80	255.43	58.1

TABLE XLII (continued)

Calculated Film Boiling Data for Cyclopentane on a 0.75 Inch

Diameter Surface at 27.0 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
			(Replicate Test)				
16860	469.62	474.49	470.04	471.38	153.20	318.18	53.0
17199	477.54	482.46	478.91	479.33	152.80	326.53	52.7
17620	484.59	489.97	485.46	486.67	152.80	333.87	52.8
18390	506.52	512.26	507.81	508.86	152.80	356.06	51.6
17047	471.21	476.78	472.49	473.49	152.80	320.69	53.2
16593	455.55	460.59	456.37	457.50	152.80	304.70	54.5
16093	444.57	449.51	445.23	446.44	152.80	293.64	54.8
15493	427.27	432.07	428.07	429.14	152.80	276.34	56.1
14967	411.74	419.91	416.07	415.91	152.80	263.10	56.9
14617	400.77	408.57	404.61	404.65	152.80	251.85	58.0
14301	386.67	394.83	391.07	390.86	152.80	238.06	60.1
13942	369.07	377.18	373.56	373.27	152.80	220.47	63.2

TABLE XLIII

Calculated Film Boiling Data for Cyclopentane on a 0.75 Inch Diameter Surface at 40.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
17793	419.91	419.74	414.67	418.11	179.28	238.82	74.5
17243	403.14	402.74	397.37	401.08	179.68	221.40	77.9
16778	387.94	387.83	383.07	386.28	179.28	207.00	81.1
17482	407.51	407.14	401.70	405.45	179.68	225.76	77.4
18152	422.51	422.31	416.67	420.49	179.68	240.81	75.4
18661	434.91	435.04	429.21	433.05	179.28	253.77	73.5
19388	457.10	456.94	450.81	454.95	178.89	276.06	70.2
20125	470.49	470.78	463.55	468.27	178.50	289.77	69.5
20838	488.78	488.88	482.36	486.67	178.12	308.56	67.5
				(Replicate Test)			
20784	482.17	491.14	485.33	486.21	180.48	305.73	68.0

TABLE XLIV

Calculated Film Boiling Data for Cyclopentane on a 1.00 Inch Diameter Surface at 27.0 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, ^oF Surface Temperature 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^oF
11759	411.64	407.57	409.24	409.48	154.40	255.08	46.1
12243	420.37	416.64	418.91	418.64	154.80	263.84	46.4
12760	432.59	428.21	429.24	430.01	154.40	275.61	46.3
13334	444.21	439.81	441.88	441.96	154.40	287.56	46.4
13818	456.44	452.14	454.07	454.21	154.40	299.81	46.1
14553	471.41	466.39	468.65	468.82	154.40	314.42	46.3
15128	483.17	478.49	480.94	480.87	153.60	327.26	46.2
15648	493.97	489.26	491.52	491.59	153.60	337.99	46.3
16296	508.48	502.73	505.65	505.62	153.60	352.02	46.3
15147	482.97	477.98	480.46	480.47	153.60	326.87	46.3
14296	461.27	456.54	458.91	458.91	153.60	305.30	46.8
13171	434.21	429.41	431.67	431.76	153.60	278.16	47.4
11449	388.67	384.51	386.81	386.66	153.60	233.06	49.1
10597	364.25	359.66	361.80	361.90	154.00	207.90	51.0
10110	351.00	346.73	348.94	348.89	153.60	195.29	51.8

TABLE XLV

Calculated Film Boiling Data for Cyclopentane on a 1.00 Inch Diameter Surface at 40.6 psia Pressure

Heat Flux Btu/hr ft^2	Surface Temperatures 1	2	3	Temperatures, ^oF Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^oF
11967	385.52	380.63	384.01	383.38	180.88	202.50	59.1
12834	406.84	401.52	403.94	404.10	180.48	223.62	57.4
13675	424.37	419.21	421.51	421.69	180.48	241.21	56.7
14604	447.61	441.78	444.61	444.66	180.48	264.18	55.3
15484	465.34	459.17	462.26	462.26	180.48	281.77	55.0
16378	482.72	477.04	479.94	479.90	180.48	299.42	54.7
17031	497.62	491.85	494.88	494.78	180.48	314.30	54.2
16025	475.43	469.36	472.36	472.38	180.48	291.90	54.9
15187	455.14	449.07	452.17	452.13	180.08	272.04	55.8
14313	432.26	426.31	429.21	429.26	180.08	249.18	57.4
13550	413.41	407.81	410.34	410.52	180.08	230.43	58.8
12706	391.56	385.73	388.57	388.62	180.08	208.54	60.9

