NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NUCLEATE POOL BOILING
CHARACTERISTICS OF R-124

by

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March 1993

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The smooth and GEWA-K 19 fin per inch tube performance in pure HCFC-124 and HCFC-124/oil mixtures ranged between 10 to 50% better than in pure CFC-114 and CFC-114/oil mixtures for all heat fluxes. The HIGH FLUX and TURBO-B tubes were similar in performance. With pure HCFC-124, the finned tubes typically provided enhancements in the heat transfer coefficient between 2 and 3 times that of a smooth tube. The HIGH FLUX and TURBO-B surfaces typically provided additional enhancements 2 times that of the finned tubes. With the addition of oil, the heat transfer increased from the smooth and finned tubes but decreased from the HIGH FLUX and TURBO-B tubes. The HIGH FLUX and TURBO-B tubes therefore exhibited enhancements less than the finned tubes at high oil concentrations and high heat fluxes.

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Nucleate Pool Boiling Characteristics of R-124

by

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ABSTRACT

This thesis examines the pool boiling heat transfer characteristics of HCFC-124 and HCFC-124/oil mixtures with up to 10% (by weight) miscible alkylbenzene oil. One smooth and 4 enhanced tubes were tested: a 19 and 26 low integral-fin tube (GEWA-K); a modified finned tube (TURBO-B); and a porous coated tube (HIGH FLUX). The tests were carried out using the procedure used for CFC-114 at the same saturation temperature of 2.2 °C. This allowed for direct comparison of the pool boiling heat transfer characteristics between the two refrigerants.

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NOMENCLATURE

A	area
Ab	tube outside surface area of active boiling section
Ac	cross-sectional area of tube
c_p	specific heat
D	diameter
D_i	tube inside diameter
D_o	outside diameter of unenhanced ends
D_1	diameter at the position of the thermocouple
D_2	diameter of test section to the base of fins
g	gravitational acceleration
h	heat-transfer coefficient
h_{fg}	latent heat of vaporization
I	current
I_s	current reading by AC Current Sensor
k	thermal conductivity of liquid refrigerant
k_c	thermal conductivity of copper
L	active boiling tube length
Lu	non-boiling length of the test tube
Nu	Nusselt number
p	tube outside wall perimeter
Pr	Prandtl Number
Q	heat-transfer rate from boiling surface
Q_f	heat-transfer rate through one non-boiling end
Q_h	heat-transfer rate from cartridge heater
q	heat flux
Ra	Rayleigh number
T	temperature
T_{avg}	average wall temperature at the thermocouple location
T_c	critical temperature

T_f	film temperature
Tn	temperature of the respective (n) thermocouple location
T_{sat}	saturation temperature
T_{wo}	outer wall temperature of the boiling test tube
V	voltage across the cartridge heater
V_s	voltage reading by AC-DC true RMS converter
α	thermal diffusivity
β	volumetric thermal expansion coefficient
δ	uncertainty in measurement and calibration
θ	superheat (Two-Tsat)
μ	dynamic viscosity
υ	kinematic viscosity
ρ	density
σ	surface tension

I. INTRODUCTION

In an ongoing effort to eliminate the use of chlorofluorocarbons (CFCs), which have been linked to the depletion of the earth's protective ozone layer, the United States Navy is looking into using recently developed alternative refrigerants. There are 2 principal alternative refrigerants: hydrofluorocarbons (HFCs), and hydrochlorofluorocarbons (HCFCs). HFCs contain no chlorine and have zero ozone depletion potential (ODP). HCFCs do contain chlorine, but with the attached hydrogen atom to the CFC structure, the molecule is less stable and the ozone damaging chlorine is released in the lower atmosphere prior to reaching the ozone layer. The ODP of HCFC-124 is about 2%, significantly less than the 70% ODP for CFC-114. Figure 1.1, provided by Baehr [Ref. 1], displays the advantages of HCFC-124 over CFC-114 with respect to both ozone depletion potential (ODP) and global warming potential (GWP).

The US Navy is currently using CFC-114 (R-114) in all of its larger capacity centrifugal air conditioning units (>100 tons). The search for a 'drop-in' replacement has identified HCFC-124 (R-124) as a possible alternative to R-114. 'Drop-in' here means operating at the same evaporating temperature as existing systems. Therefore the operating parameters of R-124 under similar conditions as present R-114 chiller systems

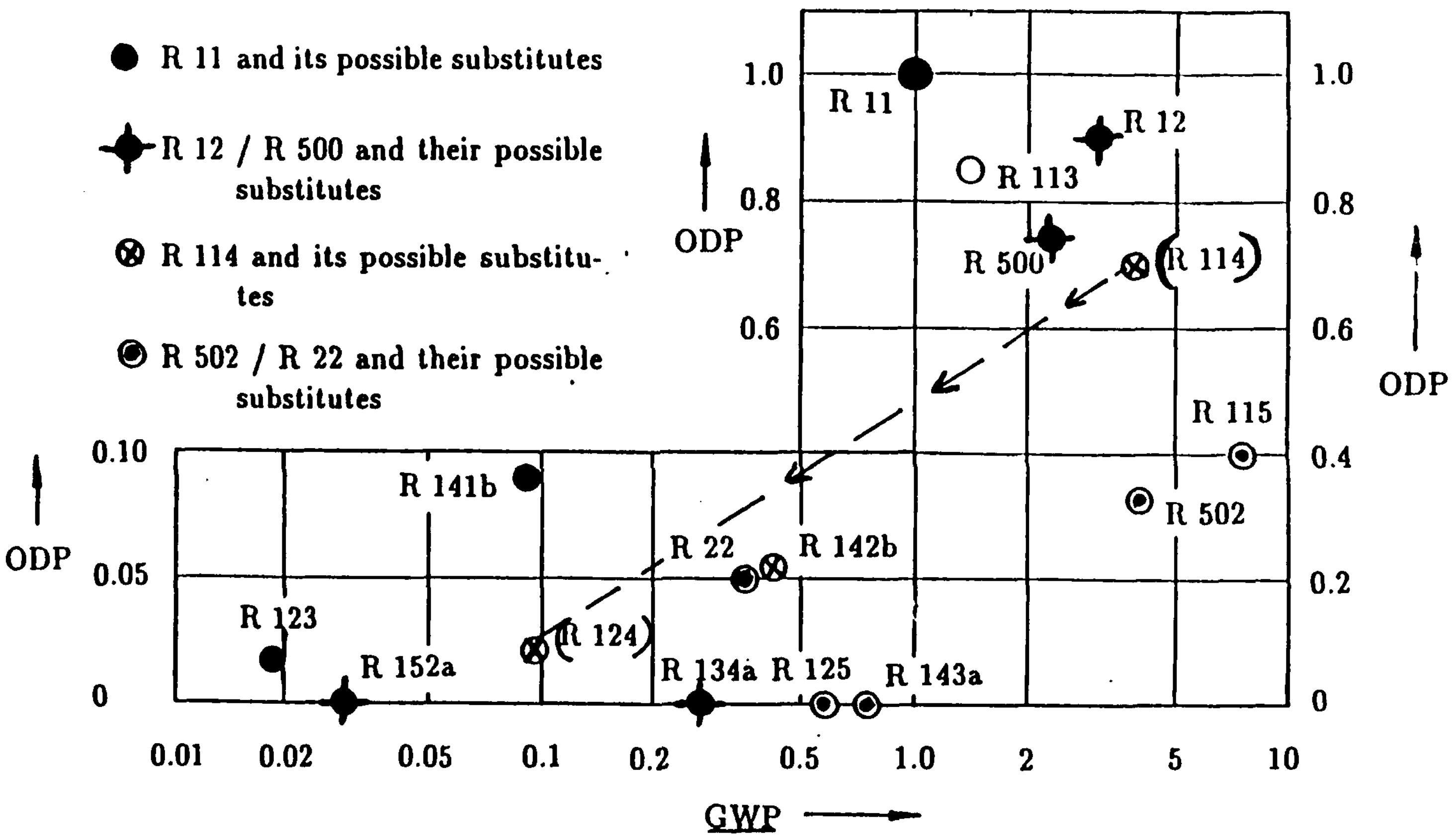


Figure 1.1 Halocarbon Ozone Depletion Potentials and Global Warming Potentials relative to R 11 (ODP = 1, GWP = 1)

must be taken into account. For example, the shell must be capable of withstanding higher pressures (11 psig for R-124 at 2.2 °C compared to 0 psig for R-114 at 2.2 °C). The shutdown system pressure is also a significant factor when the system is subjected to higher temperatures from a surrounding engine room or perhaps a casualty condition. A temperature of 100 °F would result in a system vapor pressure of 31 psig for R-114 compared to 68 psig for R-124. If the heat exchanger shell can handle the increased system pressure, hardware modifications should be limited to alterations such as compressor impeller size and changes to sealing materials to maintain leak-tight integrity.

If hardware modifications can be made, then the other major consideration is the heat transfer characteristics of R-124 compared to those of R-114. This is not such a simple comparison as the two fluids may exhibit varying boiling characteristics for each type of enhanced surface. In addition, the oil used for each fluid is different since each must be miscible in its particular refrigerant and this may significantly affect heat transfer performance.

To evaluate and compare the heat transfer performance of R-124 with that of R-114, the following thesis objectives were established:

1. Install a new fiberglass-strengthened evaporator and condenser section into existing apparatus to withstand the higher saturation pressure associated with R-124.

2. Collect pool boiling heat transfer data of pure R-114 and R-114/oil mixtures over a range of increasing and decreasing heat fluxes for the newly manufactured tubes and check their repeatability with existing R-114 data using the newly modified apparatus.

3. Modify existing data reduction program to account for the thermophysical properties of R-124.

4. Collect pool boiling heat transfer data of pure R-124 and R-124/oil mixtures over a range of increasing and decreasing heat fluxes using a smooth tube and four enhanced surface tubes.

5. Study effect of oil on boiling hysteresis for a smooth and porous coated tube.

6. Compare single tube heat transfer characteristics of R-124 with previously obtained R-114 data taken by Sugiyama [Ref. 2].

II. POOL BOILING OF REFRIGERANTS

A. POOL BOILING CURVE

The pool boiling curve, as provided by Bar-Cohen [Ref.3], is shown in Figure 2.1. The applicable regions within the curve where single tube pool boiling heat transfer tests of R-114 and R-124 refrigerants were conducted are reviewed.

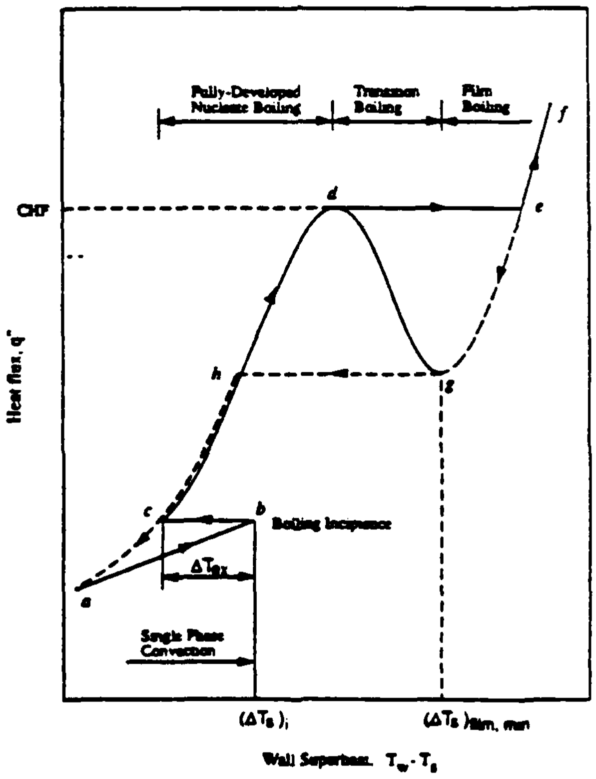


Figure 2.1 Pool Boiling Curve

1. Natural Convection

This region (a-b) occurs during the increasing heat flux phase where there are no vapor bubbles being produced at the tube surface. In this region, heat transfer is due solely to single-phase free convection effects. Several correlations are available to predict heat transfer performance in this region, including the Churchill and Chu [Ref. 4] correlation shown below in equation (1).

$$h=k/D_o[.6+.387(g\cdot\beta\cdot\Theta\cdot D_o^3/\upsilon\cdot\alpha)^{1/6}/[1+(0.559/Pr)^{9/16}]^{8/27}]^2 \quad (1)$$

2. Incipient Boiling

The transition from the natural convection region to the nucleate boiling region is the subject of numerous studies. The superheat ($T_{wall}-T_{sat}$) at which bubble inception (point b) occurs is referred to as the onset of nucleate boiling (ONB) or incipient boiling. Considerable reduction in tube wall temperature occurs at this point, resulting in a considerable reduction in superheat noted as ΔT_{ex} in Figure 2.1. This 'jump' in performance only occurs during increasing heat flux and is referred to as the thermal overshoot. A hysteresis effect occurs when decreasing heat flux data (from point c to point a) are compared to the initial ascending path (a-b-c). Several factors believed to influence the thermal overshoot at the ONB for highly-wetting liquids were studied by Bar-Cohen [Ref. 3]. Probable influential factors included: vibration, surface tension, enhanced commercial surfaces, pressure, time between test runs, oil mixture, temperature attained at end of decreasing heat flux phase of the cycle, and variation with cool-down procedure. Because of these numerous influences on the boiling incipience superheat, past studies, including Bar-Cohen [Ref. 3], reveal highly variable and widely distributed superheats at ONB. Furthermore, the process of first nucleation is inherently stochastic, leading to variations in behavior from one day to the next.

3. Nucleate Boiling Region

Once nucleate boiling commences, during increasing heat flux (point c), sustained improvement in heat transfer is realized throughout the entire fully-developed nucleate boiling region (c-d). As vapor bubbles form at nucleation sites and separate from the surface, dramatic increases in heat transfer are attained. There are several factors affecting where this region is located on the pool boiling curve, the most important of which is the number of active sites on the surface, as may occur on different boiling surfaces. Thome [Ref. 5] provides detailed insight into enhanced boiling heat transfer from various commercially available surfaces. For plain tubes, several correlations have been proposed to predict boiling performance. Two such correlations were provided by Stephan and Abdelsalam [Ref. 6] and Chongrungreong and Sauer [Ref. 7].

B. SINGLE TUBE BOILING EXPERIMENTS AT NAVAL POSTGRADUATE SCHOOL

Heat transfer measurements were collected by McManus [Ref.8] for single tube pool boiling of R-114 at a saturation temperature of 13.8°C with up to 6% oil concentration. The boiling tubes in these tests were heated internally by warm water. HIGH FLUX, TURBO-B and smooth tubes were tested in this manner. McManus [Ref. 8] reported enhancements (compared to the smooth tube) in pure R-114 as high as 14.6 and 6.4 for the HIGH FLUX and TURBO-B tubes respectively, while performance decreased to enhancements of 7.0 and 4.9 respectively with a 6% oil concentration.

Pool boiling heat transfer coefficients in pure R-114 and R-114/oil mixtures up to 10% (by weight) were measured by Wanniarachchi et al [Ref. 9] for electrically-heated smooth and enhanced tubes. These tests were run at a saturation temperature of 2.2°C. At 30 kW/m^2 Wanniarachchi et al [Ref. 9] reported enhancement results for the HIGH FLUX, Thermoexcel-E, Thermoexcel-HE, and GEWA-T tubes of 9.1, 8.2, 6.8, and 4.4 respectively. Also reported were the enhancements for these tubes with 3%, and 10% oil concentration.

Sugiyama [Ref. 2] conducted extensive pool boiling tests with R-114 and R-114/oil mixtures using a large variety of enhanced surface tubes. For the re-entrant cavity tubes with pure R-114, Sugiyama [Ref. 2] reported enhancements of 6.4 and 6.2 for the HIGH FLUX and TURBO-B tubes respectively at 35 kW/m². With 10% oil these enhancements were reduced to 3.8 and 5.6 respectively. This degradation in performance was partially attributed to the clogging of surface pores with oil. For GEWA-K 26 and 40 fpi tubes, enhancements of 2.4 and 3.1 were reported with pure R-114 at 35 kW/m². With 10% oil these same tubes were surprisingly reported to have enhancements of 3.2 and 4.6 respectively. This indicated an improved heat transfer performance with addition of oil in the case of finned tubes, believed to be caused by foaming action created within the pool that was most prevalent at higher oil concentrations (3-10%) and heat fluxes (>30 kW/m^2).

The effect of oil on the incipience of nucleate boiling for pure R-114 and R-114/oil mixtures was studied by Memory and Marto [Ref. 10] with smooth, finned and re-entrant cavity tubes. They observed a significantly lower heat flux at incipience for the HIGH FLUX and TURBO-B tubes compared with the smooth and finned tubes in pure R-114. However, consistent delay in the boiling incipience of the HIGH FLUX and TURBO-B tubes was exhibited in the presence of 3 and 10% oil concentrations. At these oil concentrations, boiling incipience for the smooth and finned tubes showed no dependence with oil. Also emphasized was the inherent randomness and variation connected with temperature overshoot associated with boiling incipience.

C. COMPARISON OF R-114 TO R-124

1. Property Comparison of R-114/R-124

Table 1 is provided to show direct comparison of the properties of R-114 and R-124 at T_{sat}=2.2°C

Table 1. R-114/R-124 PROPERTY COMPARISON

Property	R-114	R-124
P_{sat}/(kPa)	96	177
ρ(liq)/(kg/m^2)	1526	1429
ρ(vapor)/(kg/m^3)	7.5	11.3
c_p(liq)/(J/kg·K)	932	1060
h_{fg}/(kJ/kg)	134.7	158.9
k(liq)/(W/m·K)	0.0701	0.0744
μ(liq)/(g/m·s)	0.4449	0.3375
σ/(N/m)	0.0136	0.0129

2. Need for Oil Mixtures

The oil mixtures used are to simulate the actual environment in refrigeration systems which can collect lube oil within a unit's flooded evaporator to concentrations as high as 10%. The oils used for R-124 and R-114 are both miscible within their respective refrigerants. However, with R-114, a York-C mineral oil was used, while with R-124, an alkylbenzene oil was used.

3. Need for R-124 Data

There is presently no data on single tube pool boiling heat transfer with R-124 or R-124/oil mixtures. Tests must therefore be conducted with R-124 to parallel R-114 results obtained to date.

III. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. SYSTEM DESCRIPTION

Details of the relocation and early modifications to the original apparatus are given by Sugiyama [Ref. 2] and Lake [Ref. 11]. To accommodate the increased operating pressures associated with R-124, stronger evaporator and condenser units were installed. The data reduction program DRP71 was modified (DRPGB) to include the thermophysical properties of R-124.

A schematic diagram representing the experimental apparatus is shown in Figure 3.1 and comprises the following components: 1) an evaporator tee used to boil the refrigerant; (2) a condenser tee used to condense the refrigerant; (3) a reservoir for liquid refrigerant; (4) a refrigerant/oil subsystem;(5) a refrigeration cooling support system; (6) a vacuum pump; (7) a data acquisition and instrumentation system; (8) an aluminum/plexiglas framework housing items (1) to (4).

The general operation of the system was closed loop with vapor generated in the evaporator by the heated tube located within the refrigerant pool of the evaporator. The vapor passed through an aluminum 'L-shaped' tube to the condenser where the vapor was condensed by a chilled water/ethylene

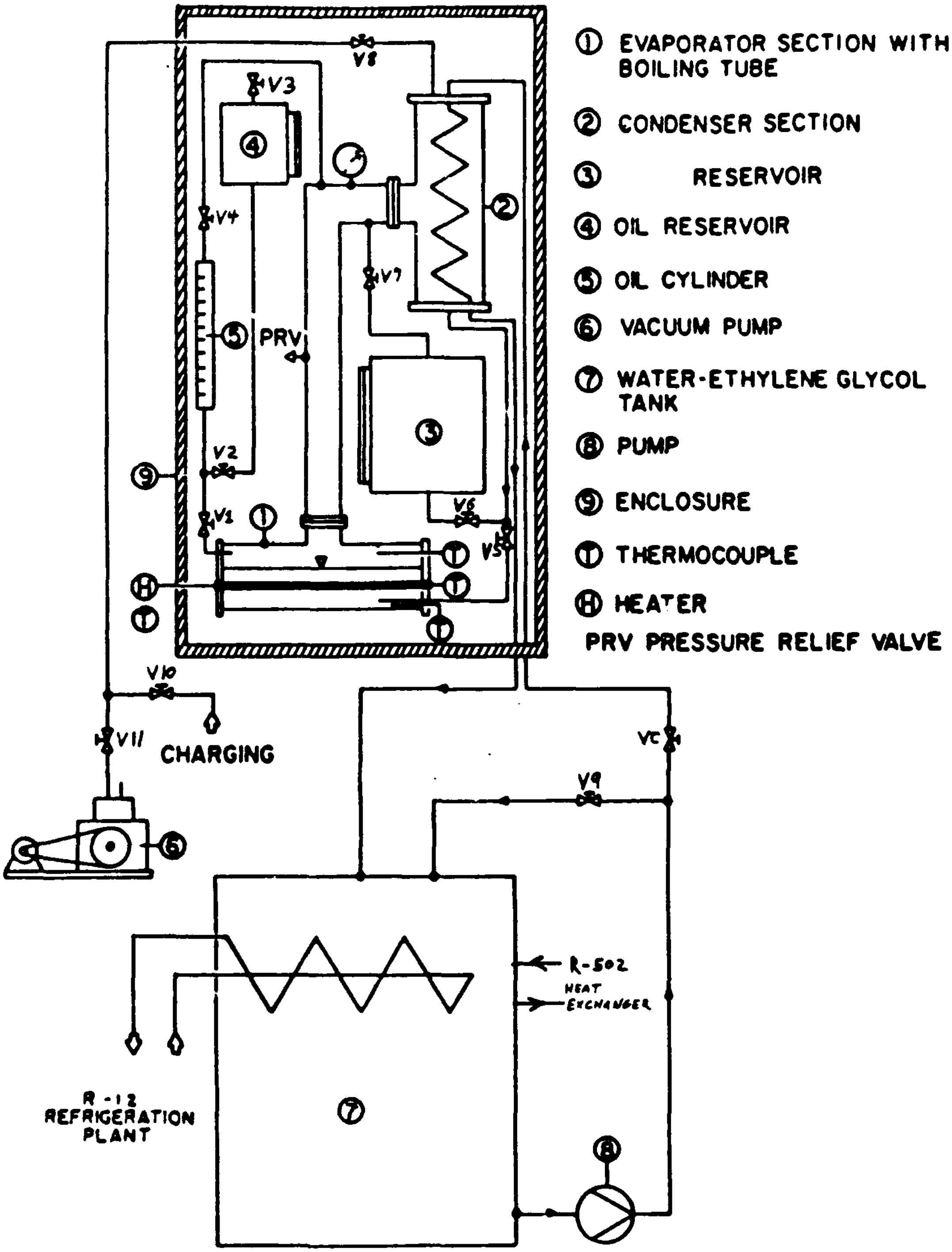


Figure 3.1 Schematic of Apparatus

glycol mixture circulated through the condenser coil by an 8 gpm turbine type positive displacement pump. The R-114 or R-124 condensate was then gravity fed back to the evaporator through a return line. R-502 and R-12 refrigeration systems maintained the water/ethylene glycol mixture in the sump between -12 and -18 degrees Celsius. Sump cooling was accomplished using a counter flow heat exchanger by recirculating the sump coolant (using an identical positive displacement pump) over the R-502 side of the heat exchanger. To further maintain this coolant temperature, the R-12 system was located directly within the water/ethylene glycol sump.

The addition of oil to the refrigerant within the evaporator was accomplished by using a graduated cylinder to measure the precise quantity. This simply drained into the evaporator by gravity.

Accurate horizontal positioning of the boiling tube was critical and accomplished by supporting each end of the tube by Teflon inserts. The tube was sealed using O-rings. For safety, a relief valve on the aluminum pipe between the evaporator and condenser was set at a gage pressure of 49 psi.

B. BOILING TEST SECTION

1. Evaporator

The evaporator was a Pyrex glass 'T' section coated with a continuous winding of fiberglass filaments impregnated with a modified epoxy resin. This upgraded evaporator shown in

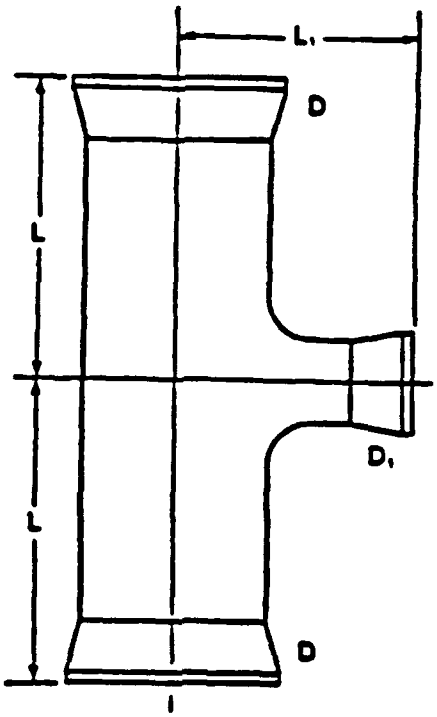
Figure 3.2 was designed for a working pressure of 50 psi gage and initially hydrostatically safety tested to 75 psi gage. The original glass was designed for a working pressure of 30 psi gage. The inside surface was the same as before and maintained the advantages of minimizing nucleate boiling at the surface as well as being corrosion resistant. The two ends of the evaporator were fitted with a cast-iron flange and gasket assembly as shown in Figure 3.2. They mated with aluminum flanges at each end of the evaporator, which in turn contained the thermocouple housings, oil entry connection and Teflon inserts containing the evaporator tube.

2. Evaporator tubes

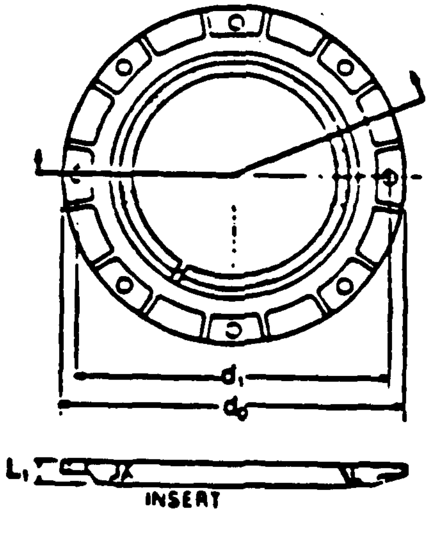
Figure 3.3 shows a schematic of a boiling tube. These were accurately held in place using Teflon inserts and sealed by O-rings. A 4-stud strong-back secured the Teflon inserts inside the aluminum flanges.

Five different tubes were tested within the apparatus. Dimensions of each tube are provided in Table 5 of Appendix C while an expanded view of the enhanced surfaces are shown in Figure 3.4. The tubes used were:

1. Smooth tube
2. GEWA-K (19 fpi) finned tube
3. GEWA-K (26 fpi) finned tube
4. HIGH FLUX (porous coated) enhanced tube
5. TURBO-B (deformed surface) enhanced tube



a) Corning Pyrex Glass Evaporator ($D \times D_1$ = 402x51 mm, L = 178 mm, L_1 = 127 mm)



b) Cast Iron Flange and Gasket (d_1 = 190mm, d_0 = 210mm, L_1 = 14mm, A = 21°)

Figure 3.2 Sketch of Pyrex Glass Vessels and Flanges

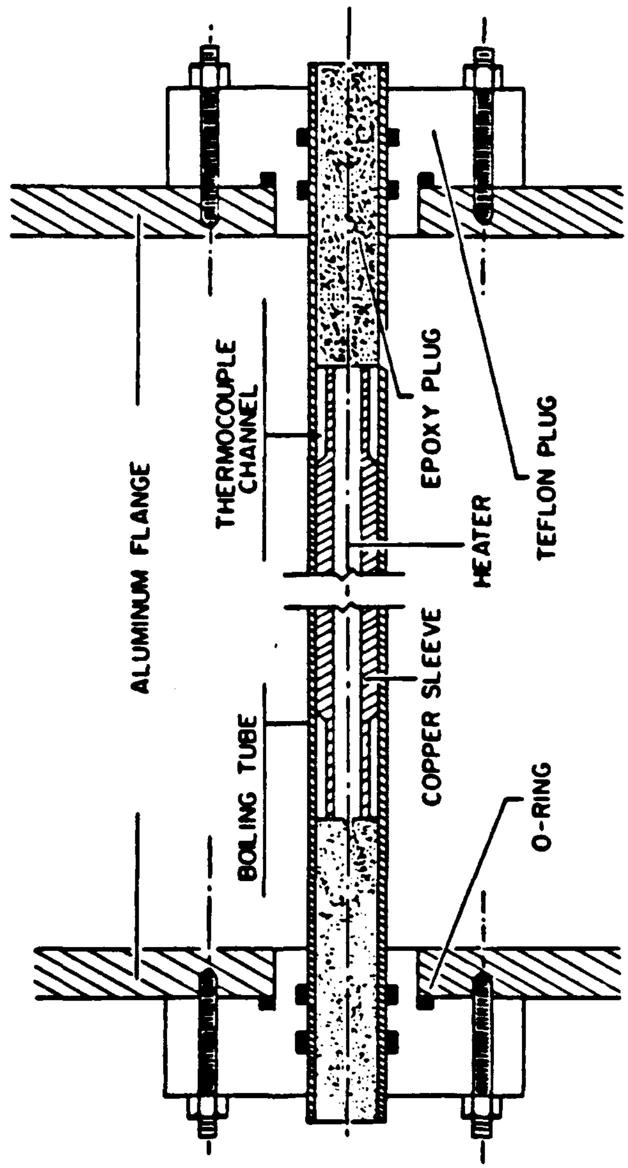
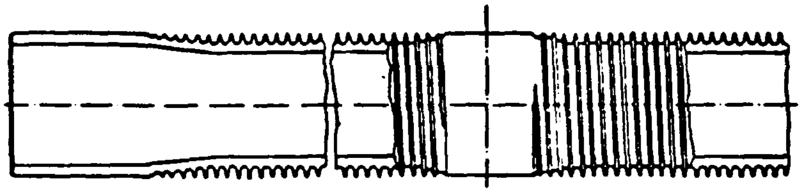
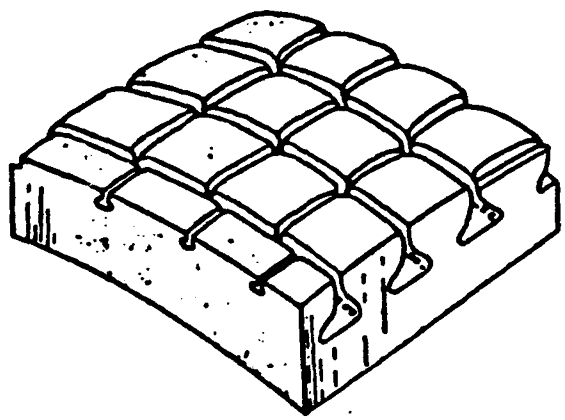


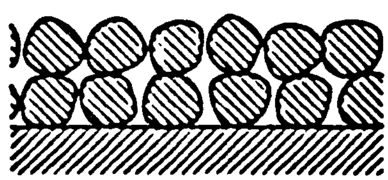
Figure 3.3 Schematic of boiling tube



FINNED SURFACE



TURBO-B SURFACE



HIGH FLUX SURFACE

Figure 3.4 Surface Profiles of Enhanced Tubes

The heater used within each boiling tube was nominally a 1 kW, 240-Volt stainless-steel cartridge heater, measuring 6.35 mm in outside diameter and 203.2 mm in length. The actual heated length of the heater was 190 mm. The HIGH FLUX and GEWA-K 26 fpi tubes were previously manufactured while the TURBO-B, GEWA-K 19 fpi and smooth tubes required assembly prior to testing with R-124 or R-114. The manufacturing process of these tubes is described below.

The heater was placed inside a copper sleeve (Figure 3.5 provides dimensions of smooth tube sleeve) with a tight mechanical fit of .001 inch clearance. The copper sleeve was machined with 6 grooves (1.27mm x 1.27mm) on its outer diameter of various lengths. Thermocouples were laid in each of these grooves and the edges of the grooves were peened over with a punch. Any resulting imperfections were smoothed out with 250 grit emery paper. The thermocouple wires and heater leads all exited the copper sleeve at the same end. The copper sleeve containing the heater and thermocouples was then placed on 2 aluminum V-blocks and the outer surface of the sleeve was covered with a flux and solder paste (50/50 tin/lead); great care was taken to ensure complete coverage of the thermocouple wires lying in the grooves. The thermocouple and heater leads were then passed through the enhanced boiling tube (the outer diameter of the copper sleeve was machined to fit tightly into each respective tube). To prevent shorting between the heater and outer tube shell, a high temperature RTV silicone rubber

(DIMENSIONS IN mm)

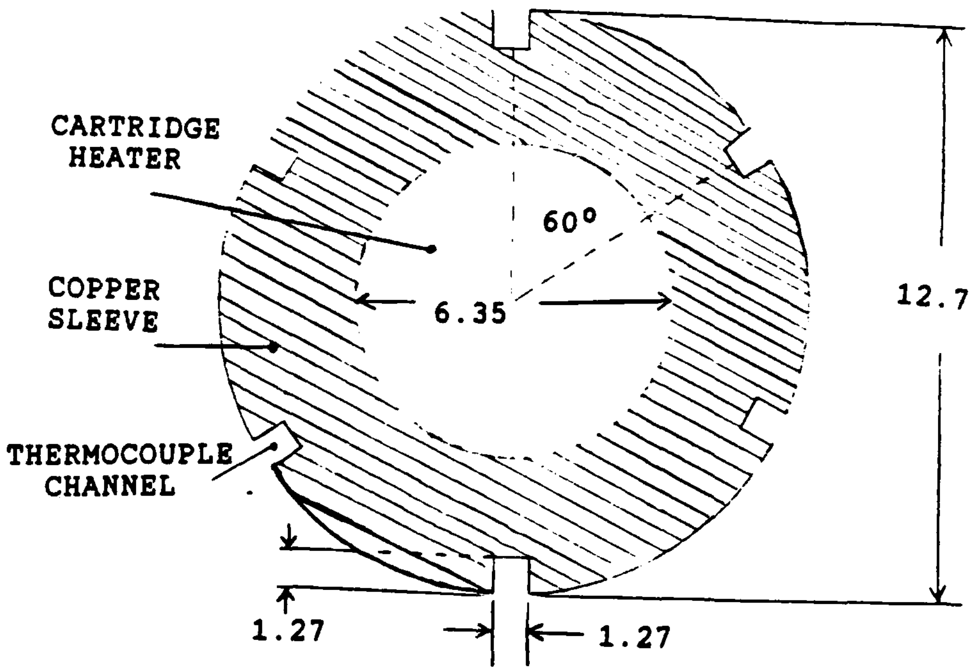


Figure 3.5 Schematic of copper sleeve

was applied to the heater and thermocouple leads at the point where they leave the sleeve. The copper sleeve was then tapped gently into the tube and positioned accurately so as to line up precisely with the 8 inch active length of the enhanced surface. This enhanced surface length was different from the actual heated length which was only 7.5 inches.

The entire assembly was then placed horizontally in an oven and heated to between 400°F and 500°F. This was the temperature 'window' at which the flux melted, but the thermocouple leads did not. The temperature of the tube was monitored by attaching the thermocouples to a simple temperature indicator. After stabilizing the oven temperature between these temperatures and ensuring that the solder had melted, the tube was taken out and quenched with a damp cloth at one end (as close to the end as possible) where the thermocouple and heater leads protrude. The oven was then placed vertically and the tube reinserted from below keeping the lower end quenched while holding both tube and cloth with a pair of channel locks. When the temperature increased to >400°F, the solder again began to melt. Additional 40/60 tin-lead solder was then applied by hand from the end which protrudes from the top of the oven. Remelting and addition of extra solder in this way ensured a uniform circumferential layer of solder and helped to prevent formation of air pockets. The tube was then removed from the oven and quenched over its whole length with a damp cloth while in a vertical position. It was then left to cool in air for 24 hours. This procedure differed from earlier manufactured tubes in that the previous copper sleeves had 4 thermocouples leaving each end of the sleeve. Trying to repeat this previous procedure accurately led to large discrepancies in the thermocouple readings (>20^{o}C) as heater power was increased. It was felt this was due to air pockets created in the fabrication procedure (the tube could never be placed vertically in the oven with leads protruding from both ends). The above procedure was much simpler and led to excellent uniformity in the thermocouple values at all heater powers.

C. CONDENSER SECTION

The condenser was also a fiberglass coated Corning Pyrex glass Tee identical in size and shape to the evaporator shown in Figure 3.2. The refrigerant was condensed on a 3/8 inch outside diameter copper tube that was coiled within the condenser. The condenser was mounted vertically. An O-ring sealed aluminum flange mounted at the top of the condenser contained not only the water ethylene/glycol coolant inlet/outlet, but also a 3/8 inch outside diameter copper tube vent, which was connected either to a vacuum pump via valve V11 or to a charging cylinder via valve V10. The bottom of the condenser was also capped with an O-ring sealed aluminum flange and contained the gravity feed return line to the evaporator via valve V5. The refrigerant vapor from the evaporator entered the condenser through an aluminum L-shaped tube, connected to the condenser by O-ring and gasketed flange. A pressure gage ranging from 30 inches mercury vacuum to 150 psig was mounted on the L-shaped tube; this was used only as a rough visual check of pressure within the facility.

D. OIL ADDITION SECTION

To provide oil addition into the refrigerant, a cylindrical aluminum reservoir, 6 inches in diameter and 6 inches high, and a graduated cylinder 355 mm in length and 25.4 mm in diameter is used as shown in Figure 3.1. The oil used with R-124 was a miscible alkylbenzene oil while the oil used with R-114 was a York-C mineral oil, also miscible. The graduated cylinder was filled from the reservoir via valve V2, while the reservoir was replenished through valve V3 at the top. Oil entered the evaporator from the graduated cylinder by gravity feed via valve V1. Oil concentrations (by weight) of 0,1,2,3,6, and 10% were used for each of the tubes.

E. COOLING SYSTEM

1. Water/Ethylene-Glycol Coolant Tank

At the base of the apparatus, a 5.35 cubic foot tank stored 30 gallons of ethylene-glycol/water mixture. Recirculation and discharge ports were connected to the tank together with a thermocouple to monitor sump temperature.

2. Refrigeration Plants

To provide the cooling of the water/ethylene glycol mixture, a 1/2 ton R-502 and 1/4 ton R-12 refrigeration system were installed near the sump as seen in Figure 3.1. Both plants contained a hermetically sealed compressor assembly, an-air cooled condenser, receiver, filter-dryer, pressure regulator, temperature control switch, and thermostatic expansion valve. The R-502 plant (Figure 3.6) used a counter current heat exchanger while the R-12 plant used a coiled evaporator placed within the sump. The sump temperature was maintained at approximately -17 ^{o}C when both these systems were used. Each plant was controlled by a temperature control switch and thermostatic expansion valve.

3. Pump and Control Valve

An 8 gpm, positive displacement pump was installed with a 1 inch diameter PVC pipe connected to the water/ethylene glycol sump. The discharge of the pump was piped to the condenser via valve VC as shown in Figure 3.1. A by-pass valve V9 was placed upstream of the control valve VC to avoid overloading the pump when control valve VC was closed and provides for mixing of the return coolant from the condenser. At high heat fluxes, the by-pass valve needed to be closed down to increase flow of coolant through the condenser. An identical pump discharged the ethylene glycol/water coolant through the R-502 counter-current heat exchanger.

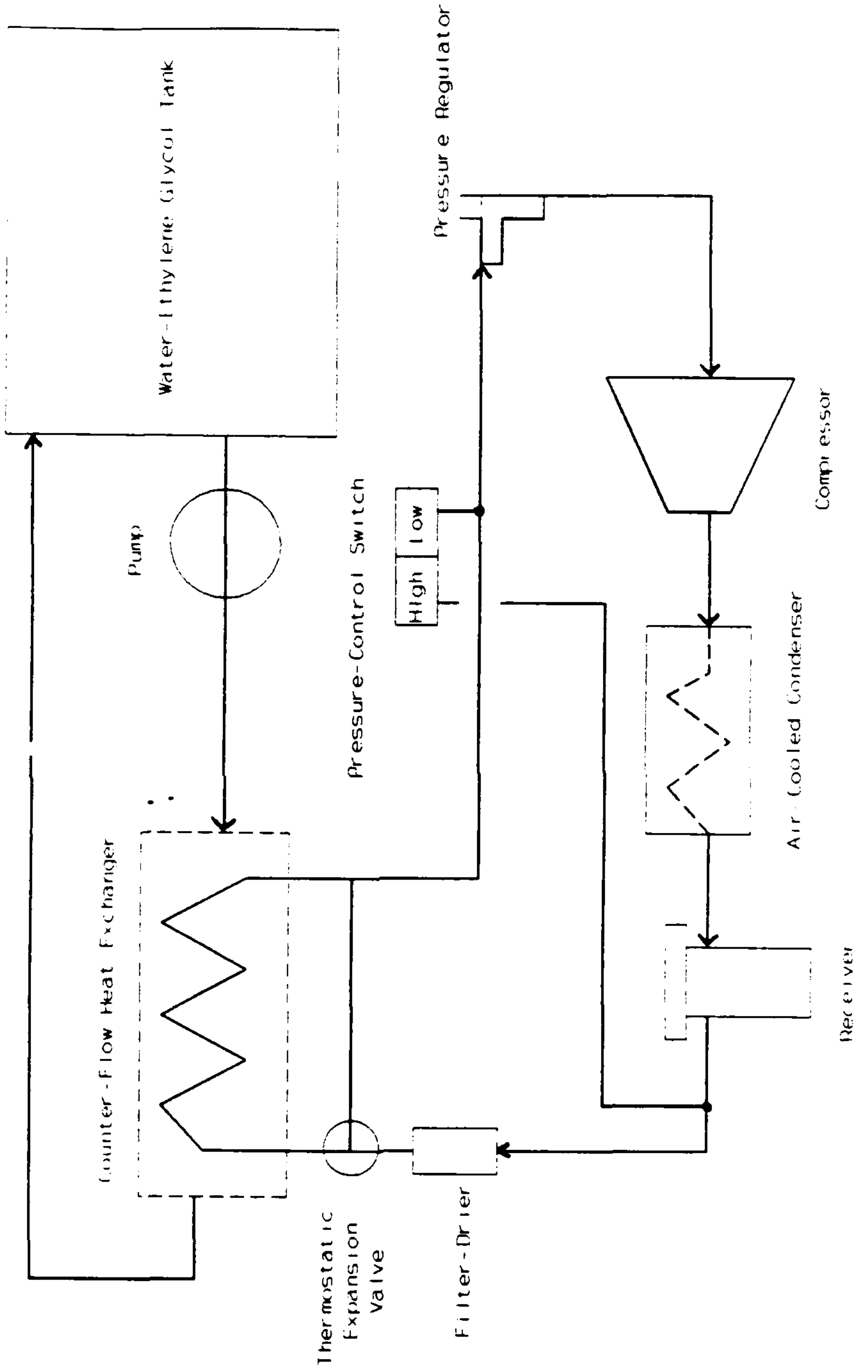


Figure 3.6 R-502 Refrigerant plant

F. REFRIGERANT RESERVOIR

The reservoir used to store the R-114 or R-124 was made from an aluminum cylinder, 9 inches in diameter and 10 inches in height. A sight glass attached on the reservoir allowed for the liquid level of refrigerant to be monitored. The reservoir was connected to the 'L' shaped tube through valve V7 and to the liquid line into the evaporator through valve V6 as shown in Figure 3.1.

G. FRAME

To house the entire assembly, an aluminum frame was constructed measuring 1070.1 mm x 509.8 mm x 610.1 mm. With a view to keeping the apparatus in an isothermal atmosphere, as well as for safety considerations, the sides were covered with 12.7 mm thick plexiglas with hinges mounted on the 2 sides to provide easy access to the assembly. The top of the frame was covered by plywood while the bottom was covered by an aluminum plate. The entire frame rested on the coolant sump tank. The front side of plexiglas had small holes to accommodate the valve stems of valves V1 through V8, so they can be operated while maintaining the integrity of the enclosed frame.

H. INSTRUMENTATION

1. Power Measurement

The boiling tube heater was powered by a 240 volt AC source, adjusted to 0-220 volts and 0-5 amps by a variac control. Power input to the heater was measured with an AC

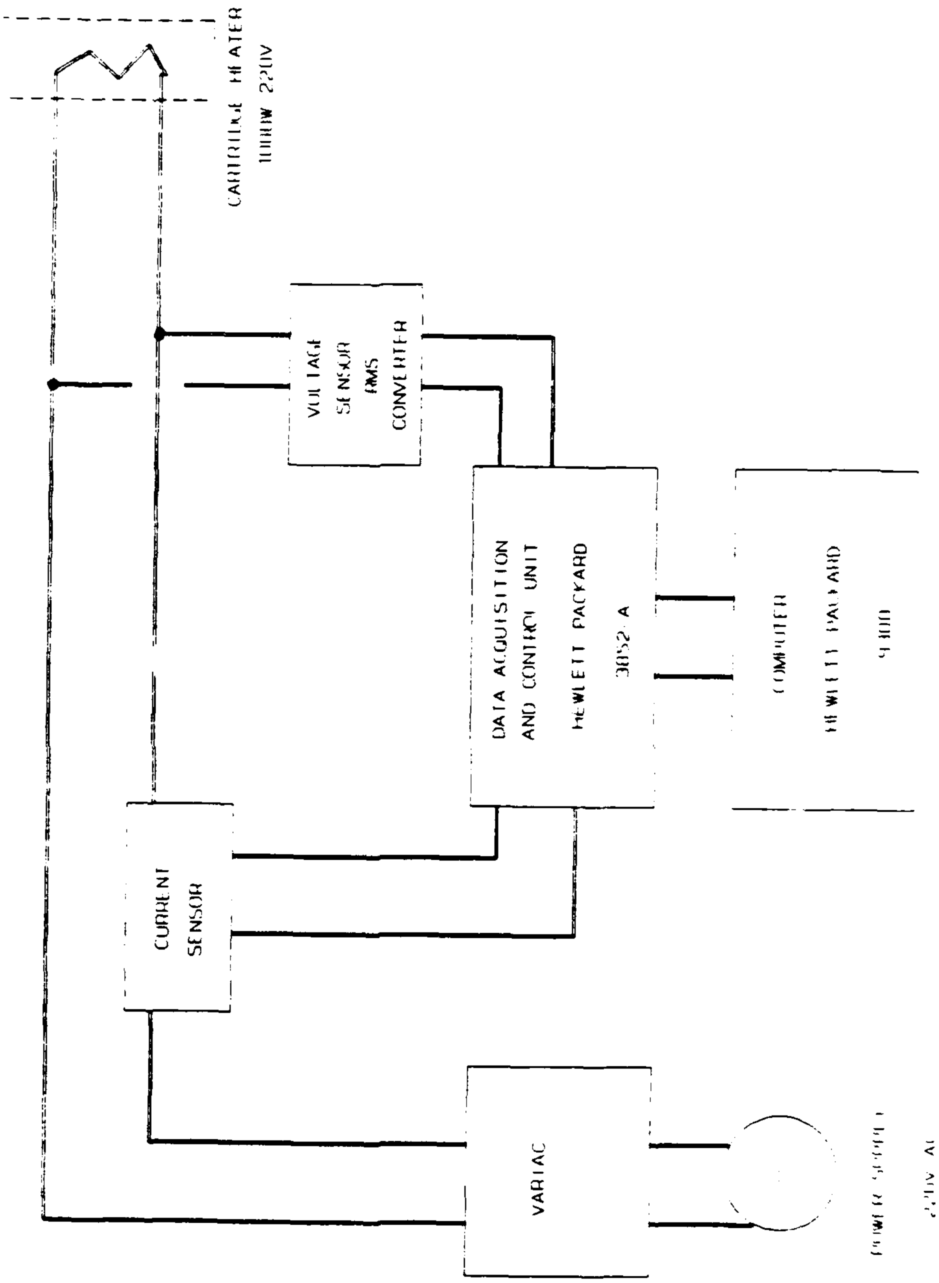


Figure 3.7 Data acquisition/control unit

current inductive sensor and a voltage sensor. The output was a proportional signal in volts having been converted through an AC-DC true R.M.S. converter. Both the AC current sensor and the AC-DC true R.M.S. converter were connected to the data acquisition/control unit as shown in Figure 3.7.

2. Temperature Measurement

The primary means of obtaining temperatures was the use of 30 gage copper-constantan thermocouples. Specific temperatures recorded were from 6 thermocouples in the boiling tube (8 in the earlier manufactured tubes), 3 thermocouples in the evaporator pool (housed within separate sealed thermocouple wells within the evaporator pool), and one thermocouple to monitor the water/ethylene glycol sump tank. A Hewlett-Packard 3497A data acquisition system controlled by a Hewlett-Packard 9826 computer read these thermocouple measurements.

I. DATA ACQUISITION AND REDUCTION PROGRAM

Data collection and reduction program DRP71, used by Sugiyama [Ref.2] for use with R-114 was modified for use with R-124. The thermophysical properties of saturated R-124 were obtained from RefProp software [Ref. 12] and were used to generate equations for use in the calculations of the reduction program. Appendix A contains plots of each property versus temperature and the respective equation. The modified program was renamed DRPGB.

The Hewlett-Packard 9826 computer reduced all the thermocouple, current, and R.M.S. voltage readings using the DRPGB program. The program was run through the keyboard allowing regulation of the data acquisition unit. A printout of the reduced data was provided by a Hewlett-Packard Inkjet printer. Table 2 lists the channel assignments for the sensor inputs to the data acquisition system.

J. PROCEDURE FROM KEYBOARD

The following procedure outlines the procedure used to collect and process data from the Hewlett Packard data acquisition system:

1. Selected the 'taking data' option after initial loading of program DRPGB.

2. Selected the refrigerant being tested, tube heating mode, (ie electrically or water heated) and thermocouple type from DRPGB.