TABLE XLVI

Calculated Film Boiling Data for Cyclopentane on a 1.00 Inch Diameter Surface at 54.1 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^oF Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
13462	388.51	382.73	385.52	385.59	200.12	185.47	72.6
14333	410.07	404.11	406.71	406.96	200.12	206.84	69.3
14779	420.61	414.74	417.64	417.66	200.50	217.16	68.1
15573	440.14	434.37	437.31	437.27	200.50	236.77	65.8
16462	460.46	453.94	457.17	457.19	200.50	256.69	64.1
17414	479.91	473.20	476.78	476.63	200.89	275.74	63.2
18297	500.23	493.01	496.56	496.60	200.12	296.48	61.7
18620	507.68	501.14	505.04	504.62	199.73	304.89	61.1
17888	489.91	482.81	486.39	486.37	200.12	286.25	62.5
17024	468.59	461.44	465.24	465.09	200.12	264.97	64.2
16114	447.04	439.81	443.59	443.48	200.12	243.36	66.2
15326	425.94	419.07	422.71	422.57	199.73	222.84	68.8

TABLE XLVII

Calculated Film Boiling Data for Cyclopentane on a 1.00 Inch Diameter Surface at 67.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^{o}F}$
16718	435.04	427.57	431.31	431.31	216.41	214.89	77.8
16304	423.91	415.91	420.07	419.96	216.87	203.09	80.3
17568	452.62	445.88	450.65	449.72	216.87	232.85	75.4
18516	471.97	464.26	467.87	468.04	216.41	251.62	73.6
19505	490.39	482.65	486.56	486.53	216.87	269.67	72.3
20310	505.01	496.81	500.94	500.92	217.23	283.69	71.6
20719	511.01	502.41	506.56	506.66	217.23	289.43	71.6

TABLE XLVIII

Calculated Film Boiling Data for Benzene on a 1.00 Inch Diameter Surface at 14.7 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures, °F 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ {}^oF}$
13361	426.91	425.91	426.91	426.57	177.32	249.25	53.6
14212	454.59	453.94	454.91	454.48	177.32	277.16	51.3
14924	477.66	476.72	477.66	477.35	177.32	300.02	49.7
15794	501.78	499.23	502.10	501.04	177.32	323.71	48.8
16778	526.23	523.69	526.23	525.38	177.32	348.06	48.2
17653	548.23	549.48	549.79	549.16	177.32	371.84	47.5
18593	567.57	566.63	569.73	567.98	177.32	390.66	47.6
19326	586.41	581.48	586.41	584.77	177.32	407.45	47.4
20267	605.73	604.19	605.41	605.11	177.32	427.79	47.4
21068	626.44	623.70	626.44	625.53	177.32	448.20	47.0
19580	593.16	588.57	591.32	591.02	177.32	413.70	47.3
16856	525.91	520.85	524.32	523.69	177.32	346.37	48.7

TABLE XLVIII (continued)

Calculated Film Boiling Data for Benzene on a 1.00 Inch

Diameter Surface at 14.7 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, $^\circ F$ Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 $^\circ F$
(Replicate Test)							
17883	534.10	536.32	530.94	533.79	177.32	356.47	50.2
18764	565.10	565.40	559.79	563.43	177.32	386.11	48.6
19651	586.73	588.57	581.48	585.59	177.32	408.27	48.1
16490	504.01	504.01	501.46	503.16	177.32	325.84	50.6
15356	475.10	475.10	471.21	473.80	177.32	296.48	51.8
14568	452.30	452.30	449.01	451.20	177.32	273.88	53.2
13792	426.91	426.91	423.24	425.68	177.32	248.36	55.5
15014	462.10	462.10	459.17	461.12	177.32	283.80	52.9
16136	489.59	489.59	486.04	488.40	177.32	311.08	51.9
16732	507.52	507.52	502.10	505.72	177.32	328.39	51.0