3. Assigned name to file of data to be processed and stored.

4. Identified and entered any defective thermocouples by channel # 1-8, noting that the new tubes have only 6 thermocouples and channels 7 & 8 were always 'defective'.

5. Selected test tube type.

6. Set desired saturation temperature (2.22^0C) for present tests.

7. Set desired heat flux desired using variac adjustment.

8. Attained desired saturation temperature by adjusting flow of coolant through condenser coils with control valve VC.

9. Once saturation temperature was achieved, waited 5 minutes for steady state conditions prior to taking data.

10. Prompted data acquisition unit to scan all the channels listed in Table 2. All channel readings were made in volts and stored in user specified fields.

11. Calculated temperature and power from these voltages.

12. Calculated heat transfer rate from cartridge heater.

13. Calculated the average wall temperature of the test tube and calculated wall superheat (Twall- Tsat).

14. Calculated physical properties of R-124 using property correlations from RefProp [Ref.12] at film temperature (Twall+Tsat)/2.

15. Calculated the natural convection heat-transfer coefficient of R-124 from the unheated ends of the test tube.

16. Computed heat losses from unheated ends of the test tube.

17. Calculated heat flux from heated length of the test tube.

18. Calculated the heat-transfer coefficient from the heated length of the test tube.

19. Stored heat flux and wall superheat for each data set in user specified fields.

20. Plotted data on available software.

Sample calculations of the above procedure are given in Appendix C.

TABLE 2. HP 3497A CHANNEL ASSIGNMENTS

Channel	Channel Assignments
00-07	tube wall temperatures
08-10	pool liquid temperature
11	sump temperature
20	RMS voltage
21	current sensor

IV. EXPERIMENTAL PROCEDURE

A. ASSEMBLY PREPARATION

1. Vacuum test of the apparatus

After placing the desired boiler tube in position within the evaporator, the system was evacuated down to a pressure of 29 inch Hg. vacuum using a portable vacuum pump via valves V11 and V8 in Figure 3.1. The system was then isolated for approximately 30 minutes to check for leak-tight integrity (indicated by any significant vacuum loss). If a leak was detected, a positive air pressure (20 psig) was placed on the system via valves V10 and V8. A soap/water solution was applied on the sealing areas to identify any leaks (if there is a leak, bubbles are seen). If identified, the leak source was corrected and the system integrity retested.

2. Charging apparatus with refrigerant

After system in egrity was ensured, the evaporator was filled with refrigerant to a level of 20 mm above the test tube. The refrigerant was drained by gravity from the reservoir into the evaporator through valves V6 and V5. Valve V7 was also open to equalize pressure in the system. The reservoir was then isolated from the system with the closure of valves V5 through V7.

3. Degassing and Data Acquisition Channel Check

Prior to connecting all thermocouple leads, the resistance between the heater leads and outer tube wall was checked with a simple multimeter. Readings were usually greater than 1 $M\Omega$. Each channel's output was checked using program SETUP71. Any problem thermocouples were either fixed or excluded from the calculations in program DRPGB. Before energizing the heater and starting the tests, the evaporator pool was slowly cooled to a saturation pressure of 2.22 ^{o}C by allowing a low coolant flow through the condenser. Once completed, the heating surface flux was set to approximately 90 kW/m^2 to degas the refrigerant; any non-condensible gases were collected in the condenser and vented off using the vacuum pump for approximately one minute. The apparatus was then secured for a period of approximately 8 hours prior to operation to allow the surface to cool and become fully wetted in the refrigerant.

B. OPERATIONAL PROCEDURE

The following procedure was used to operate the facility (this follows closely the procedure used by Sugiyama [Ref.2]):

1. The R-502 and R-12 refrigeration units were utilized until the temperature of the water-ethylene glycol sump reached a minimum of -8 ^{o}C before starting tests (with continued cooling to -17 ^{o}C).

2. The data acquisition unit, computer and variac control panel were switched on.

3. The computer program SETUP was loaded and run. All data acquisition channels were rechecked. The refrigerant pool temperature was then cooled down slowly to 2.2 °C by circulating coolant through the condenser.

4. The data acquisition/reduction program DRPGB was loaded and run.

5. The desired heat flux setting for the test tube was input to the program DRPGB and the variac was adjusted to attain that heat flux. Starting heat flux was between 500 and 600 W/m^2.

6. Control valve VC was adjusted to control coolant flow through the condenser to maintain a constant saturation temperature of 2.22 °C ± 0.1 °C.

7. At each heat flux setting, the thermocouple values were allowed to stabilize for about 5 minutes prior to taking data.

8. The following data were then taken and used in the acquisition/reduction program DRPGB: pool temperature; test tube wall temperatures; sump temperature; current and voltage sensor readings.

9. Data were taken at each desired heat flux setting and always at the same saturation temperature (the coolant flow in the condenser was adjusted to ensure this). At each heat flux setting, program DRPGB generated a permanent printout listing: wall temperatures of the test tubes; refrigerant pool temperatures; sump temperature; wall superheat; heat-transfer coefficient and the corrected heat flux (ie. to account for heat-transfer lost from each end).

10. For each heat flux setting, steps 6 through 9 were repeated. The superheat (Twall-Tsat) and the respective heat flux were plotted on a log-log scale.

11. Table 3 provides a summarized listing of all data runs.

TABLE 3. LISTING OF DATA RUNS

Data File	Refrigerant	Tube Type	Purpose
D0821SM0	R-114	Smooth	repeatability
D0824SM0	R-114	Smooth	repeatability
D1015SM0	R-124	Smooth	Data
D1017SM0	R-124	Smooth	Data
D1223SM0	R-124	Smooth	Data
D1222SM0	R-124	Smooth	Data
D1221SM0	R-124	Smooth	Data/samp calc
D1220SM0	R-124	Smooth	uncert analys
D1219SM0	R-124	Smooth	Data
D1217SM0	R-124	Smooth	Data
D1016SM4.44*	R-124	Smooth	Data Tsat4.4°C
D1114SM0	R-124	Smooth	Data
D1114SM1	R-124	Smooth	Data
D1114SM2	R-124	Smooth	Data
D0108SM3	R-124	Smooth	Data
D0107SM3	R-124	Smooth	Data
D0106ASM3	R-124	Smooth	Data
D0106SM3	R-124	Smooth	Data
D0105SM3	R-124	Smooth	Data
D0104SM3	R-124	Smooth	Data
D1227SM3	R-124	Smooth	Data
D1116SM3	R-124	Smooth	Data
D1116SM6	R-124	Smooth	Data
D0112ASM10	R-124	Smooth	Data
D0112SM10	R-124	Smooth	Data
D0111ASM10	R-124	Smooth	Data
D0111SM10	R-124	Smooth	Data

Continuation of Table 3.

Data File	Refrigerant	tube type	Purpose
D0110SM10	R-124	Smooth	Data
D0109ASM10	R-124	Smooth	Data
D0109SM10	R-124	Smooth	Data
D1117SM10	R-124	Smooth	Data
D1011190	R-114	GK-19	Data
D1010190	R-114	GK-19	Data
D0901190	R-114	GK-19	Data
D0907193	R-114	GK-19	Data
D09091910	R-114	GK-19	Data
D1105190	R-124	GK-19	Data
D1118190	R-124	GK-19	Data
D1118191	R-124	GK-19	Data
D1118192	R-124	GK-19	Data
D1119193	R-124	GK-19	Data
D1120196	R-124	GK-19	Data
D11211910	R-124	GK-19	Data
D0803260	R-114	GK-26	Repeatability
D1021260	R-124	GK-26	Data
D1122260	R-124	GK-26	Data
D1122261	R-124	GK-26	Data
D1122262	R-124	GK-26	Data
D1123263	R-124	GK-26	Data
D1123266	R-124	GK-26	Data
D11252610	R-124	GK-26	Data
D11242610	R-124	GK-26	Data
D1004TB0	R-114	TURBO-B	Data
D1006TB0	R-114	TURBO-B	Repeatability

Continuation of Table 3.

Data File	Refrigerant	Tube Type	Purpose
D1002GYX0	R-114	GEWA-YX	Data
D1110TB0	R-124	TURBO-B	Data
D1110TB0	R-124	TURBO-B	Data
D1111TB1	R-124	TURBO-B	Data
D1111TB2	R-124	TURBO-B	Data
D1112TB3	R-124	TURBO-B	Data
D1112TB6	R-124	TURBO-B	Data
D1113TB10	R-124	TURBO-B	Data
D0119AHF0	R-124	HIGH FLUX	Data
D0118BHF0	R-124	HIGH FLUX	Uncert Analys
D0118HF0	R-124	HIGH FLUX	Data
D0114HF0	R-124	HIGH FLUX	Data
D0113AHF0	R-124	HIGH FLUX	Data
D0113HF0	R-124	HIGH FLUX	Data
D1108HF0	R-124	HIGH FLUX	Data
D1126HF0	R-124	HIGH FLUX	Data
D1126HF1	R-124	HIGH FLUX	Data
D1126HF2	R-124	HIGH FLUX	Data
D0125HF3	R-124	HIGH FLUX	Data
D0122HF3	R-124	HIGH FLUX	Data
D0121CHF3	R-124	HIGH FLUX	Data
D0121HF3	R-124	HIGH FLUX	Data
D0120AHF3	R-124	HIGH FLUX	Data
D0120HF3	R-124	HIGH FLUX	Data
D0119AHF3	R-124	HIGH FLUX	Data
D1128HF3	R-124	HIGH FLUX	Data
D1128HF6	R-124	HIGH FLUX	Data

Continuation of Table 3.

Data File	Refrigerant	Tube Type	Purpose
D1130HF10	R-124	HIGH FLUX	Data
D0128HF10	R-124	HIGH FLUX	Data
D0127CHF10	R-124	HIGH FLUX	Data
D0127BHF10	R-124	HIGH FLUX	Data
D0127HF10	R-124	HIGH FLUX	Data
D0126BHF10	R-124	HIGH FLUX	Data
D0126AHF10	R-124	HIGH FLUX	Data
D0126HF10	R-124	HIGH FLUX	Data

The tabulated data was filed using the following file name system:

Example (D0126AHF10):

1. First letter D simply refers to data

2. The following 4 characters are always the date; in this case Jan 26.

3. The next letter represents order of the day test was completed on the respective date;
   no letter- 1st run
   A- 2nd run
   B- 3rd run
   etc.

4. The following 2 letters represented the tube used;

   SM= smooth
   19= 19 fpi GEWA-K
   26= 26 fpi GEWA-K
   HF= HIGH FLUX
   TB= TURBO-B

5. The last 1 or 2 numbers represent the percentage of oil; in this case 10%.

* this one run was pure R-124 tested at 4.4 °C vice 2.2 °C

V. RESULTS AND DISCUSSION

A. REPRODUCTION OF EXPERIMENTAL DATA

The first tests conducted were to verify the reproducibility of the single tube data taken by Sugiyama [Ref. 2] with R-114. A GEWA-K 26 fin per inch (fpi) tube comparison with R-114 is given in Figure 5.1 and shows very similar results with previous data. Uncertainty bands for both wall superheat and heat flux are given on the figure. Consequently, at low heat flux (< 1000 W/m^2), there is more scatter due to the lower wall superheats and hence higher uncertainty. Overall, the agreement between the two data sets is satisfactory.

In Figure 5.2, an increasing heat flux data run using a smooth tube is compared with Sugiyama's [Ref. 2] data. It can be seen that in the low heat flux, natural convection region and the high heat flux, nucleate boiling region the data agreement is good. In the mid-range of heat flux, (3 $kW/m^2 < q < 15$ kW/m^2), the data varies somewhat, depending upon how the tube nucleates. Curve #1 nucleates at a relatively low wall superheat (12.5 ^{o}C) while curve #2 (both taken by Sugiyama [Ref.1]) nucleates at a high wall superheat of about 35 ^{o}C (point C). The present data (curve #3) exhibits partial

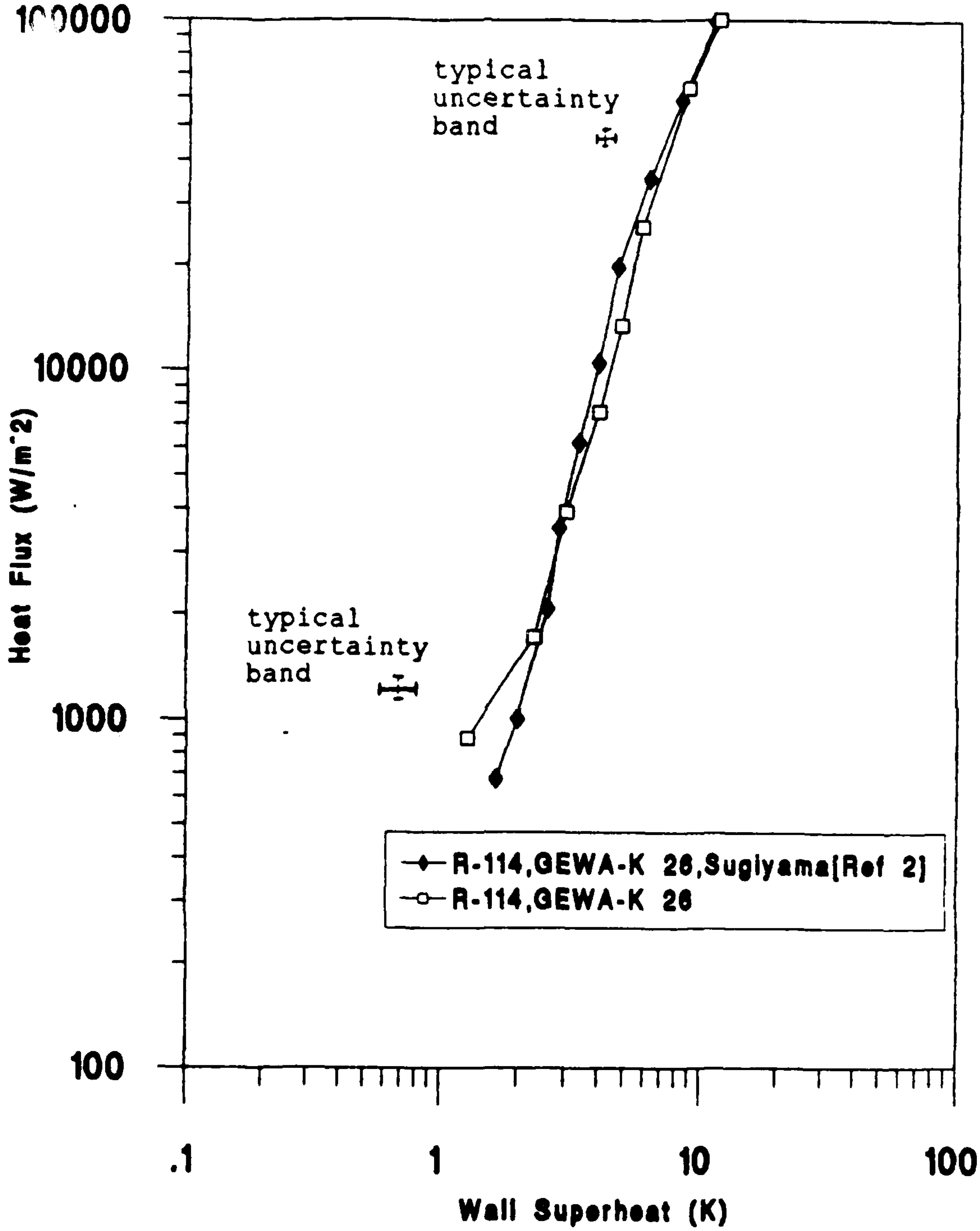


Figure 5.1 Comparison of R-114 Data with 0% Oil for GEWA-K 26 fpi tube (decreasing flux)

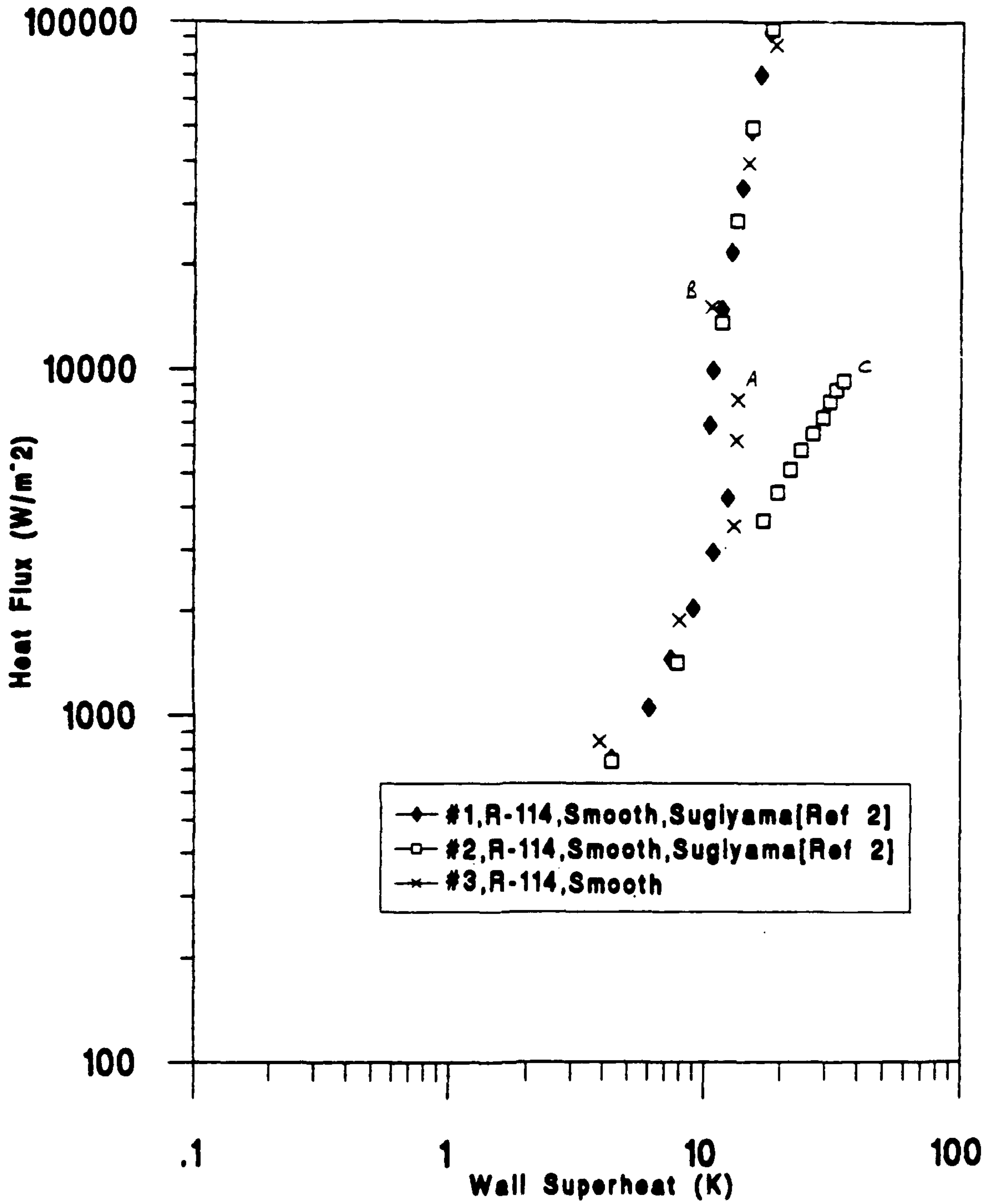


Figure 5.2 Comparison of R-114 Data with 0% Oil for Smooth Tube (increasing flux)

nucleation (see point A) where 3 of the six thermocouples had a low wall superheat (< 14 °C) and the remaining 3 had a wall superheat (> 18 °C). Observing the tube surface, it could be clearly seen that half the tube was boiling while the other half was in the natural convection mode. At point B, all six thermocouples were within 0.9 °C of each other, indicating complete nucleation over the entire surface. At this point (and above), agreement with the previous data is excellent. The discrepancies in this mid heat flux region demonstrate the random behavior of nucleate boiling incipience; this is further investigated later in this chapter. After all sites nucleated (Point B), the standard deviation was 0.9 °C with an average thermocouple temperature of 12.9°C. The point of incipience and its random occurrence at different levels of superheat will be examined later in this chapter.

Sugiyama [Ref.2] did not conduct tests on a 19 fpi GEWA-K tube. This is one of the most common tubes used in commercial evaporators. Therefore, base-line data for the 19 fpi GEWA-K tube with R-114 and R-114/oil mixtures were taken during this thesis before evacuating and cleaning the apparatus, and filling with R-124. The R-114 data obtained was incorporated in the R-124/R-114 comparison of the 19 fpi tube (Figure 5.12).

Figure 5.3 shows the repeatability of decreasing heat flux data for the newly constructed 19 fpi GEWA-K tube using R-124. The good agreement is an indication of the consistency

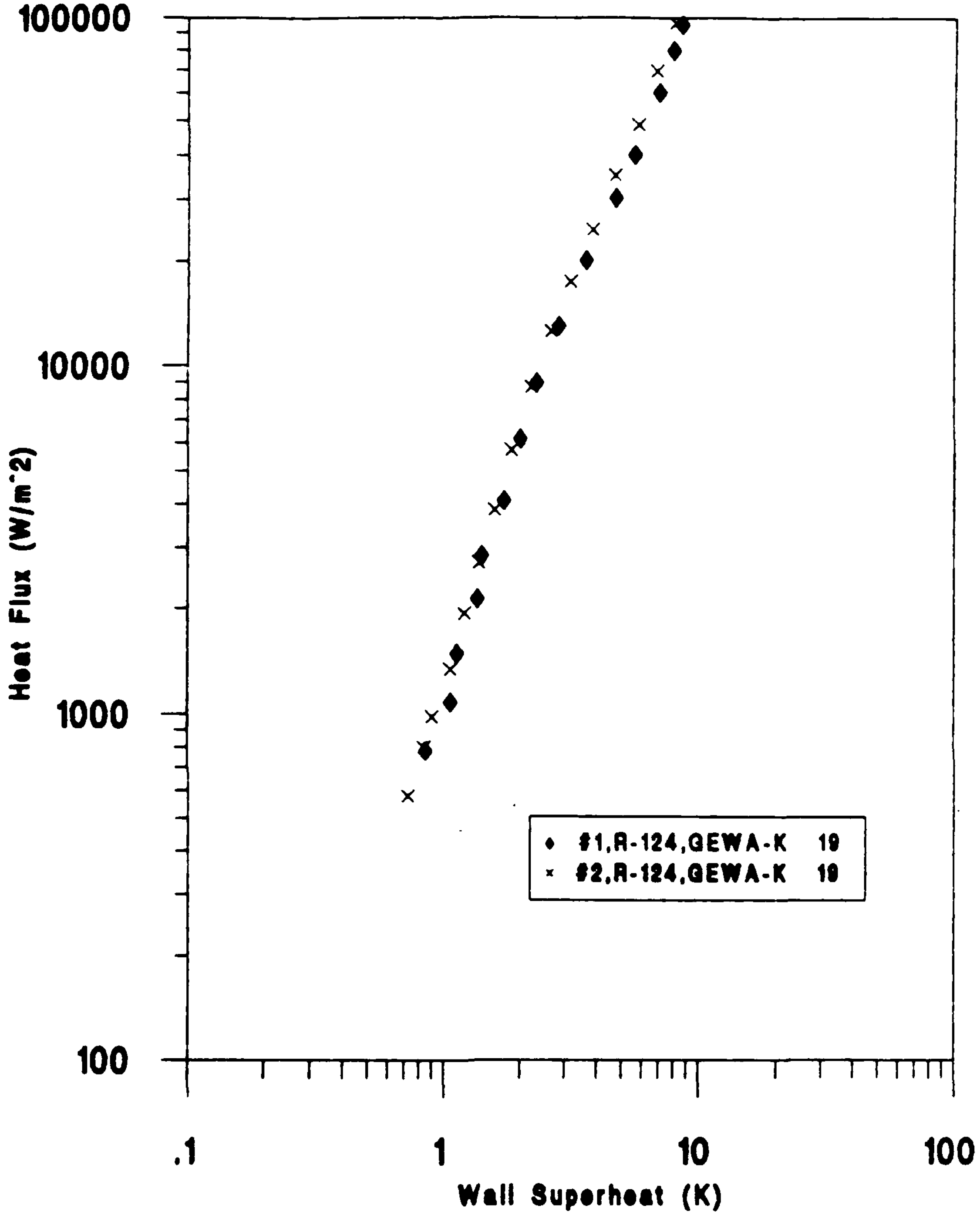


Figure 5.3 Repeatability Comparison of R-124 Data with 0% Oil for 19 fpi GEWA-K Tube (decreasing flux)

of the data reduction program DRPGB, the apparatus and the operator. Decreasing heat flux runs provide better comparison as temperature overshoot and hysteresis effects are avoided.

B. POOL BOILING HEAT-TRANSFER COEFFICIENT CORRELATIONS

Among the correlations available to predict pool boiling heat transfer coefficients for a smooth tube, most can be expressed as heat flux as a function of wall superheat. The pure R-124 smooth tube data is fitted very closely by the equation:

$$q=17.0\ \Delta T^{3.0} \qquad (1)$$

A correlation in terms of fluid physical properties and tube geometry is given by Chongrungreong and Sauer [Ref. 7]. For R-124 at 177 kPa, this reduces to:

$$q=45.8\ \Delta T^{2.32} \qquad (2)$$

Another simpler correlation based only on system pressure is also given by Chongrungreong and Sauer [Ref. 7]:

$$q=76.9\ \Delta T^{2.22} \qquad (3)$$

Stephan and Abdelsalem [Ref. 6] present a statistical correlation for four different groups of fluids. For refrigerants, their correlation is presented in the form:

$$q=\ (C1\Delta T)^{3.92} \qquad (4)$$

where C1 is given as a function of refrigerant type and system pressure. Unfortunately, as R-124 is a relatively new refrigerant, their graphical representation of C1 does not include R-124. However, the present data could be fitted to an equation of the form given in equation (4):

$$q=(1.34\ \Delta T)^{3.92} \qquad (5)$$

Hence, at a pressure of 1 atm, C1= 1.34.

Figure 5.4 shows the present R-124 smooth tube data for decreasing heat flux along with the above correlations. At lower heat fluxes the prediction of the Chongrungreong and Sauer [Ref. 7] correlation (equation (2) above) exhibits considerably closer prediction than the other correlations. In the more complex nucleate boiling region, the Stephan and Abdelsalem [Ref. 6] correlation and the Chongrungreong and Sauer [Ref. 7] correlation (equation (3)) display a fair prediction of the slope.

C. SMOOTH TUBE DATA IN REFRIGERANT/OIL MIXTURES

Although tests were conducted with oil concentrations of 0,1,2,3,6, & 10%, only data with 0,3 and 10% have been plotted in most of the figures for clarity. Figures 5.5 and 5.6 show the heat transfer performance of pure R-124, R-124/3% oil, and R-124/10% oil for a smooth tube during increasing and decreasing heat flux respectively. It can be seen that at the highest heat fluxes, as oil concentration is increased to 3%, the heat transfer is enhanced by a maximum of 17% over pure R-124. For further increases in oil concentrations to 10%, performance drops off. This drop-off in thermal performance has also been observed by Jensen and Jackman [Ref. 13] who

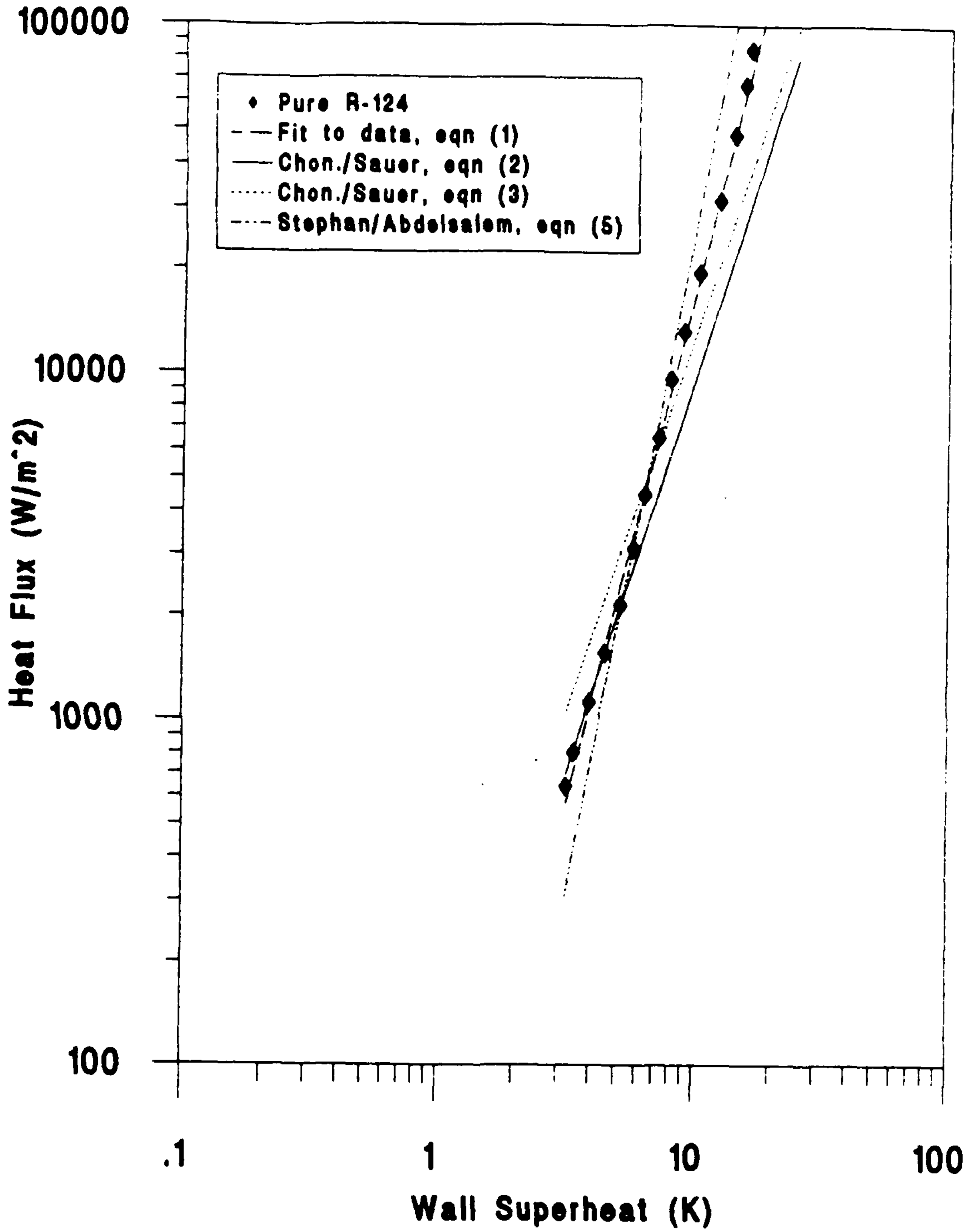


Figure 5.4 Comparison of Smooth Tube Performance for Pure R-124 with Prediction

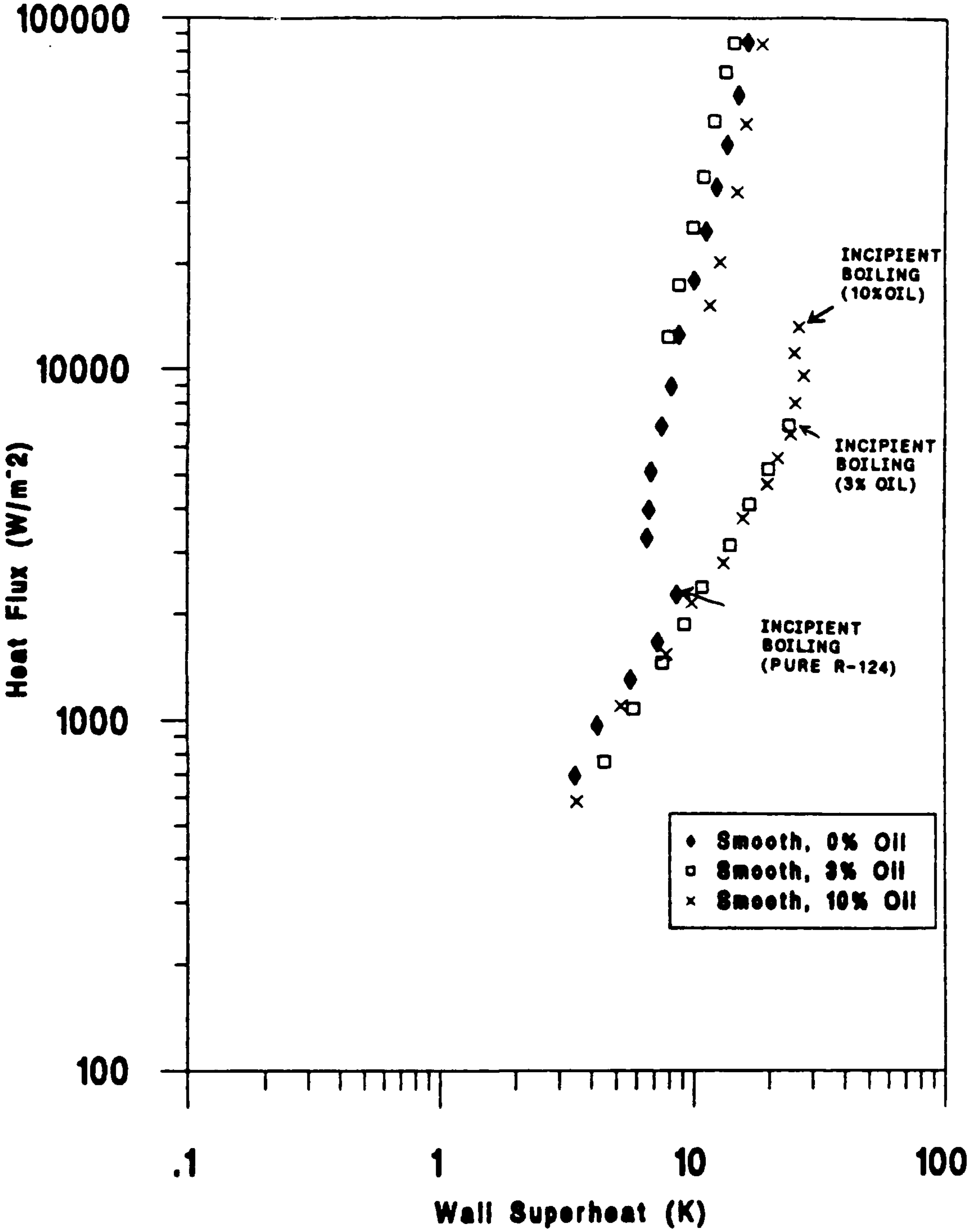


Figure 5.5 Performance Comparison for Boiling R-124/ 0%, 3%, & 10% Mixtures for Smooth Tube (increasing flux)

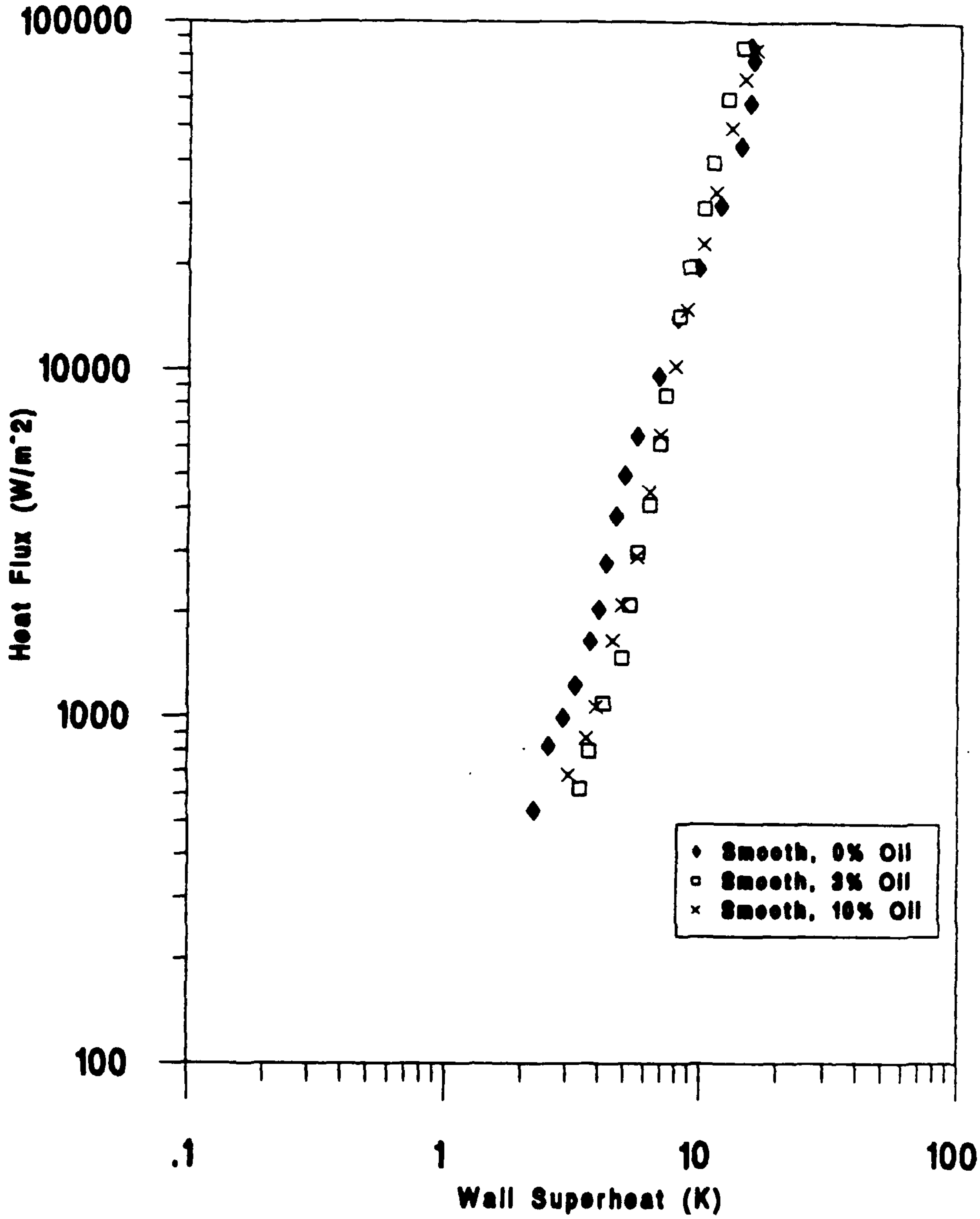


Figure 5.6 Performance Comparison for Boiling R-124/ 0%, 3%, & 10% Mixtures for Smooth Tube (decreasing flux)

attributed the decline to a steeper oil concentration gradient, inhibiting bubble growth.

When oil is mixed with R-124, two competing mechanisms occur: (1) Oil accumulates in the vicinity of the vapor bubble surface as the more volatile refrigerant is evaporated; (2) diffusion of this accumulated oil back into the bulk mixture establishes an equilibrium concentration gradient near the departing bubble. Mechanisms (1) and (2) should act to inhibit bubble growth and lead to an overall decrease in the heat transfer with oil addition compared with pure refrigerant. It therefore appears that there is an additional mechanism that has a significant impact on the thermal performance of pool boiling of refrigerants with small quantities of oil. For R-124/oil mixtures of 3% and greater, significant foaming in the evaporator was observed at mid to high heat fluxes (> 10000 kW/m^2). It is possible that a third mechanism which could be affecting heat transfer is this foaming that occurred within the bulk R-124/oil mixture. Udomboresuwan and Mesler [Ref.14] reported enhancement in pool boiling in the presence of foam. They attributed this enhancement to the foam causing the liquid/vapor interface to be closer to the tube wall. This would create a thin liquid film between a vapor bubble and the heated tube surface, thereby providing large heat-transfer coefficients. Higher heat fluxes and greater oil concentrations tend to increase the foaming, which could explain why this enhancement is seen more predominately at high heat fluxes. However, as oil concentration increases, eventually the oil concentration gradient becomes so steep that mechanisms (1) and (2) tend to dominate and heat transfer performance drops off (ie. the foaming enhancement effect is offset).

At low heat fluxes, the scatter in the data is attributed to uncertainty. For the increasing heat flux data (Fig 5.5), it appears that the addition of oil tends to delay the point at which boiling commences. Due to the statistical nature of incipience, however, one should be wary of drawing much conclusion from this figure. The effect of oil on incipience is discussed in greater detail later in this chapter.

Figure 5.7 compares smooth tube decreasing heat flux data from this thesis for R-124 with Sugiyama [Ref. 2] R-114 data at oil concentrations of 0%, 3%, and 10%. At all levels of heat flux, the R-124 data consistently demonstrate improvement in heat transfer over R-114. This ranges from 50% at low heat flux to 15% at high heat flux. The heat flux from a boiling surface is proportional to bubble diameter (d_b), bubble departure frequency (f_b), number of active nucleation sites per unit area, vapor density (ρ), and latent heat of vaporization (h_{fg}). Barthau [Ref. 15] concluded, after determination of d_b, f_b, and active nucleation site density for a smooth copper tube in R-114 using optical techniques, that as saturation pressure was increased, d_b decreased, while

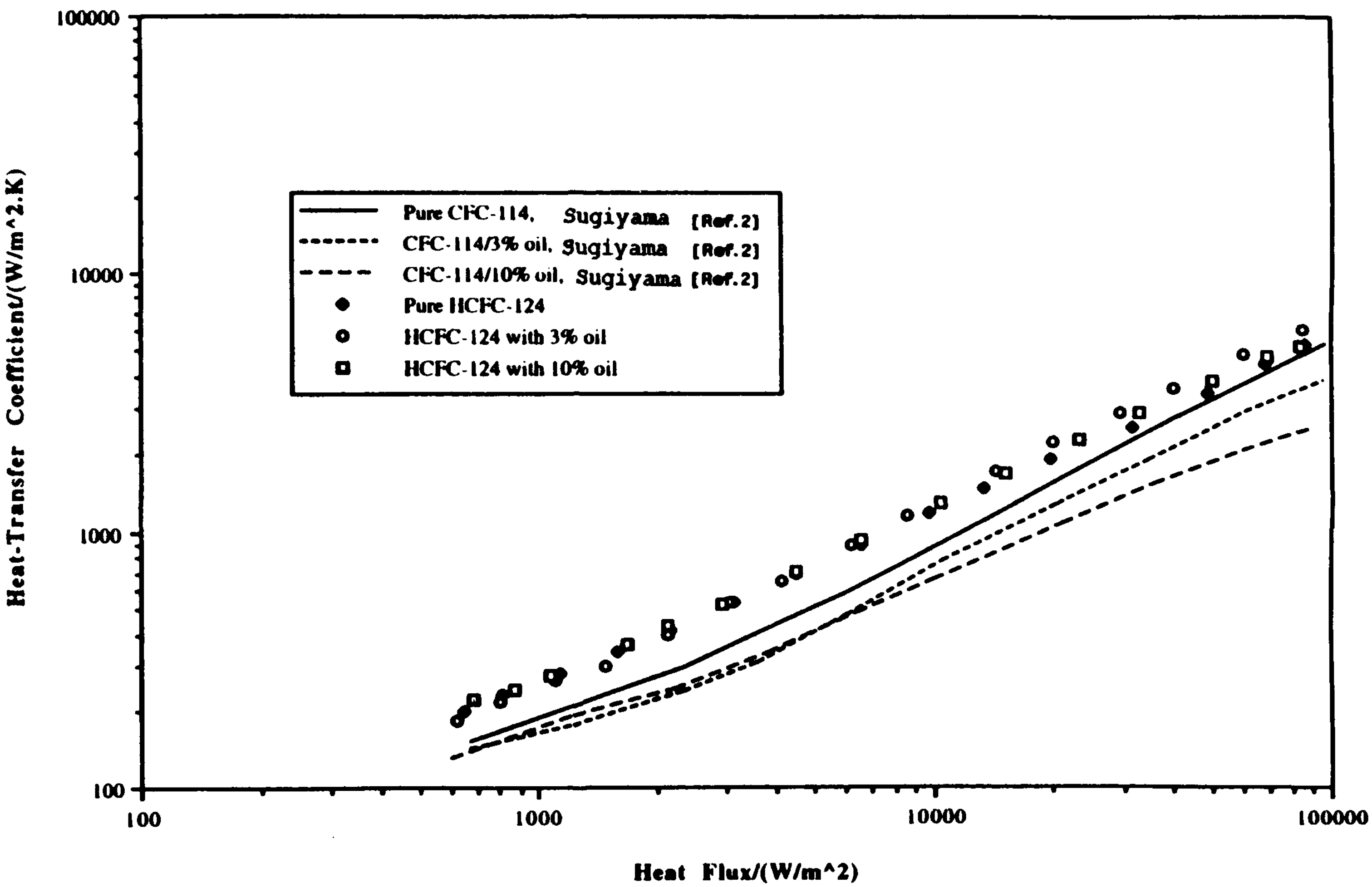


Figure 5.7 Comparison of HCFC-124 and HCFC-124/Oil Mixtures to CFC-114 and CFC-114/Oil Mixtures for Smooth Tube

f_b, nucleation site density and heat transfer increased. While conducting the tests at 2.2 ^{o}C the corresponding saturation pressure of 11 psig for R-124 is greater than the pressure of 0 psig for R-114. This suggests that the nucleation site density was greater for R-124 than for R-114 at the same saturation temperature. Added to this is the higher latent heat of vaporization, vapor density, and thermal conductivity for R-124 at this saturation temperature. The R-114/R-124 property comparison at 2.2 ^{o}C saturation temperature is summarized in Table 1. It is therefore reasonable to expect a higher heat transfer coefficient for R-124 at the tested saturation temperature of 2.2 ^{o}C.

D. BOILING PERFORMANCE OF 19 AND 26 FPI GEWA-K TUBES

Figures 5.8 and 5.9 show the heat transfer performance of a 19 fpi GEWA-K tube in pure R-124, R-124/3% oil, and R-124/10% oil during increasing and decreasing heat flux respectively. There is a consistent increase in thermal performance for oil concentrations of 3% and 10% over pure R-124 at high heat fluxes. This increase is substantially greater than that obtained with the GEWA-K 26 fpi tube for the same oil mixtures, as shown in Figures 5.10 and 5.11 for increasing and decreasing flux respectively. Surprisingly for both tubes, there seems to be a significant influence of oil in the natural convection region (Figs 5.8 & 5.10). There

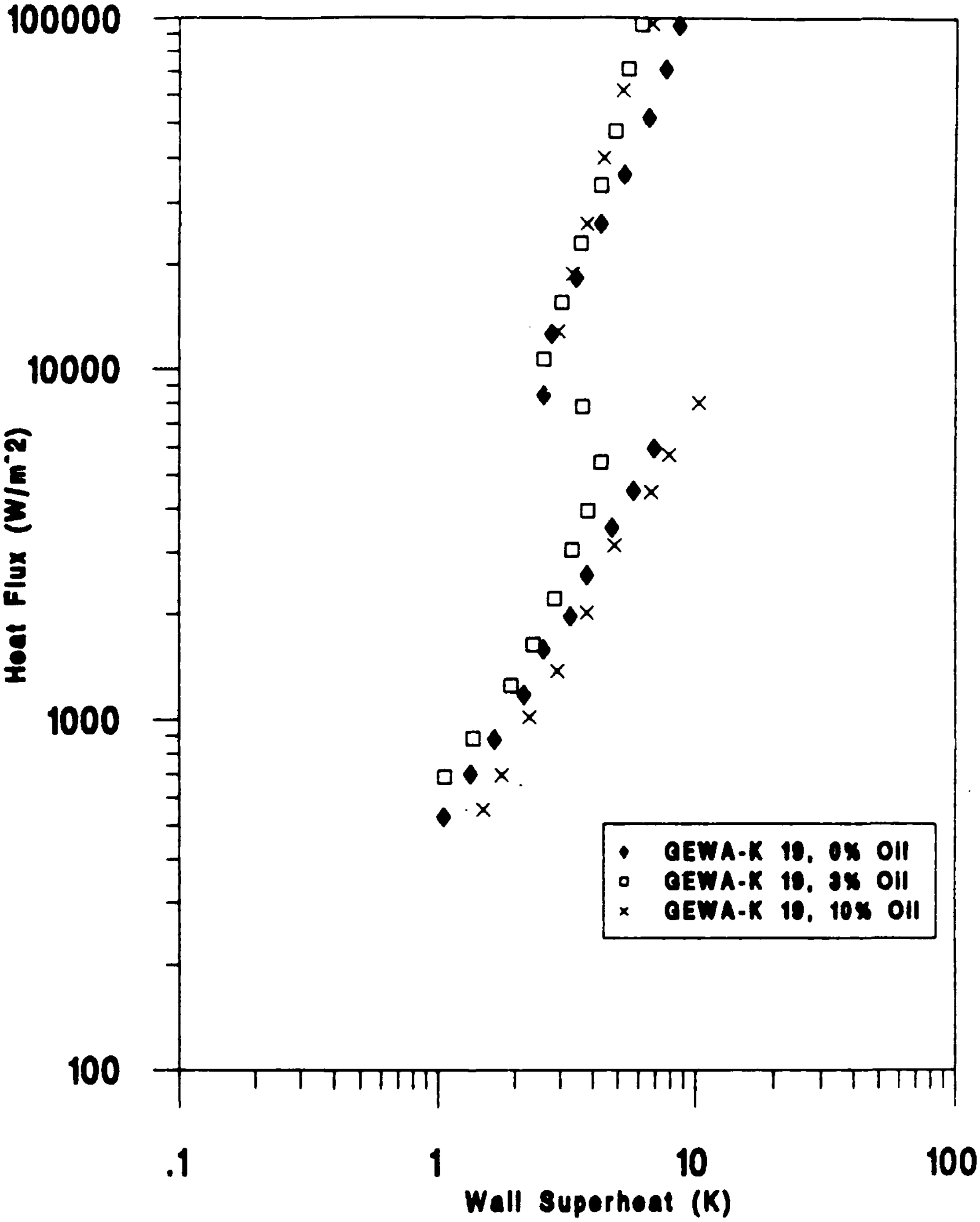


Figure 5.8 Performance Comparison for Boiling R-124/ 0%,3%,& 10% Mixtures for 19 fpi GEWA-K Tube (increasing flux)