TABLE XLVIX

Calculated Film Boiling Data for Benzene on a 1.00 Inch Diameter Surface at 29.4 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^{o}F
19688	521.48	521.48	516.43	519.79	218.62	301.17	65.4
20584	540.39	540.72	534.10	538.41	218.62	319.79	64.4
21412	557.60	557.60	552.60	555.93	218.62	337.32	63.5
22218	574.37	574.37	571.28	573.34	218.62	354.72	62.6
23068	595.95	596.25	588.57	593.59	218.62	374.97	61.5
24276	622.16	624.62	616.71	621.16	218.62	402.54	60.3
23537	603.28	603.28	597.16	601.24	218.62	382.62	61.5
22500	581.79	581.79	578.70	580.76	218.62	362.14	62.1
21582	562.60	562.60	557.60	560.93	218.62	342.32	63.0
20965	550.10	550.10	546.66	548.96	218.62	330.34	63.5
20056	529.07	529.07	525.91	528.02	218.62	309.40	64.8
19158	509.43	509.75	508.48	509.22	218.62	290.60	65.9
18211	487.01	487.01	484.43	486.15	218.62	267.53	68.1
19860	526.23	526.23	523.38	525.28	218.62	306.66	64.8

TABLE L

Calculated Film Boiling Data for Benzene on a 1.00 Inch Diameter Surface at 44.1 psia Pressure

Heat Flux Btu/hr ft^2	Temperatures, ^{o}F Surface Temperatures 1	2	3	Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient Btu/hr ft^2 ^{o}F
23829	571.58	572.20	571.28	571.69	247.74	323.94	73.6
24701	588.57	588.57	586.41	587.85	247.74	340.11	72.6
25547	605.10	607.25	603.89	605.41	247.74	357.67	71.4
26374	623.70	626.74	623.70	624.71	247.74	376.97	70.0
27567	646.38	649.38	644.26	646.68	247.74	398.93	69.1
26776	632.50	633.11	629.77	631.79	247.74	384.05	69.7
25950	617.01	619.44	616.71	617.72	247.74	369.97	70.1
25167	597.79	600.83	595.95	598.19	247.74	350.44	71.8
24297	581.16	581.48	580.55	581.06	247.74	333.32	72.9
23417	562.29	565.10	562.60	563.33	247.74	315.58	74.2
22569	541.04	541.35	541.35	541.25	247.74	293.50	76.9
21815	521.48	524.32	523.69	523.16	247.74	275.42	79.2
20948	502.10	502.41	502.41	502.31	247.74	254.56	82.3
20098	478.94	478.94	478.94	478.94	247.74	231.20	86.9
19568	462.43	462.43	462.43	462.43	247.74	214.68	91.1
21174	506.88	507.20	507.20	507.09	247.74	259.35	81.6
22310	534.10	534.10	534.10	534.10	247.74	286.36	77.9
23070	550.73	550.73	550.73	550.73	247.74	302.98	76.1

TABLE LI

Calculated Film Boiling Data for Benzene on a 1.00 Inch Diameter Surface at 73.6 psia Pressure

Heat Flux $\frac{Btu}{hr\ ft^2}$	Surface Temperatures 1	2	3	Temperatures, ^oF Average T_{sur}	Saturation Temperature T_{sat}	Temperature Difference $T_{sur}-T_{sat}$	Heat Transfer Coefficient $\frac{Btu}{hr\ ft^2\ ^oF}$
23611	572.20	572.20	574.37	572.92	288.93	283.99	83.1
24775	595.63	595.01	595.95	595.53	288.93	306.60	80.8
25942	616.40	614.26	617.31	615.99	288.93	327.06	79.3
26727	627.95	627.95	630.68	628.86	288.93	339.93	78.6
27998	647.29	646.99	649.69	647.99	288.93	359.06	78.0
23846	561.98	563.85	565.10	563.64	288.93	274.71	86.8
22800	533.79	537.26	538.51	536.52	288.93	247.58	92.1
22447	525.91	528.75	529.07	527.91	288.93	238.98	93.9
21813	491.85	497.30	497.62	495.59	288.93	206.65	105.2
24806	574.37	579.01	579.63	577.67	288.93	288.74	85.9
25993	602.67	602.98	605.10	603.58	288.93	314.65	82.6
25993	602.67	602.98	605.10	603.58	288.93	314.65	82.6
26830	619.13	620.95	621.86	620.65	288.93	331.72	80.9
27821	639.14	639.14	640.35	639.54	288.93	350.61	79.4
28611	654.20	653.90	656.90	655.00	288.93	366.07	78.2
29573	675.20	674.53	674.23	674.62	288.93	385.69	76.7
26196	609.37	609.37	609.98	609.57	288.93	320.64	81.7
24878	574.34	578.70	579.01	577.36	288.93	288.43	86.3
23783	547.91	549.79	550.10	549.27	288.93	260.33	91.4