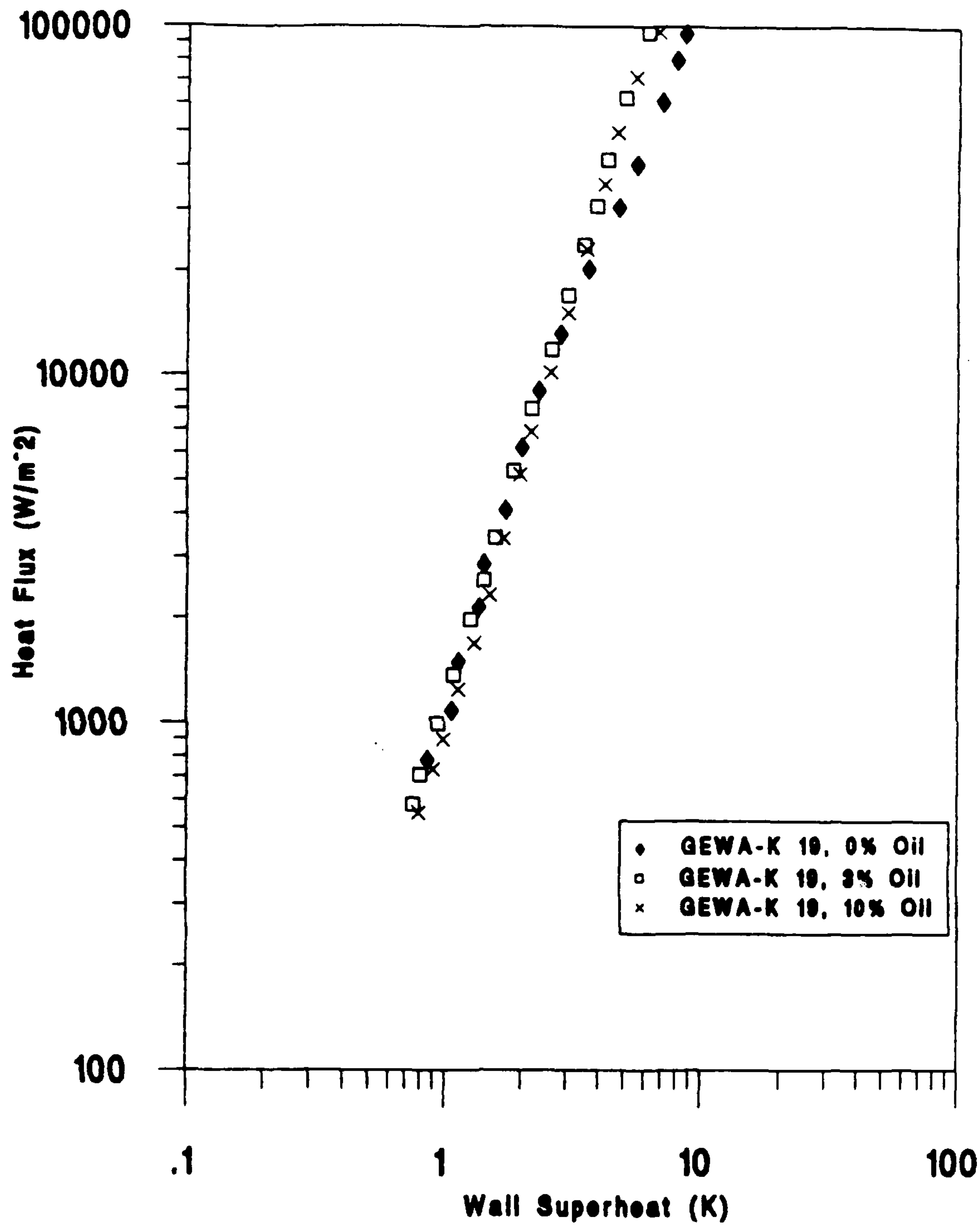


Figure 5.9 Performance Comparison for Boiling R-124/0%,3%,10% Mixtures for 19 fpi GEWA-K Tube (decreasing flux)

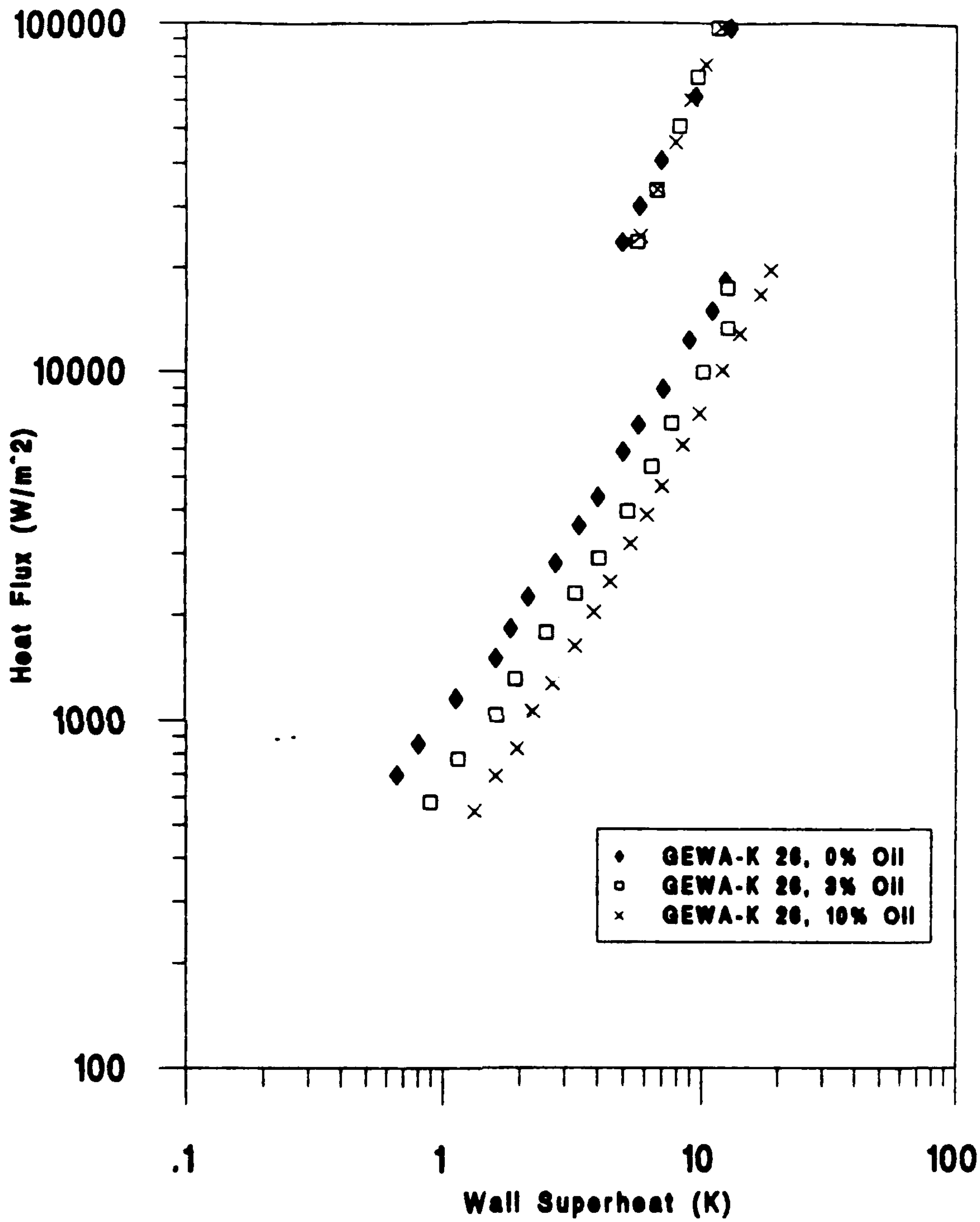


Figure 5.10 Performance Comparison for Boiling R-124/ 0%, 3%, & 10% Oil Mixtures for 26 fpi GEWA-K Tube (increasing flux)

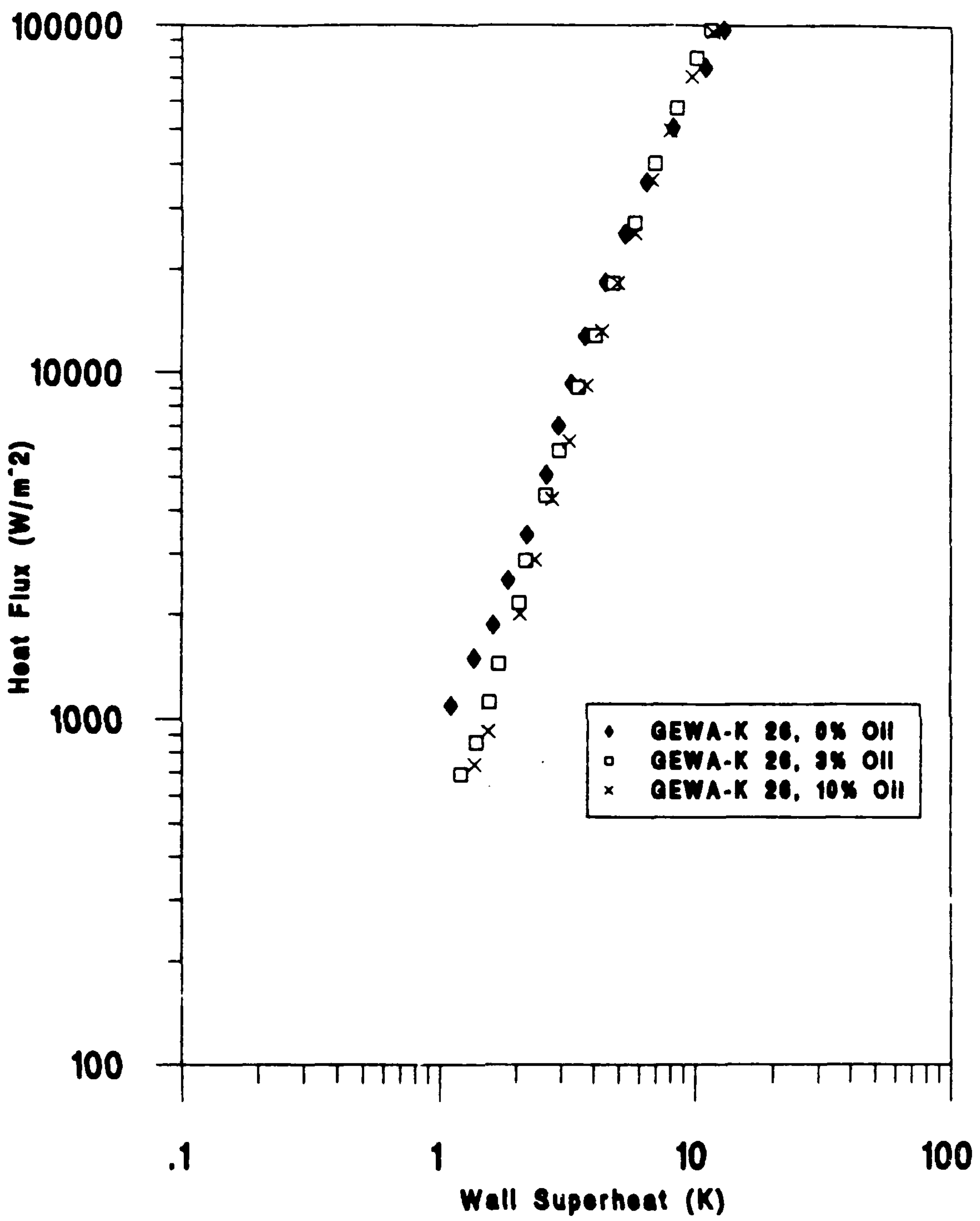


Figure 5.11 Performance Comparison for Boiling R-124/ 0%,3%, & 10% Oil Mixtures for 26 fpi GEWA-K Tube (decreasing flux)

tends to be a decrease in performance for increasing oil concentration. This was not so obvious with Sugiyama [Ref. 2] R-114 data. Once again, the point of incipience seems to be slightly delayed with increasing oil percentage. The thermal performance of the finned tube is better than the smooth tube, evidenced by thermal enhancements of 2.1 to 2.9 with the 19 fpi tube and 1.3 to 2.1 with the 26 fpi tube. However, it should be noted that the heat flux calculation does not account for the increased surface area of the finned tube, but rather uses a root diameter. Some of the enhancement is therefore due to the increased surface area of the fins (Figs. 5.24-5.26 compare heat transfer coefficients with smooth tube), with each fin behaving essentially as the copper surface of a smooth tube in terms of thermal performance.

Figures 5.12 and 5.13 compare R-124 and R-114 decreasing heat flux data for the 19 and 26 fpi GEWA-K tubes respectively for 0%, 3%, and 10% oil concentrations. The 19 fpi tube shows considerable improvement over the entire heat flux range while the 26 fpi tube shows improvement only in the low heat flux region. The improvement of the lower fin density tube can be speculated to be due in large part to better circulation and mixing between the fins. For both tubes at low oil concentrations and high heat flux, the foaming effect provides improvement in heat transfer similar to that seen with the smooth tube.

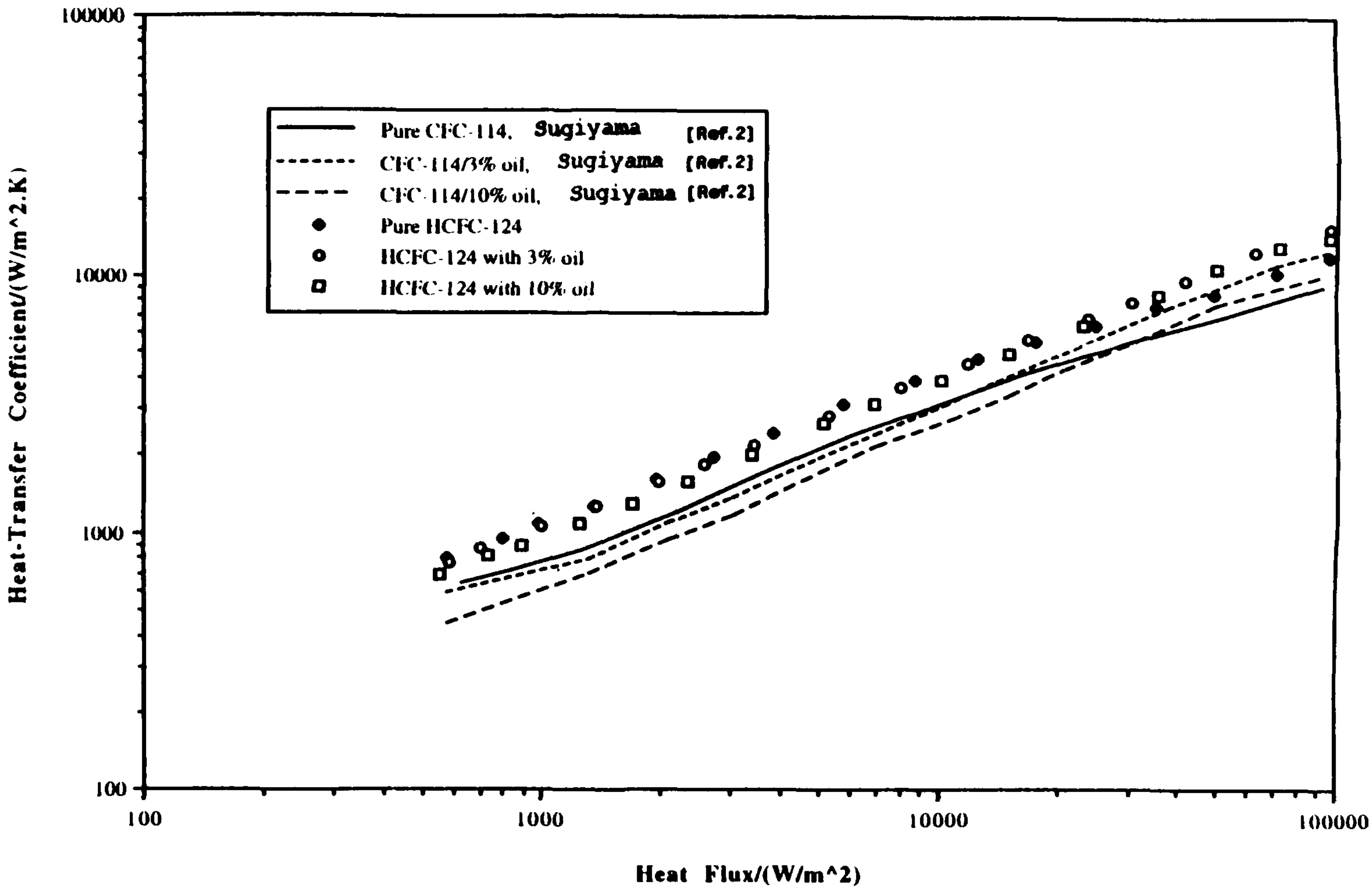


Figure 5.12 Comparison of HCFC-124 and HCFC-124/Oil Mixtures to CFC-114 and CFC-114/Oil Mixtures for 19 fpi Tube

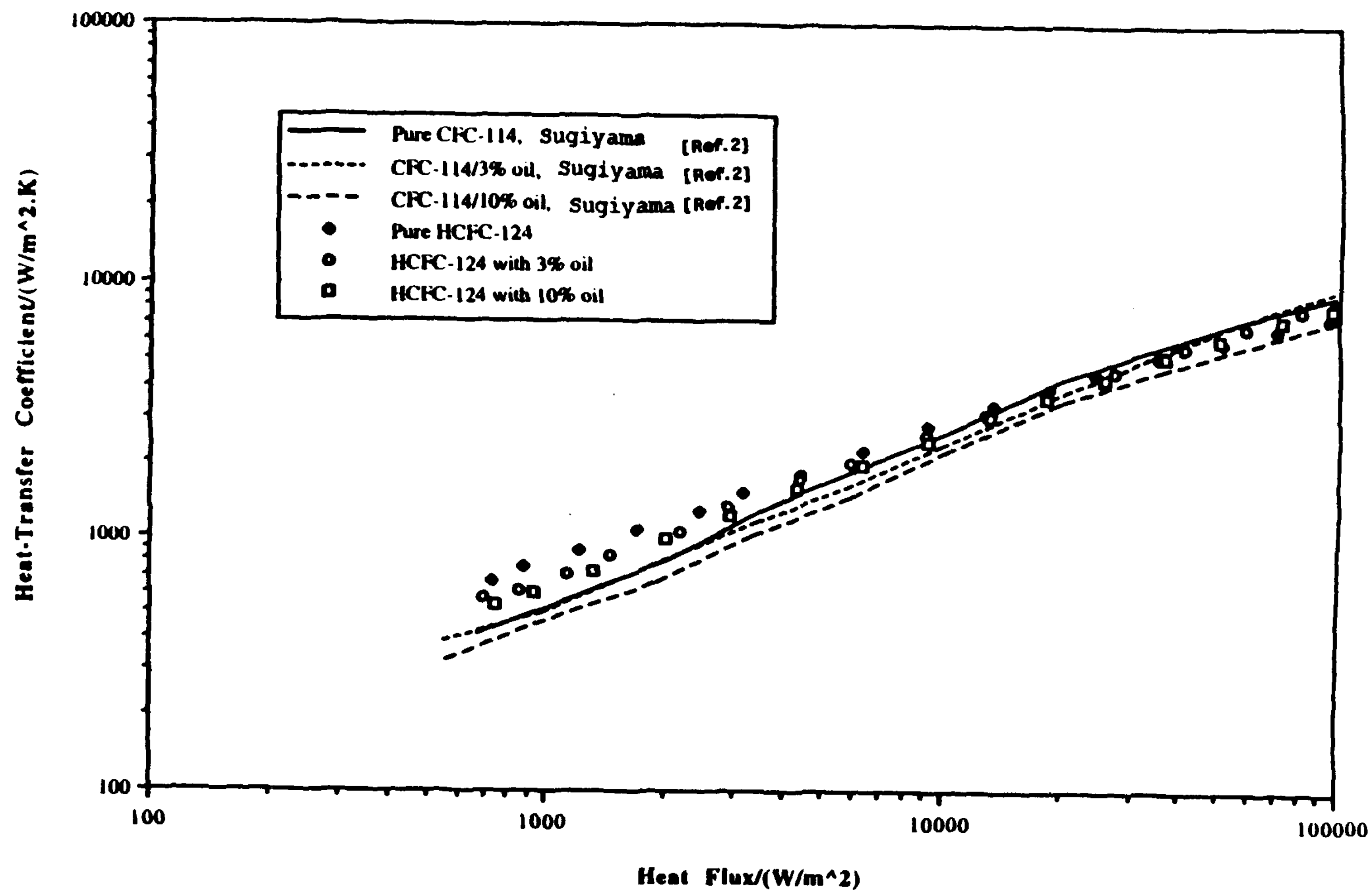


Figure 5.13 Comparison of HCFC-124 and HCFC-124/Oil Mixtures to CFC-114 and CFC-114/Oil Mixtures for 26 fpi Tube

E. BOILING PERFORMANCE OF HIGH FLUX AND TURBO-B TUBES

Figures 5.14 and 5.15 show the heat transfer performance of a HIGH FLUX tube in pure R-124, R-124/3% oil, and R-124/10% oil during increasing and decreasing heat flux respectively. Uncertainty analysis (Appendix D) was performed on the HIGH FLUX tube and typical uncertainty bands are also given. The uncertainty is largest at low wall superheat and low heat flux since the uncertainty is of the order of the measured values. It can be seen that the heat transfer performance decreases for all heat fluxes as oil concentration increases. This decrease in performance is due most likely to the oil becoming trapped within the porous coating. As the refrigerant is evaporated, a very steep concentration gradient is developed within the pores; oil diffusion is also retarded because of the presence of the interconnected pores; this is particularly severe at high heat fluxes with 10% oil mixture, where a very large drop-off in performance is seen. In the natural convection region, the effect of oil is not as pronounced as at high flux, exhibiting only minor reduction in heat transfer compared to the pure refrigerant. Any advantageous effect of foaming is negated due to the pores remaining impenetrable to the foam. Figure 5.16 compares R-124 and R-114 decreasing heat flux data for the HIGH FLUX tube for 0%,3%, and 10% oil concentrations. The trend of the data for both fluids is very similar. With such a high density of nucleation sites already

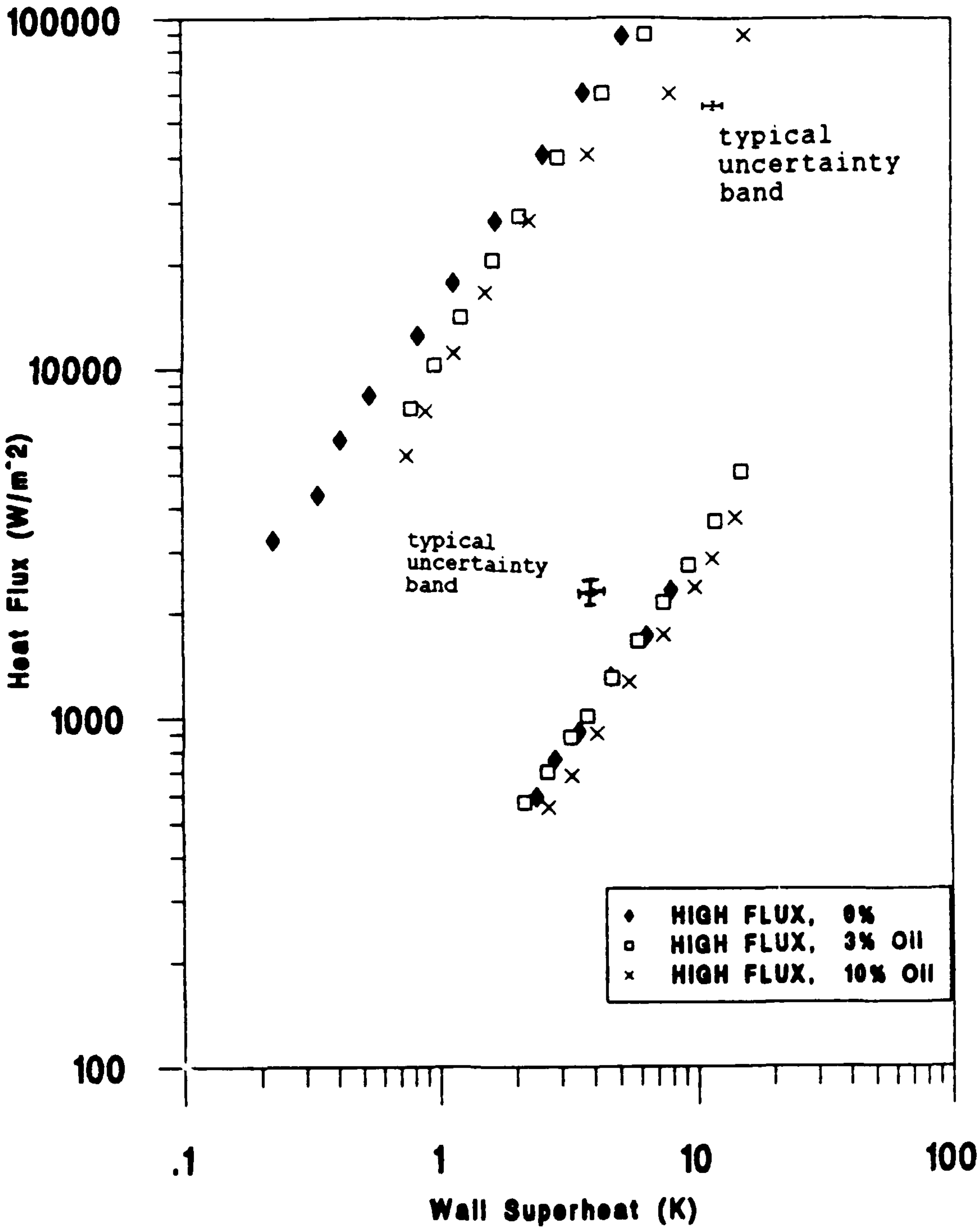


Figure 5.14 Performance Comparison for Boiling R-124/0%,3% & 10% Oil Mixtures for HIGH FLUX Tube (increasing flux)

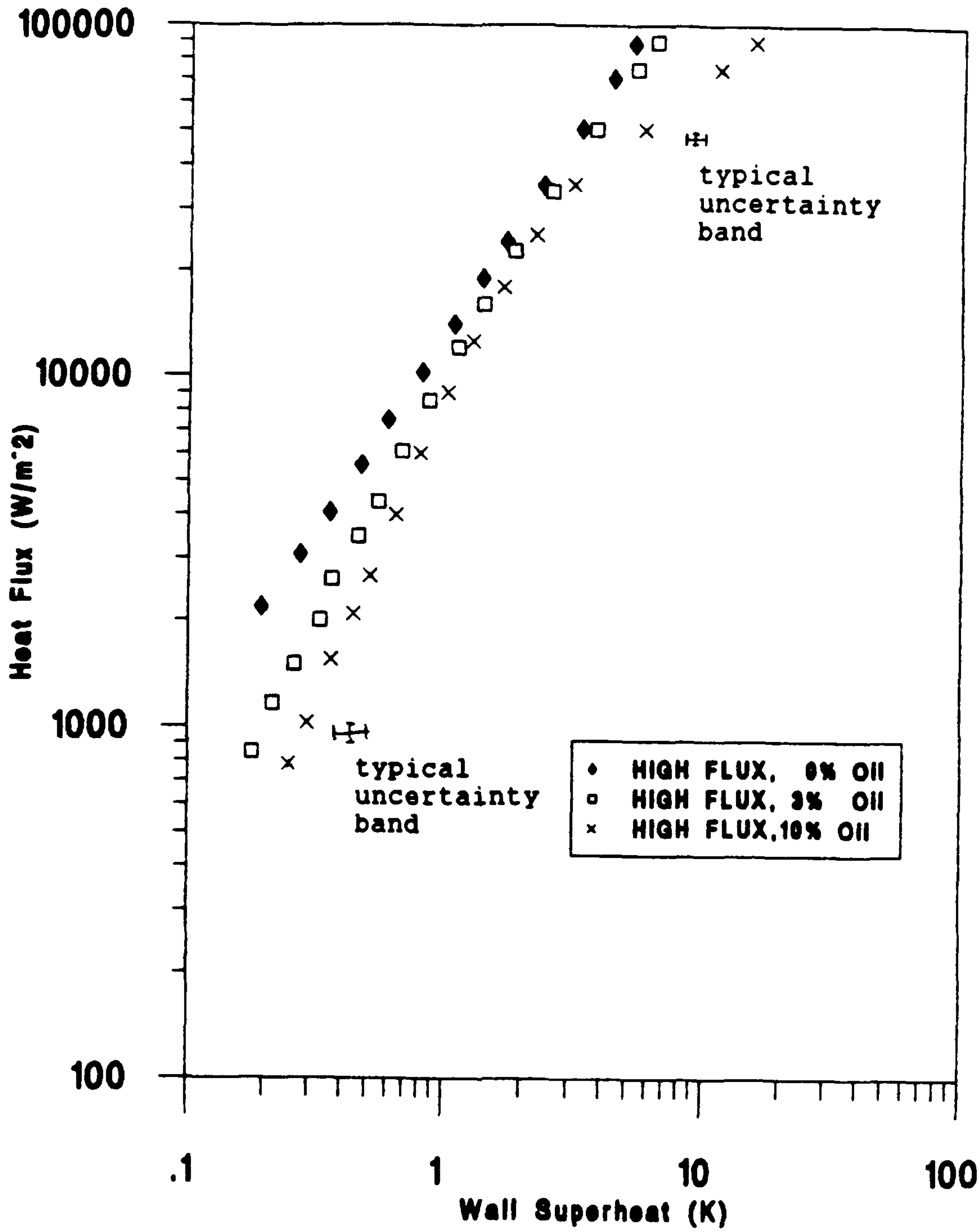


Figure 5.15 Performance Comparison for Boiling R-124/0%,3% & 10% Oil Mixtures for HIGH FLUX Tube (decreasing flux)

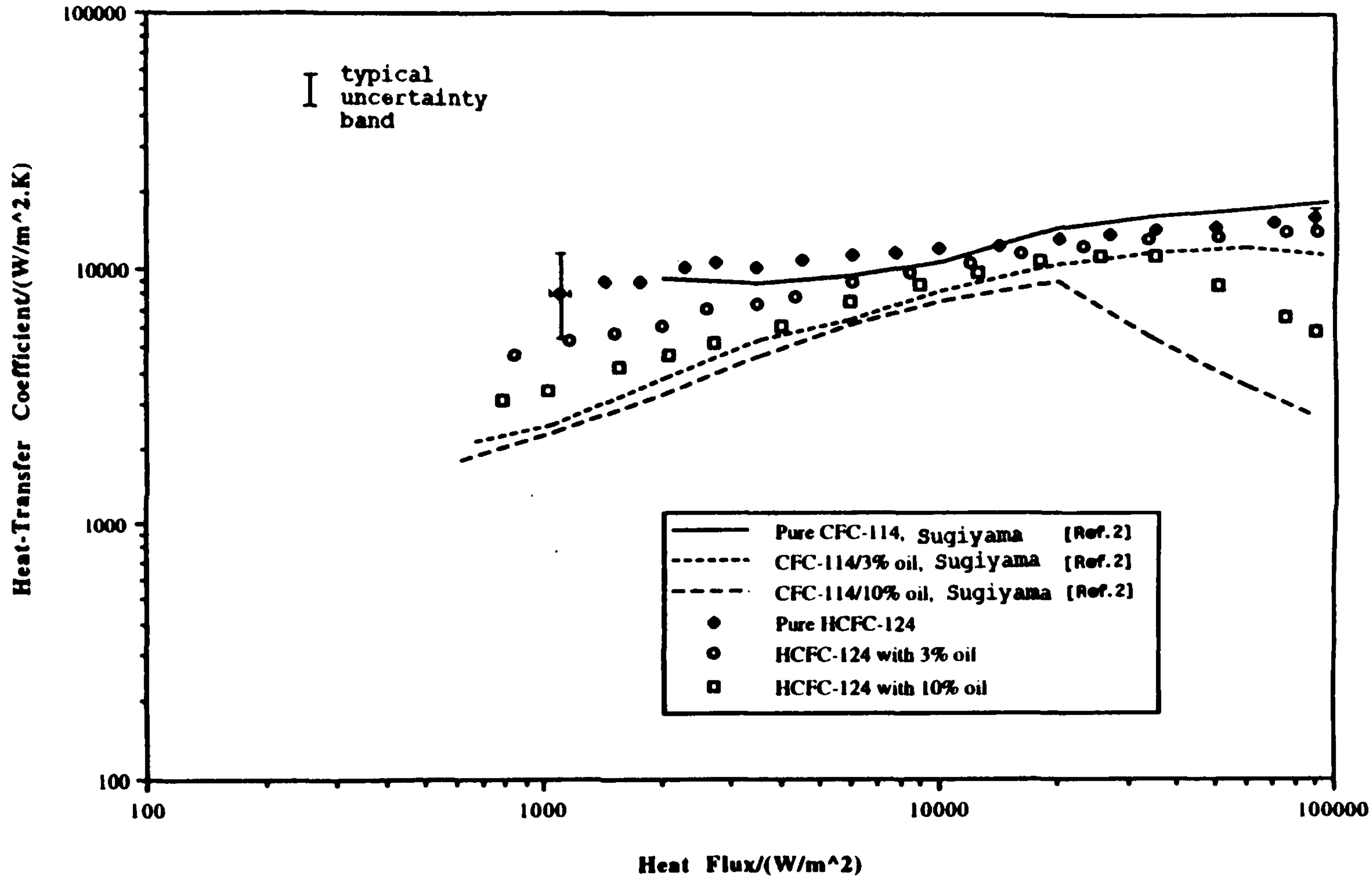


Figure 5.16 Comparison of HCFC-124 and HCFC-124/Oil Mixtures to CFC-114 and CFC-114/Oil Mixtures for HIGH FLUX Tube

present on the surface, there does not appear to be a significant thermal enhancement at higher operating pressures as seen with the finned and smooth tubes.

Figures 5.17 and 5.18 show the heat transfer performance of a TURBO-B tube in pure R-124, R-124/3% oil, and R-124/10% oil mixtures during increasing and decreasing heat flux respectively. The results of oil addition are similar to the HIGH FLUX tube. The notable exception is that at high oil concentrations and high heat fluxes, the heat transfer performance of the TURBO-B tube does not drop off as rapidly as the HIGH FLUX tube. Again, only a small effect of oil in the natural convection region was observed.

Figure 5.19 compares R-124 and R-114 decreasing heat flux data for the TURBO-B tube for 0%, 3%, and 10% oil concentrations. Again, this comparison is similar to the results already discussed with the HIGH FLUX tube.

F. EFFECT OF R-124/OIL MIXTURES ON INCIPIENCE OF NUCLEATE BOILING

Separate tests were conducted to analyze the incipience of nucleate boiling or the onset of nucleate boiling (ONB) in pure R-124 and how this was affected by the presence of oil. These tests were taken in accordance with the general procedures outlined in the preceeding chapter. However, smaller heat flux increments were applied to the test tube during the natural convection region in order to obtain the most accurate wall superheat at the ONB. Also, during these

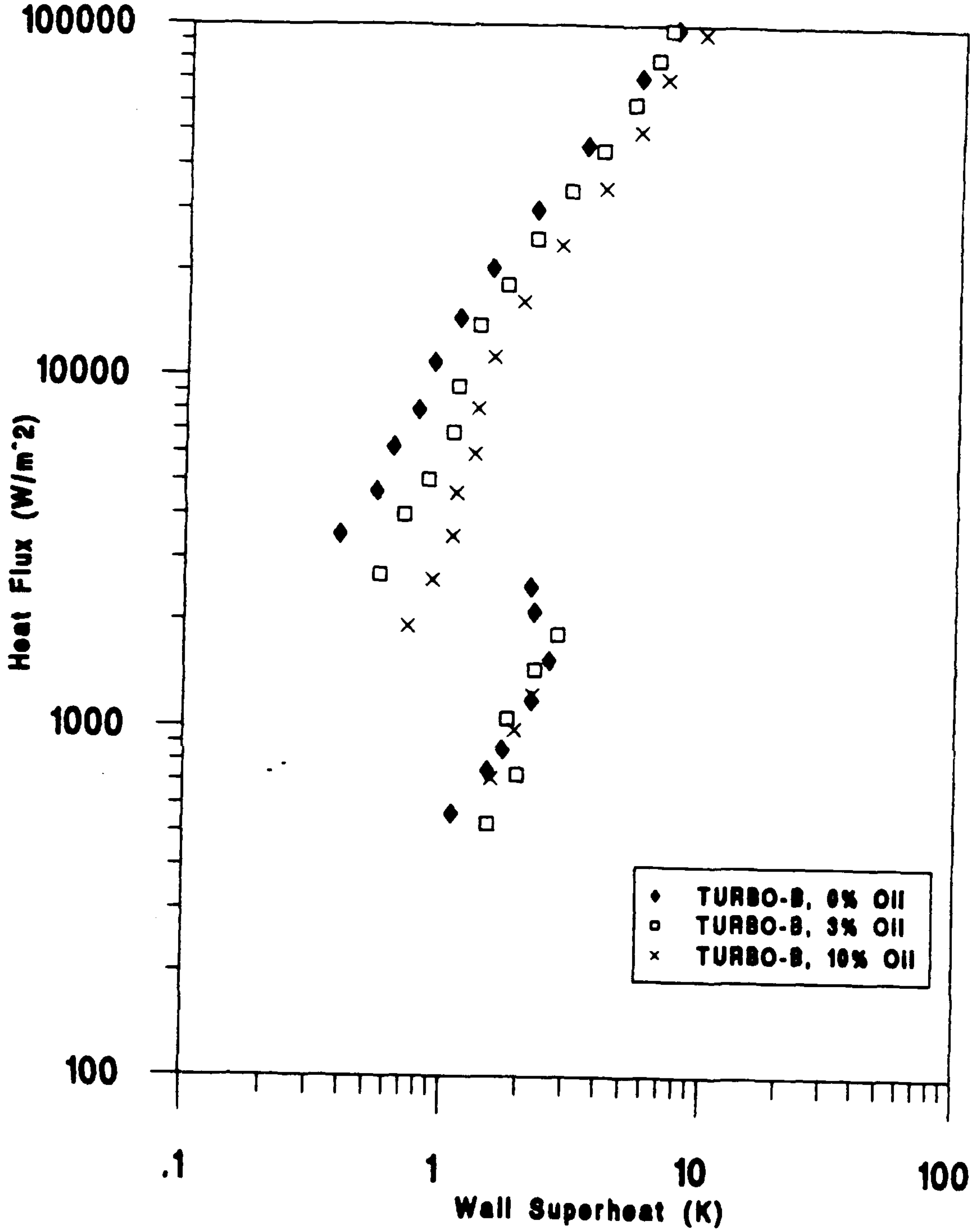


Figure 5.17 Performance Comparison for Boiling R-124/0%,3%, & 10% Oil Mixtures for TURBO-B Tube (increasing flux)

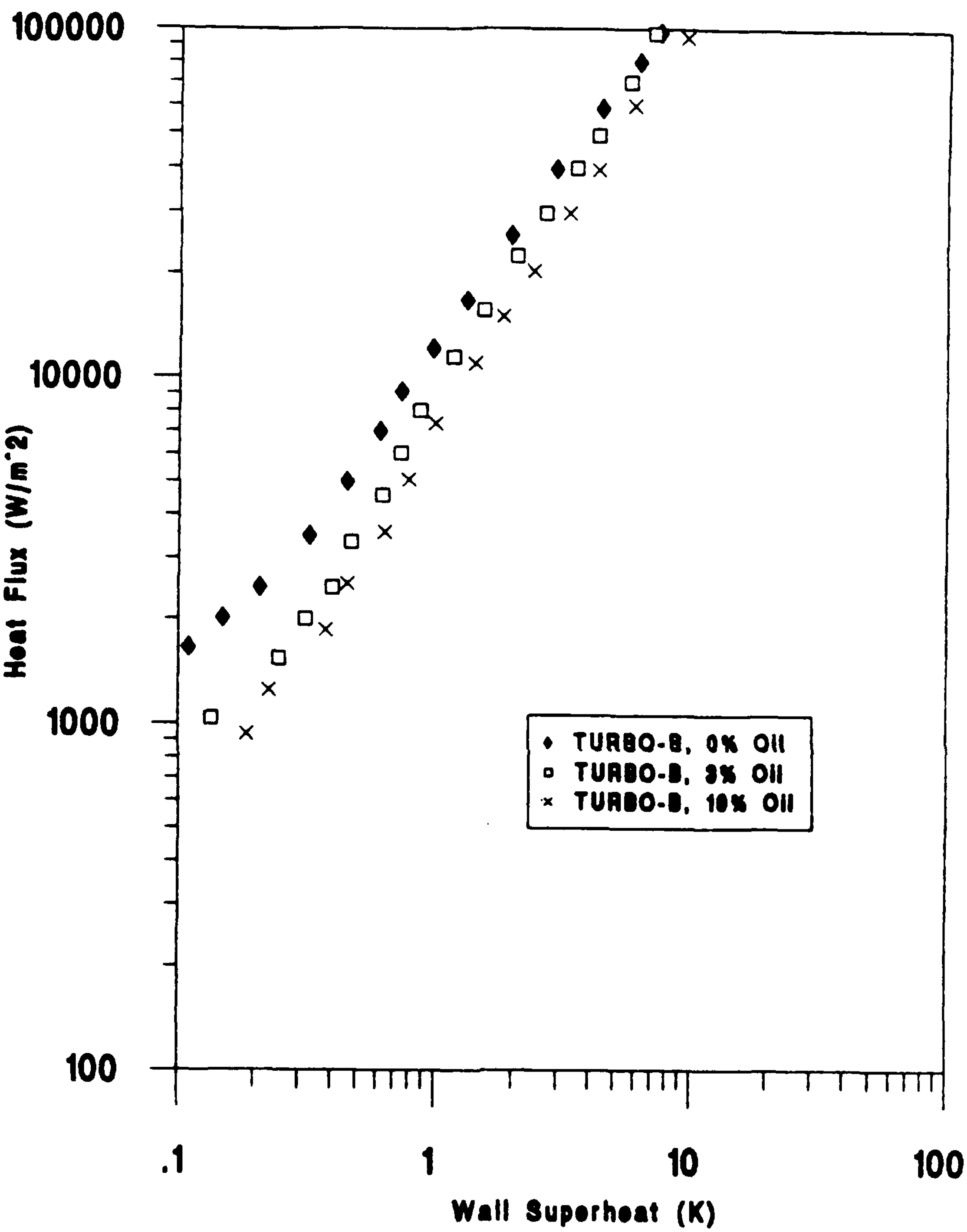


Figure 5.18 Performance Comparison for Boiling R-124/0%,3%, & 10% Oil Mixtures for TURBO-B Tube (decreasing flux)

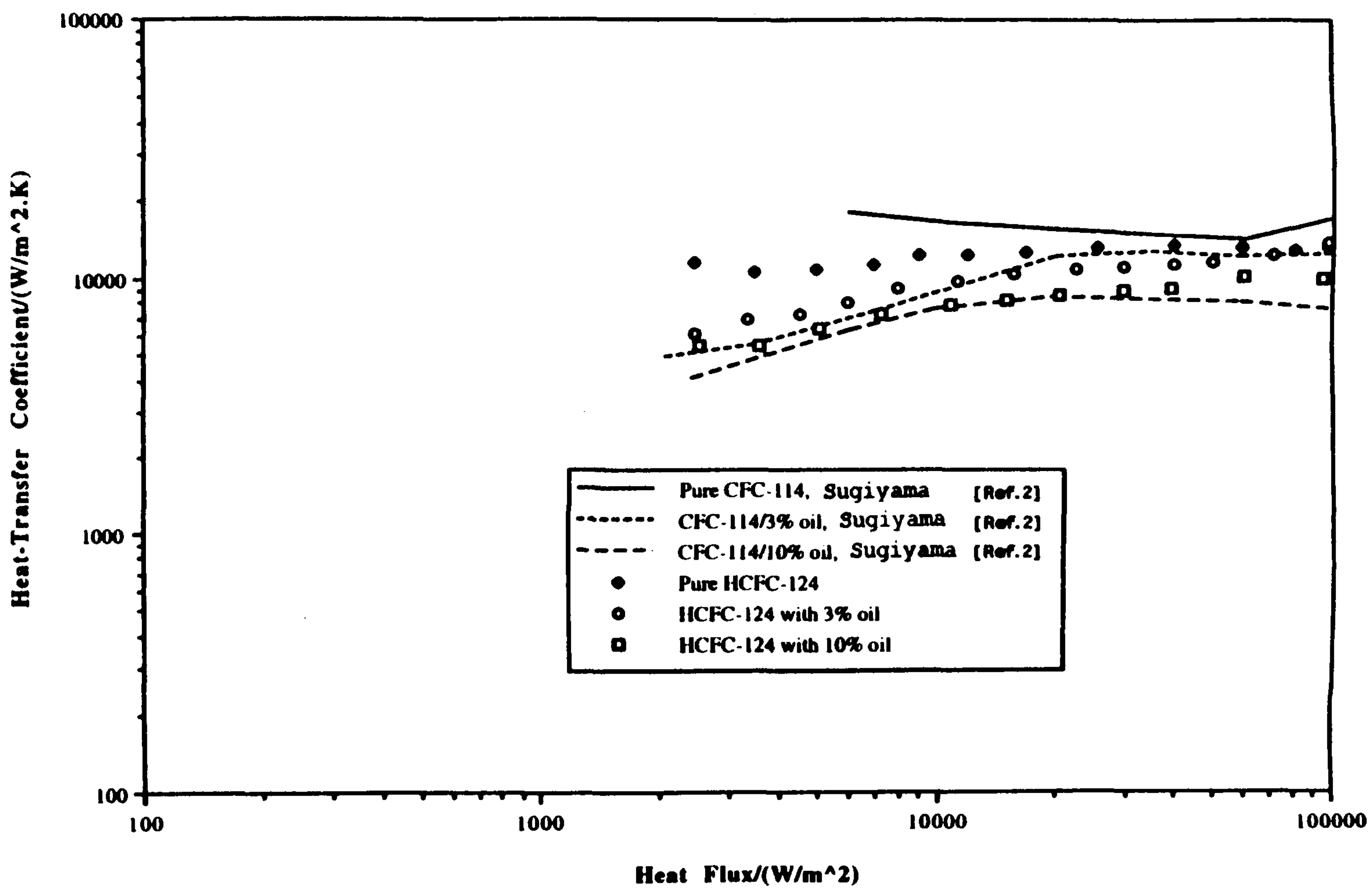


Figure 5.19 Comparison of HCFC-124 and HCFC-124/Oil Mixtures to CFC-114 and CFC-114/Oil Mixtures for TURBO-B Tube

incipience tests the refrigerant pool was cooled down at approximately half the rate of the prior increasing and decreasing heat flux runs. Each incipience test was conducted with a minimum of 8 hours between between re-testing to allow adequate time for the R-124 pool to settle and for the nucleation sites to de-activate. The maximum time allowed for the aging of the tube surface was 48 hours. Similar tests were repeated seven times on the smooth and HIGH FLUX tubes. Figure 5.20 summarizes the data on a probability chart. Due to the statistical nature of ONB, You et al [Ref. 16] proposed this chart as the best means of presenting incipient data. The seven incipient wall superheats for each condition are given for the smooth and HIGH FLUX tube at 0%, 3%, and 10% oil concentrations as the percent probability of nucleation occurring. For example, the smooth tube in pure refrigerant never nucleated at a wall superheat less than 12°C. Also the data show that for a smooth tube in pure R-124, nucleation occurred four times at a wall superheat greater than 20 °C, and three times at a lower wall superheat; this corresponds to a probability of nucleation occurring at a superheat of 20 °C between 3/7 (43)% and 4/7 (57)%. As the superheat further increases, the probability increases also until at a superheat of 28°C there is a 100% probability of nucleation. Bar-Cohen [Ref. 3] also reported widely varying R-113 superheats when 'departure from convection' or nucleation occurred. The

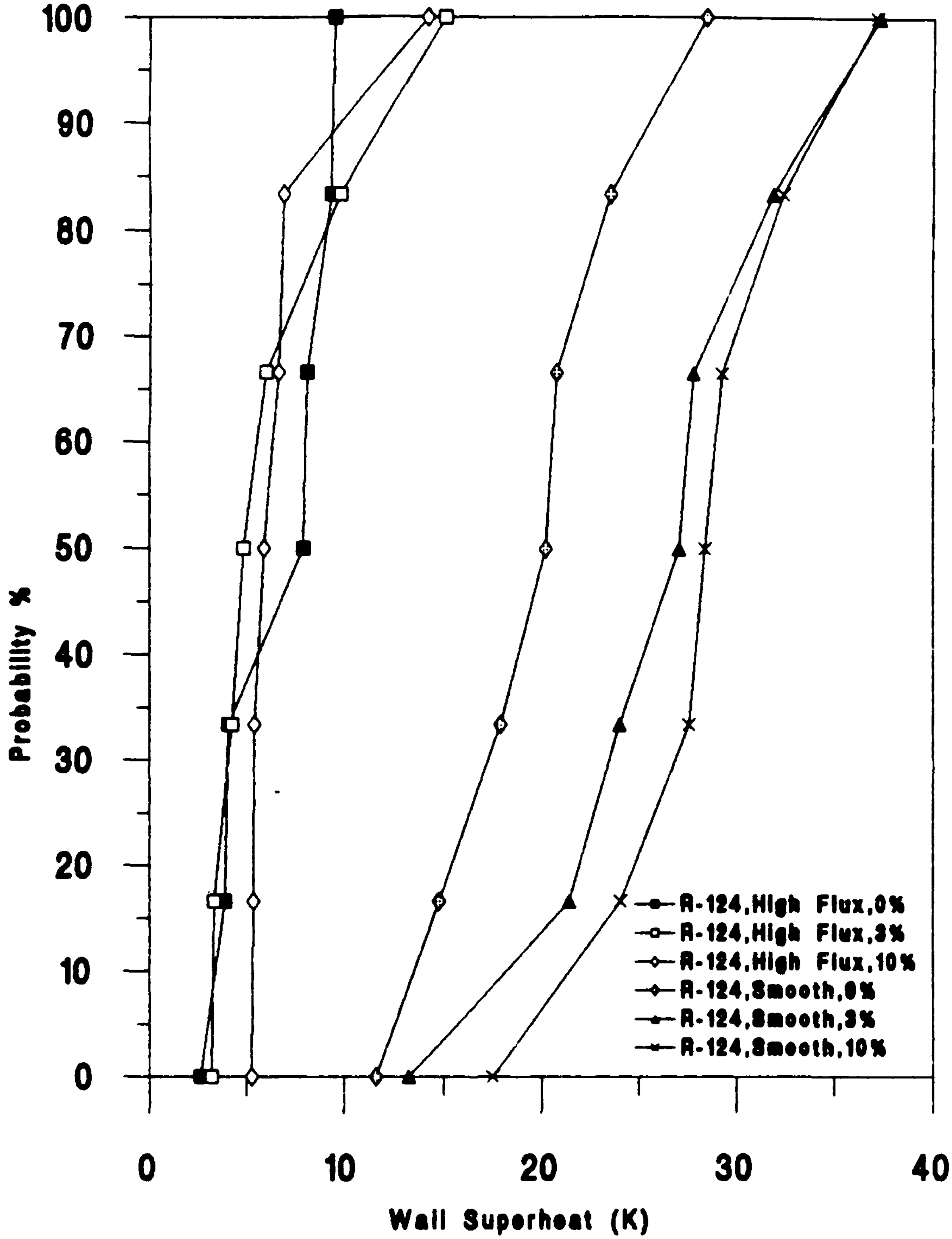


Figure 5.20 Probability of Nucleation Occurring with Smooth and HIGH FLUX Tube for 0%,3%, & 10% Oil Mixture

probability chart of Figure 5.20 can be made more accurate by plotting a greater number of incipient superheats for each tube.

For the smooth tube, there is a distinct shift to higher superheats with increases in oil concentration. This represents a delay in incipience caused by the addition of oil. Memory and Marto [Ref. 10] conducted similar tests with R-114 and R-114/oil mixtures and reported the oil concentration to have no systematic effect on the point of incipient boiling for the smooth tube. Wanniarachchi et al [Ref. 9] reported an increase in the wall superheat needed to initiate boiling for the smooth tube in R-114 with 10% oil, noting that 3% oil caused no increase. Memory and Marto [Ref. 10] precicted the effect of oil on superheat needed to nucleate from a vapor-filled cavity by incorporating the physical properties of the refrigerant/oil mixture into a nucleation parameter (N) given by Marto and Lepere [Ref. 17]:

$$N = \sigma \cdot T_{sat} / \rho_{vapor} \cdot h_{fg}$$

If the parameter were to increase, a delay in the incipient point with increasing oil concentrations would appear likely. However, it is not clear how the oil effects this parameter; with the smooth tube in R-124/oil mixtures it resulted in a delay in incipience, while the HIGH FLUX tube exhibited no distinct delay in incipience. Also the HIGH FLUX tube has a whole range of sites that can be easily activated while the smooth tube only tends to have very small sites which may move outside the range of sites that can be activated when a refrigerant/oil mixture is used.

In the case of pure refrigerant, it does appear that with the relatively few incipient tests conducted, the wall superheats at incipience for the smooth and HIGH FLUX tubes are larger on average for R-114 than for R-124. This initial result would support the approximately 50% greater nucleation parameter of R-114 over R-124. This subject requires further study.

Figure 5.21 shows an expanded view of the smooth tube's heater sleeve rolled out to show the exact locations of each thermocouple (longitudinal and circumferential) imbedded on the surface of the sleeve. Several data sets were taken for the smooth tube and then repeated after reversing the position of the tube within the pool. This procedure was conducted to see if there were any noticeable trends in the thermocouple readings which may be an indication of local hot or cold regions within the pool. However, this reversal of the tube had no consistent effect on the thermocouple readings or the point at which nucleation occurred. This appears to underline the uniformity of thermocouple output within the pool. A more detailed survey of this data needs to be done.

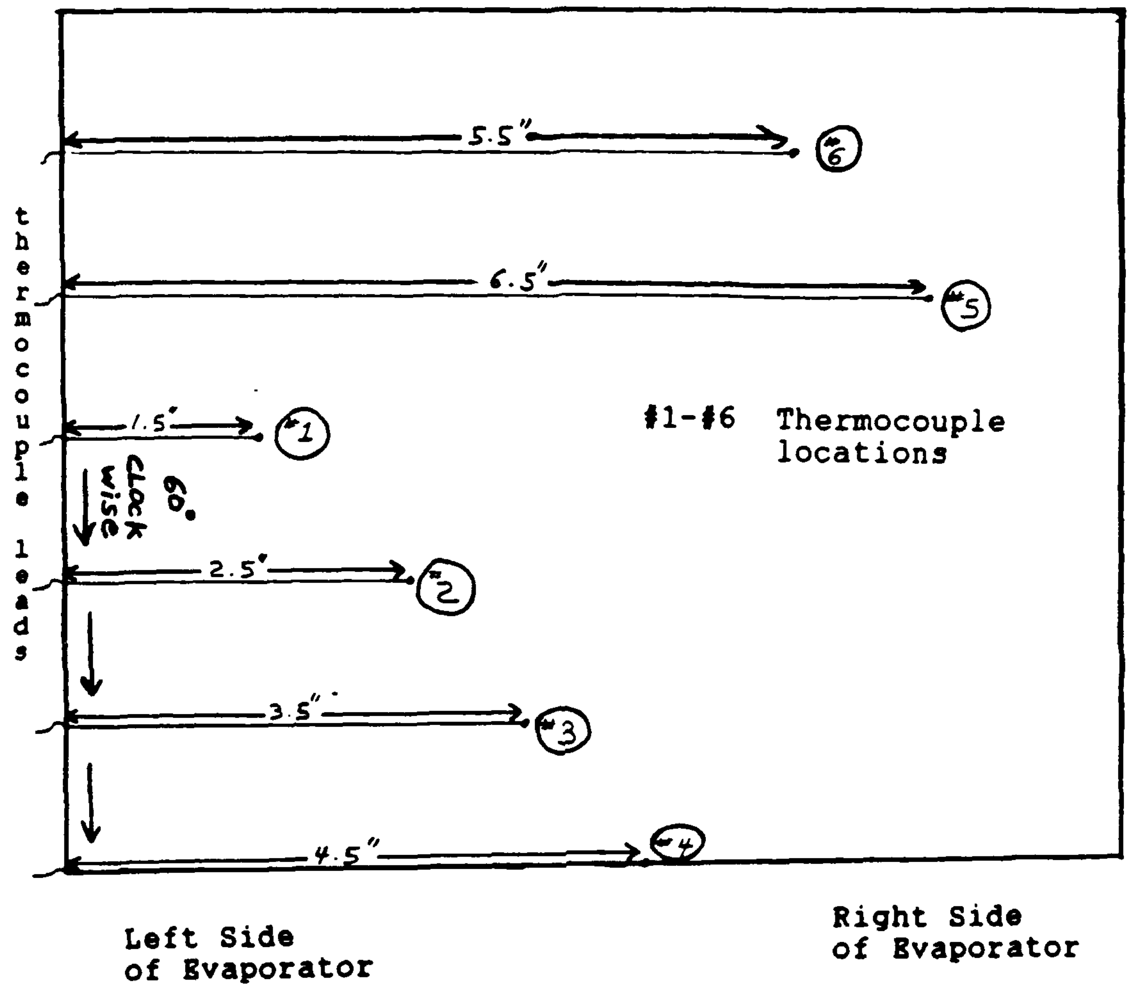


Figure 5.21 Expanded View of Thermocouple Locations within the Heater Sleeve of Smooth Tube (#1 at 12 O'clock)

G. SUMMARY OF THE R-124 DATA

Figures 5.22 and 5.23 summarize the effect of all oil concentrations (0,1,2,3,6,&10%) in R-124 for the five tubes at heat fluxes of 25 and 90 KW/m^2 respectively; 25 kW/m^2 represents a typical operating heat flux. For each tube, the ratio of the heat-transfer coefficient at a given oil concentration divided by that for the same tube in pure R-124 is given. At low heat flux, the smooth tube and the 19 fpi tube give an increase in performance as oil is added, up to concentrations of 6%. The smooth tube does the best in this respect, giving an increase in heat transfer of about 23% (compared to a smooth tube in pure R-124) at 6% oil concentration. The HIGH FLUX and TURBO-B tubes show a decrease in performance as oil is added, while the 26 fpi tube shows no change. At the highest oil concentration (10%), performance for all tubes is worse than that at 6%, although the smooth tube still indicates better heat transfer than when no oil was added, which is rather surprising. Similar trends were obtained for R-114, although at 10% oil, all tubes had poorer heat transfer than with no oil. At higher heat flux, general effects are similar, although now the 19 fpi tube shows the best performance of about 35% at 6% oil concentration. Interestingly, between 3 and 6% oil concentrations, all tubes except the HIGH FLUX tube show improved heat transfer over the same tube in pure refrigerant. Although below 3% oil there is an unexplained 'dip' in the heat transfer coefficient ratio with the TURBO-B tube. The HIGH FLUX surface has very poor performance at 10% oil concentration, being only 35% of that in the pure fluid.

Figures 5.24, 5.25 and 5.26 compare the five tubes directly for oil concentrations of 0, 3, and 10% respectively. From these figures, enhancements (ie. improvement in heat transfer compared to the smooth tube) can be calculated at any desired heat flux. These are provided in Table 4 at heat fluxes 25 and 90 kW/m^2. The advantages of enhanced surfaces are clearly apparent. The smooth tube always has the poorest performance (as expected) and is used as a base-line with which the other tubes are compared. Between the finned tubes, the 19 fpi tube consistently outperforms the 26 fpi tube at all heat fluxes and oil concentrations: enhancements range between 2.1-2.9 for the 19 fpi tube and 1.3-2.1 for the 26 fpi tube. Indeed, at the highest heat fluxes at 10% oil concentration, the 19 fpi tube is the best tube tested (enhancement of 2.6). The GEWA-K 19 fpi tube to smooth tube area ratio is 2.4, while the GEWA-K 26 fpi tube to smooth tube area ratio is 3.2. The HIGH FLUX and TURBO-B tubes are the best tubes over most conditions of heat flux and oil concentration, with both having fairly equal performance. The exception is the HIGH FLUX tube at high heat flux and oil concentration, where performance drops off rapidly, as already mentioned. Over practical heat flux ranges (15-30 kW/m^2) therefore, the porous coated and modified fin tubes are the best for all oil concentrations. Although the TURBO-B and HIGH FLUX tube performance is degraded at 10% oil concentration, in-service oil separators should maintain a 3% or less concentration in an actual evaporator system. At this level, the TURBO-B and HIGH FLUX tube are superior at normal chiller heat flux between 10 and 30 KW/m^2.

A point of interest worth noting was that the Viton and neoprene O-rings used experienced considerable swelling of approximately 30% by volume when subjected to R-124. This was enough to prevent their re-use when the Teflon inserts were removed to change the tube. Also noted was that the O-rings only swelled when taken out of the system. When undisturbed, they maintained a good seal (this might not be true if the tube were sliding past the O-ring). Also significant, after removed from use within the apparatus for 60 days, both types of O-rings did shrink back to their original size.

Table 4. ENHANCEMENT SUMMARY FOR R-124

Heat Flux	25 kW/m^2			90 kW/m^2		
Oil Concentration	0%	3%	10%	0%	3%	10%
Smooth	1.0	1.0	1.0	1.0	1.0	1.0
19 fpi	2.9	2.7	2.8	2.1	2.4	2.6
26 fpi	2.1	1.7	1.8	1.3	1.3	1.5
HIGH FLUX	6.2	4.9	4.8	2.9	2.3	1.1
TURBO-B	6.0	4.3	3.7	2.4	2.2	1.9

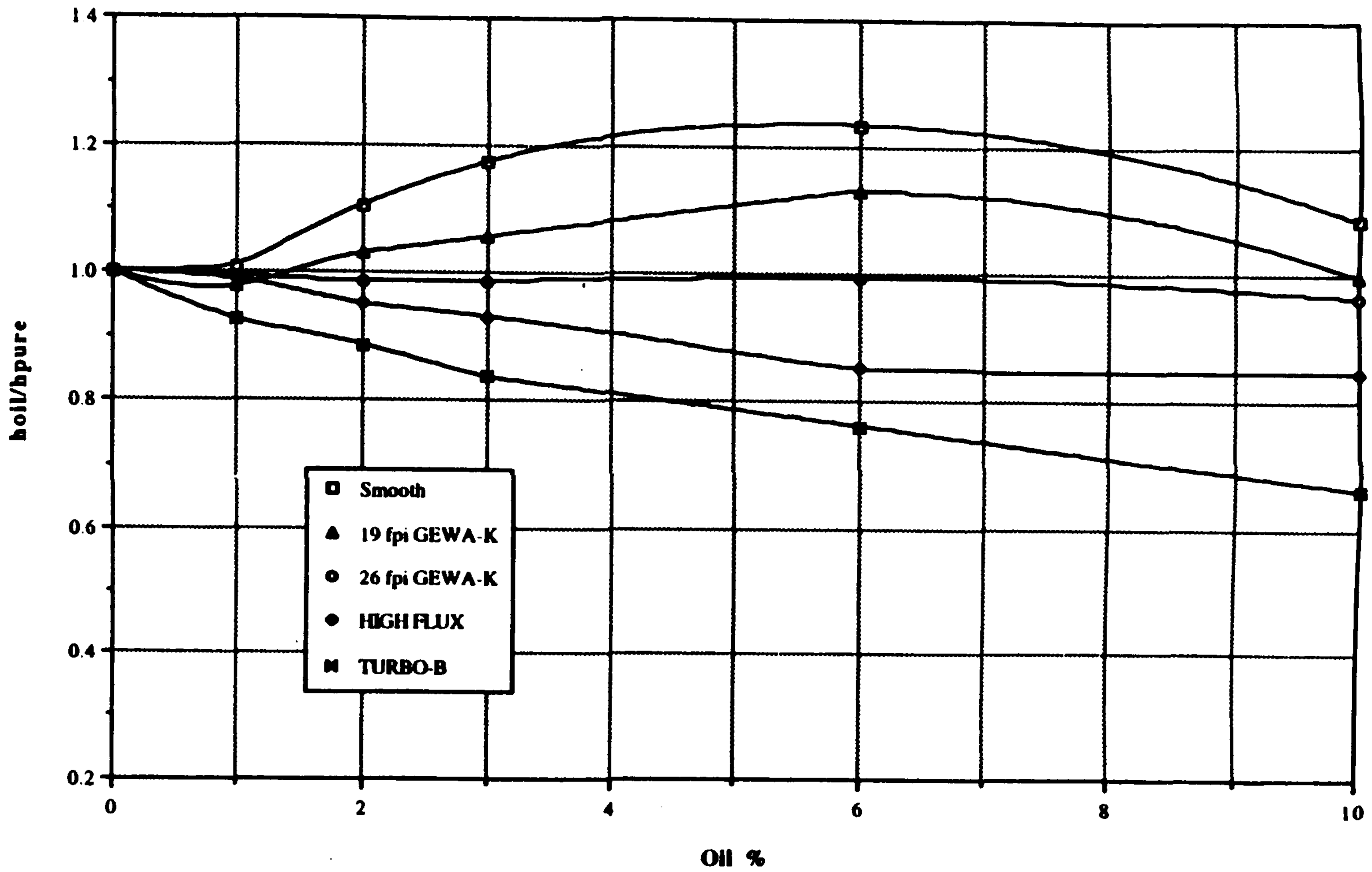


Figure 5.22 Effect of Oil Concentration on Heat Transfer Coefficient at a Heat Flux of 25 kW/m²

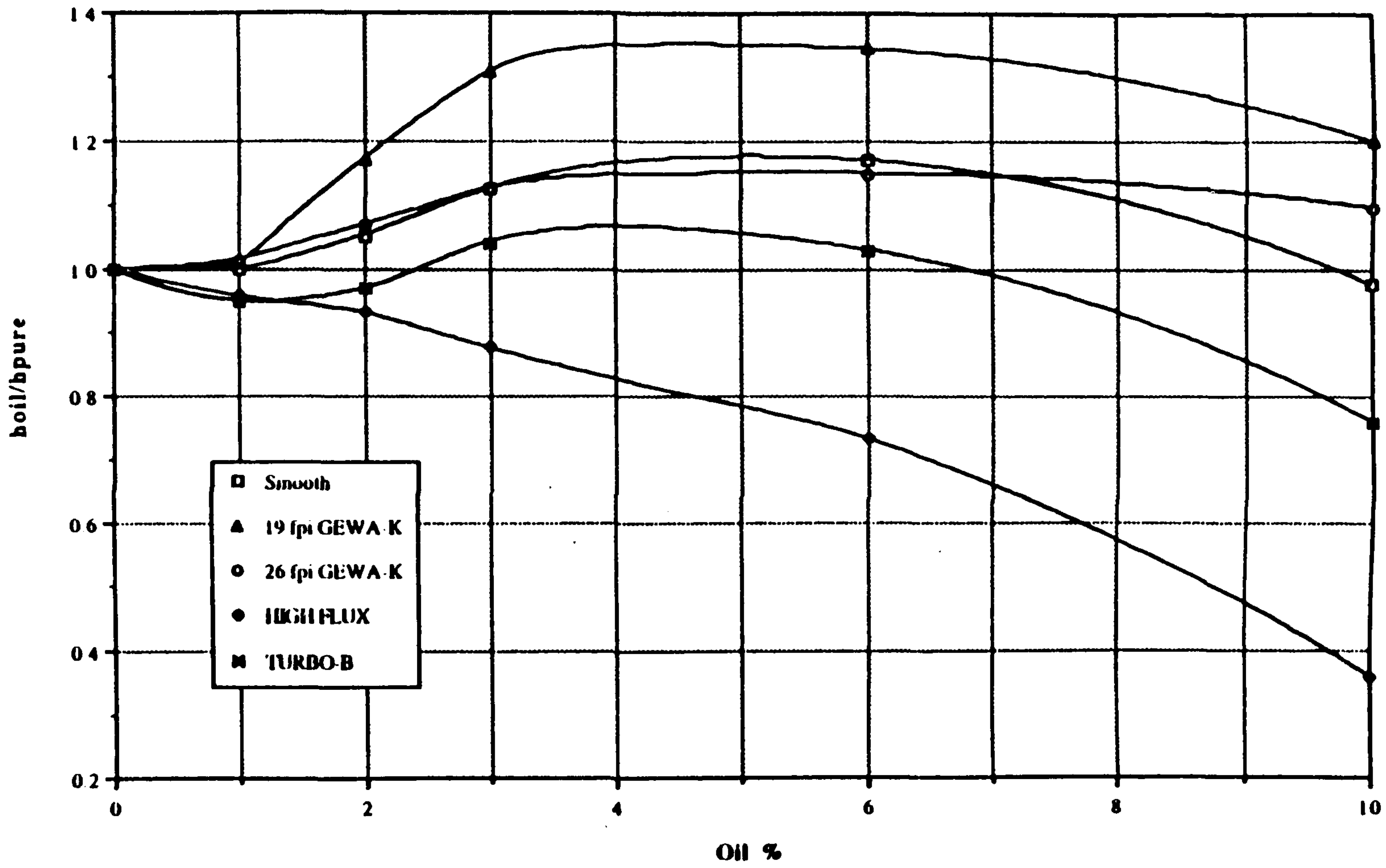


Figure 5.23 Effect of Oil Concentration on Heat Transfer Coefficient at a Heat Flux of 90 kW/m²

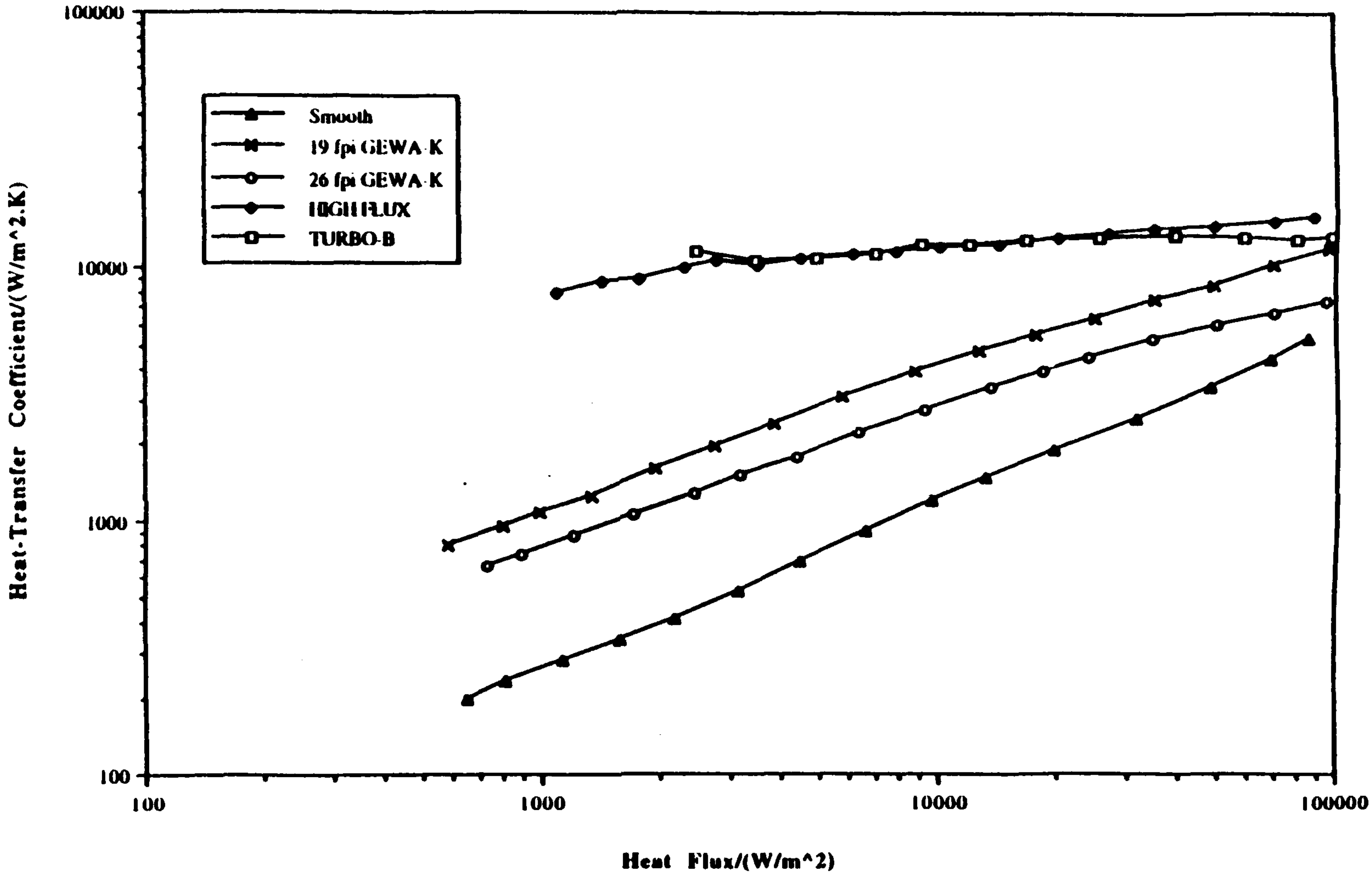


Figure 5.24 Comparison of All Tubes at 0% Oil Concentration in R-124

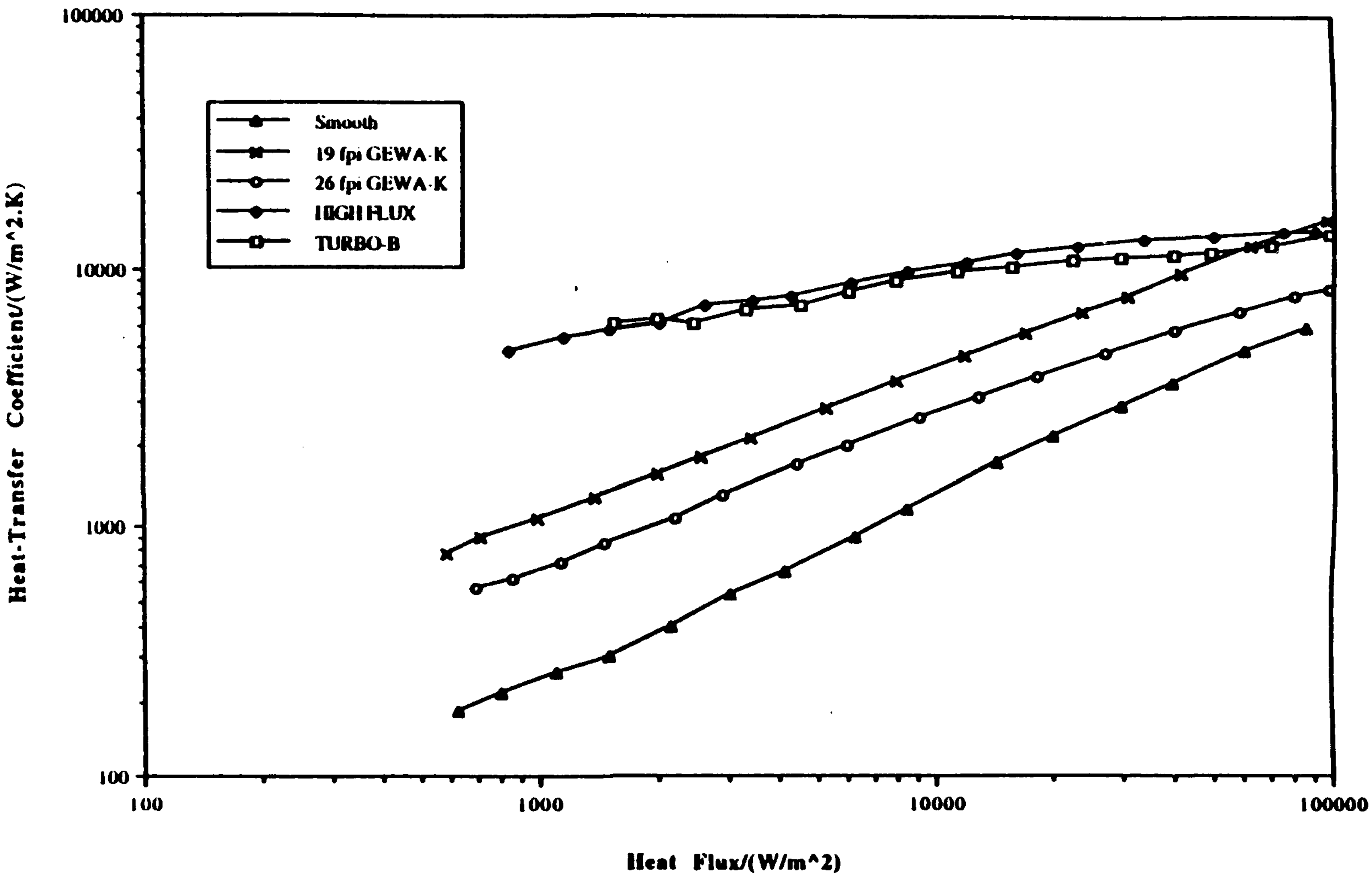


Figure 5.25 Comparison of All Tubes at 3% Oil Concentration in R-124

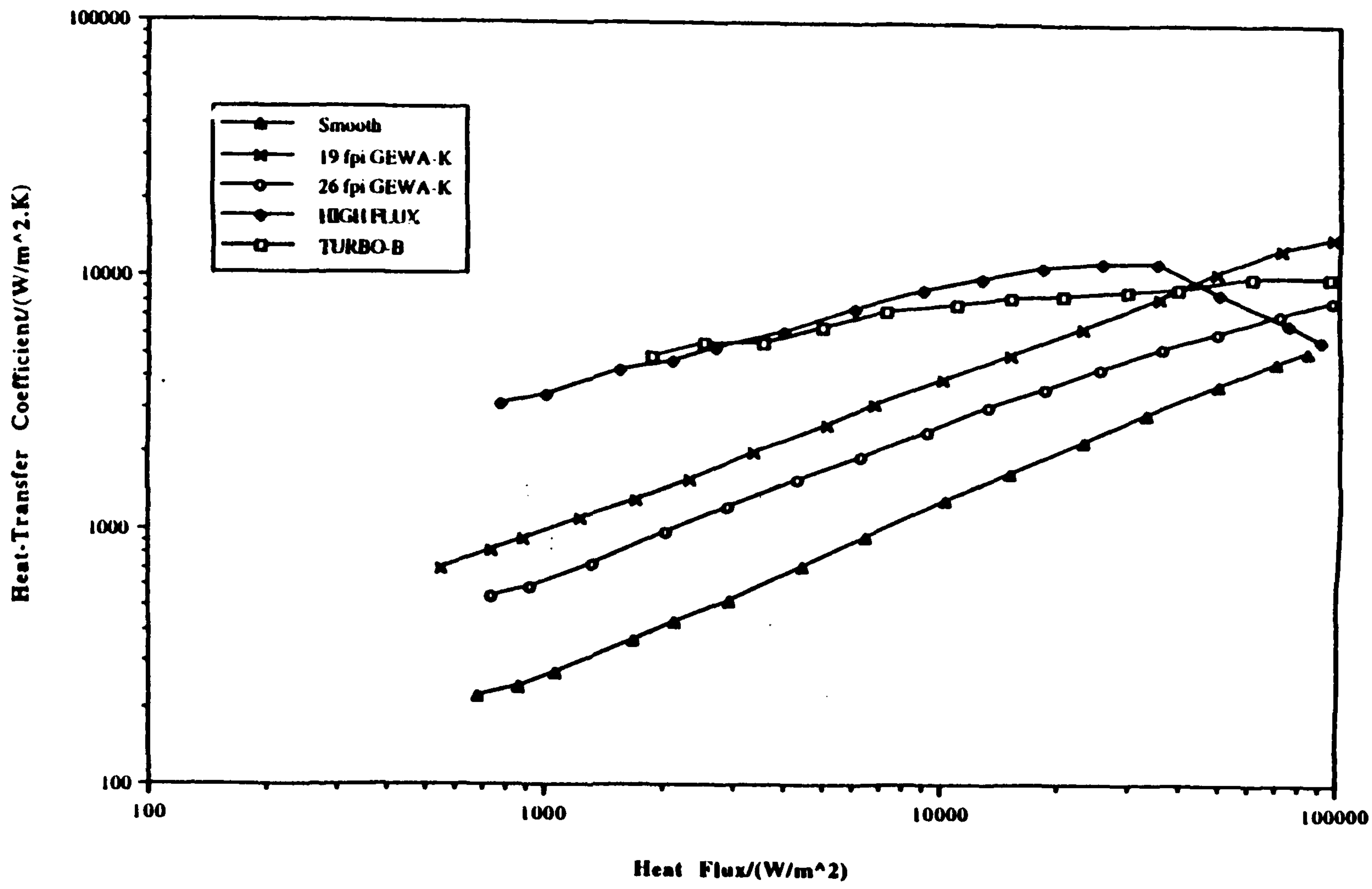


Figure 5.26 Comparison of All Tubes at 10% Oil Concentration in R-124

VI. CONCLUSIONS

1. For the smooth and finned tubes, significant improvements in heat transfer (>50%) were obtained in pure R-124 compared with pure R-114 at the same saturation temperature. This was attributed to the higher saturation pressure of R-124 activating more nucleation sites and the higher latent heat of vaporization, vapor density, and thermal conductivity of R-124 over R-114.

2. For the HIGH FLUX and TURBO-B surfaces, performance in the two refrigerants was similar, since the number of active nucleation sites is already high.

3. For pure R-124, the HIGH FLUX tube gave the largest enhancement of any tube over the whole range of heat flux.

4. For the smooth and finned tubes, significant improvements in the heat transfer (>50%) were also obtained in R-124/oil mixtures when compared with R-114/oil mixtures at the same saturation temperature. This is also assumed to be due to the higher saturation pressures associated with R-124.

5. Increasing the oil concentration in R-124 by up to 6% for the smooth and finned tubes improved heat transfer performance compared to the pure refrigerant. For example at a heat flux of at 90 kW/m^2, performance for the smooth and finned tubes increased by 18% and 35% respectively. At higher oil concentrations, performance deteriorated.

6. Any increase in oil concentration in R-124 for the HIGH FLUX or TURBO-B tubes led to a decrease in performance such that at high heat fluxes and high oil concentrations, the HIGH FLUX tube gave only 35% of its performance in pure R-124 and the 19 fpi tube gave the best overall performance.

7. At chiller design heat fluxes (10-30 kW/m^2) and oil concentrations of 3% maximum, the HIGH FLUX and TURBO-B surfaces still provide the best heat transfer which is about the same as with R-114. Therefore, similar or slightly better performance is expected with R-124 when used as a 'drop-in' replacement for R-114 in a refrigerant evaporator operated at the same saturation temperature.

8. Addition of oil delays the point of incipience (occurs at a higher wall superheat) for the smooth tube. For the HIGH FLUX tube, oil addition has no measurable effect on the wall superheat at incipience.

VII. RECOMMENDATIONS

1. The remaining enhanced tubes should be tested in R-124 at 0%,3%, and 10% oil concentrations and compared to the five tubes above and their prior performance in R-114 and R-114/oil mixtures.

2. Incipience tests performed with finned tubes and TURBO-B tubes should be conducted to compare the influence of oil on wall superheat.

3. The influence of the variation in time between test runs on boiling nucleation (ie. onset of nucleate boiling) must be investigated more thoroughly.

4. The single tube apparatus should be modified to test an array of two horizontal boiling tubes and compare these results with the R-114 tube array data previously recorded.

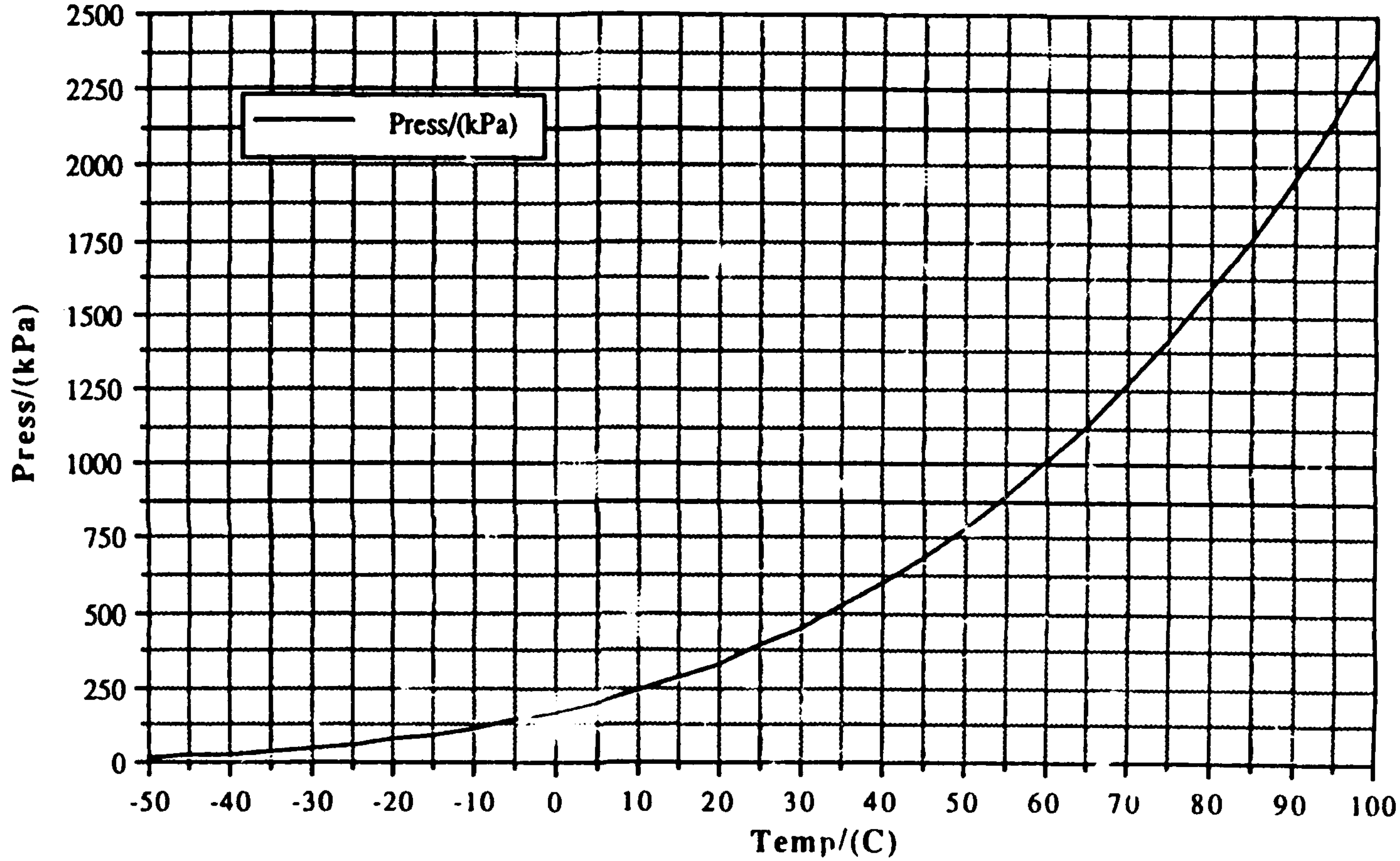
5. A prototype chiller presently using R-114 should be tested with R-124 to monitor the performance.

APPENDIX A. THERMOPHYSICAL PROPERTIES OF R-124

The following thermophysical properties of saturated R-124 are plotted versus temperature in degrees Celsius. They were generated from REFPROP [Ref. 12].

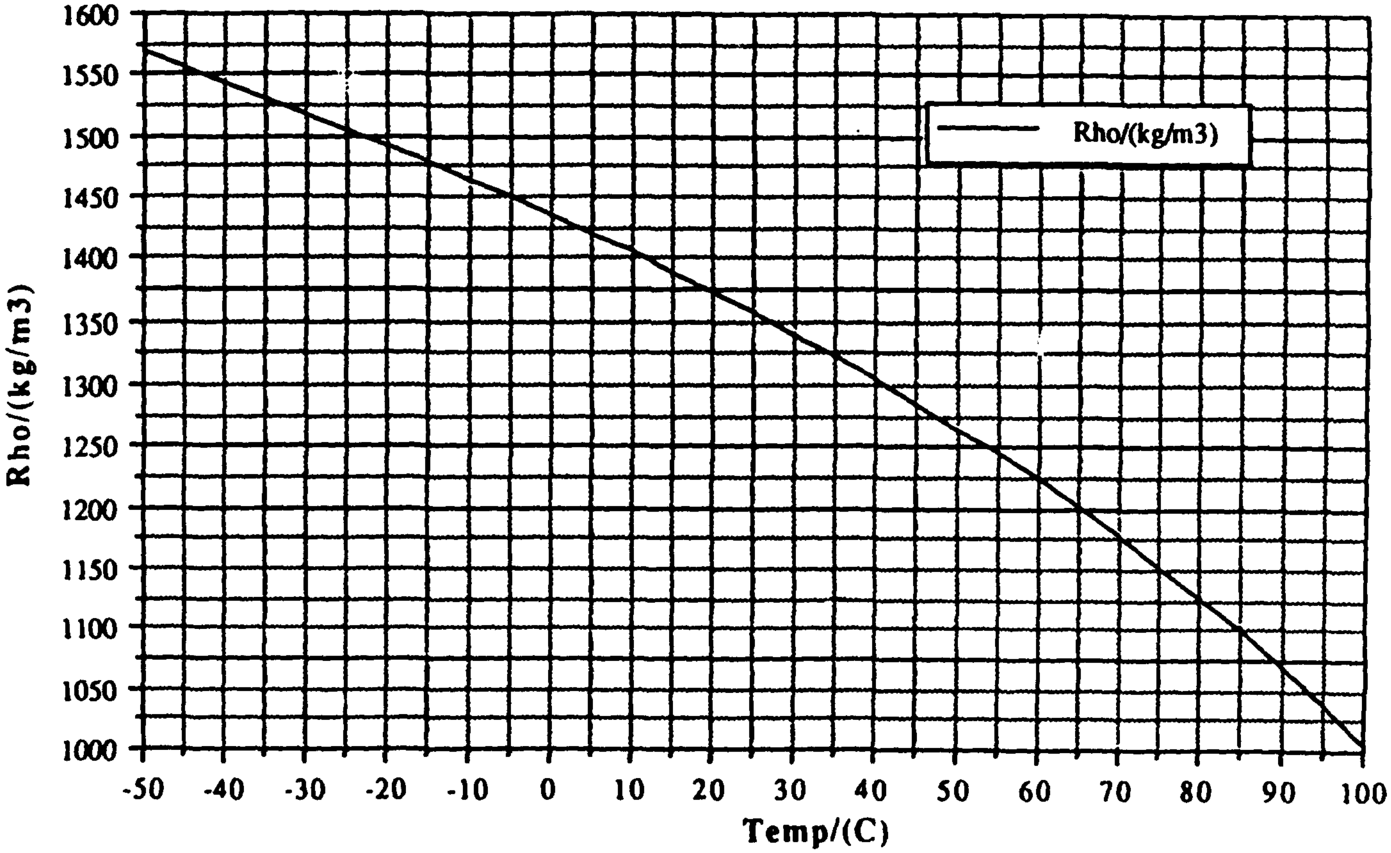
1.	Saturation Pressure /(kPa)
2.	Liquid Density /(kg/m^3)
3.	Latent Heat of Vaporization /(kJ/kg)
4.	Liquid Specific Heat /(kJ/kg K)
5.	Liquid Viscosity /(mP) note: 1 mP= 1x10^{-4} kg/m s
6.	Liquid Thermal Conductivity /(W/m K)

Saturation Pressure for R-124



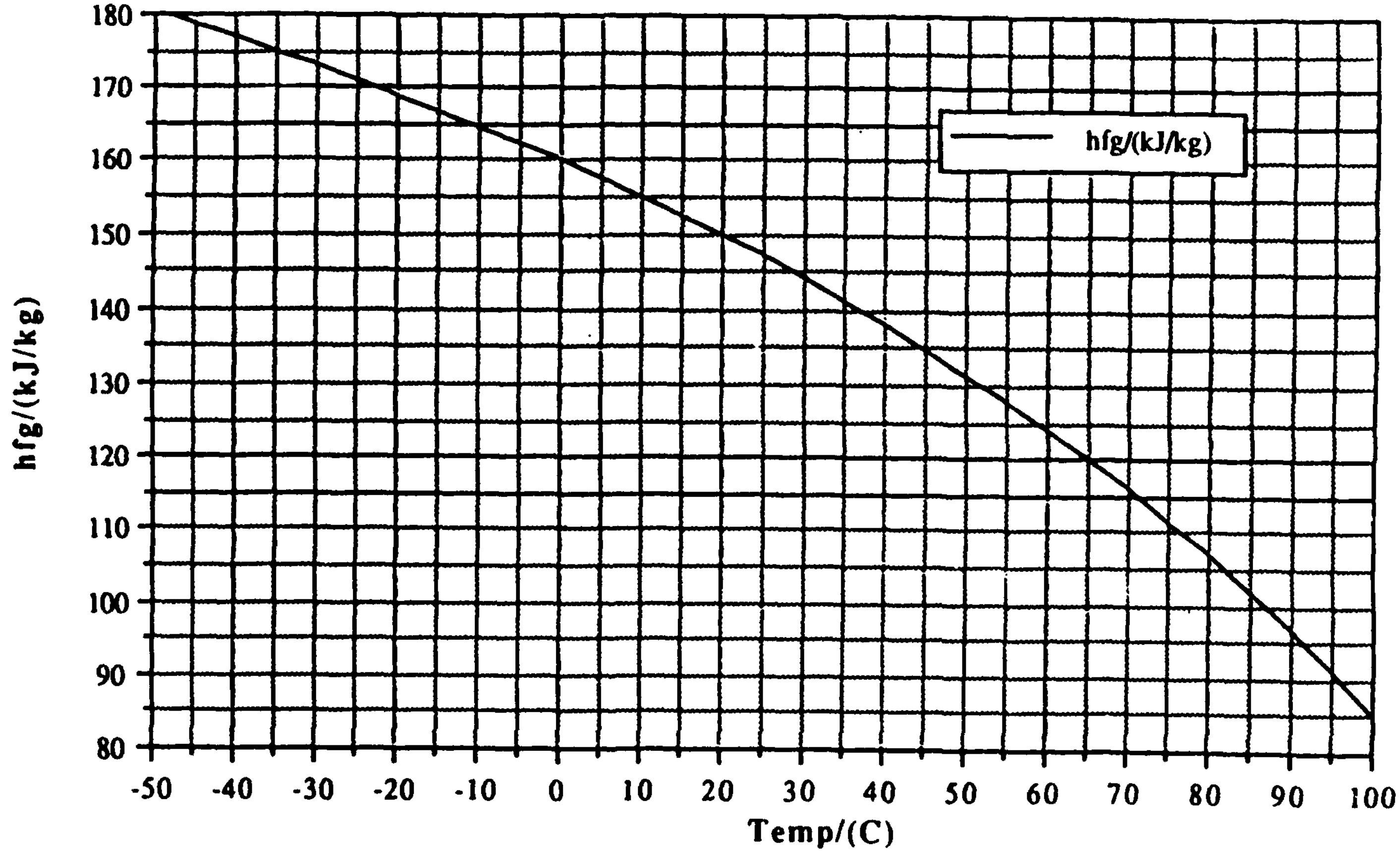
$$P_{sat} = 162.68 + 5.946(T) + 9.2081 \times 10^{-2}(T)^2 + 6.9359 \times 10^{-4}(T)^3$$

Liquid Density for R-124

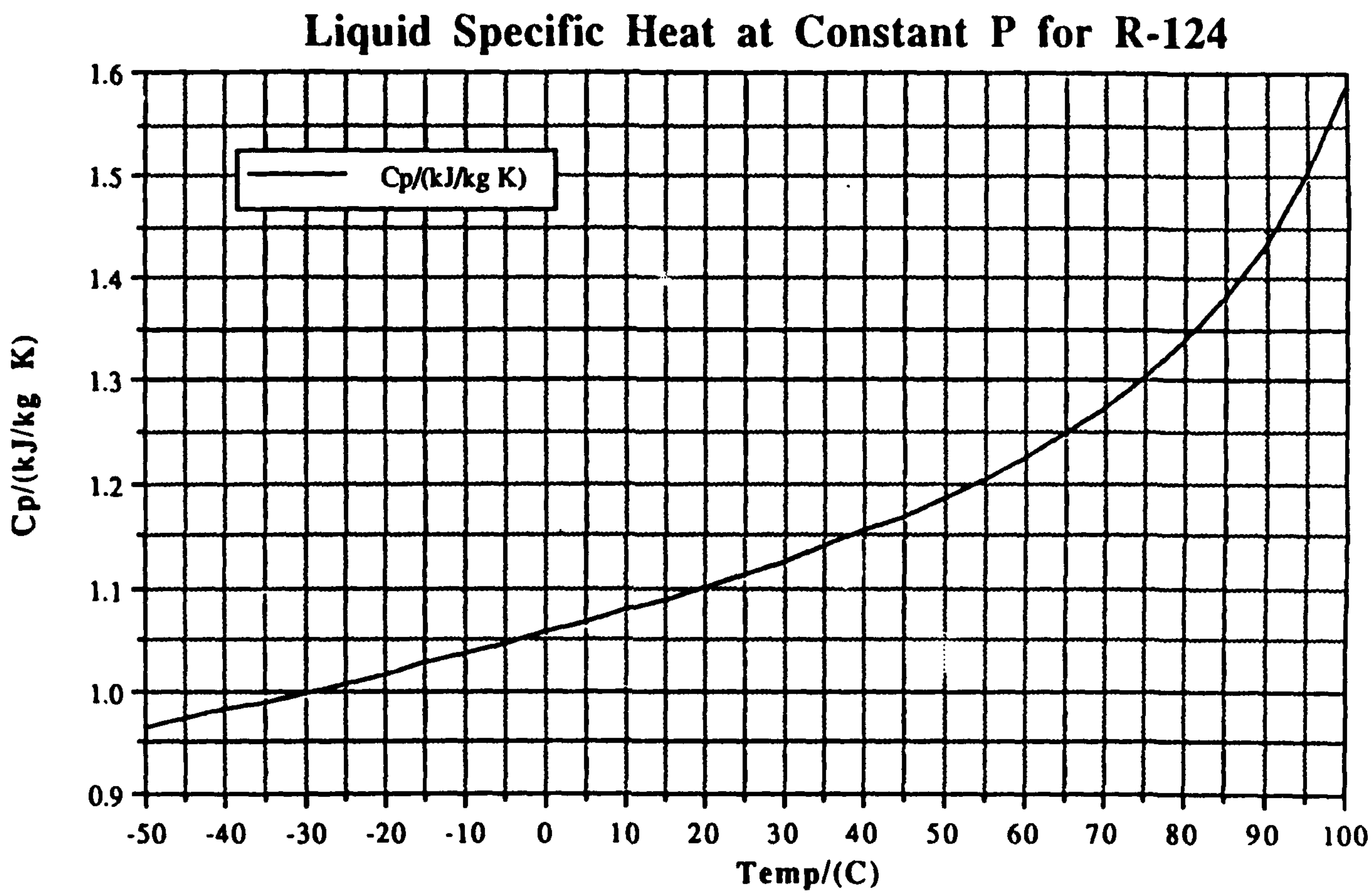


$$\rho = 1434.8 - 2.8619(T) - 6.7267\times10^{-3}(T)^2 - 7.2852\times10^{-5}(T)^3$$

Latent Heat of Vaporization for R-124

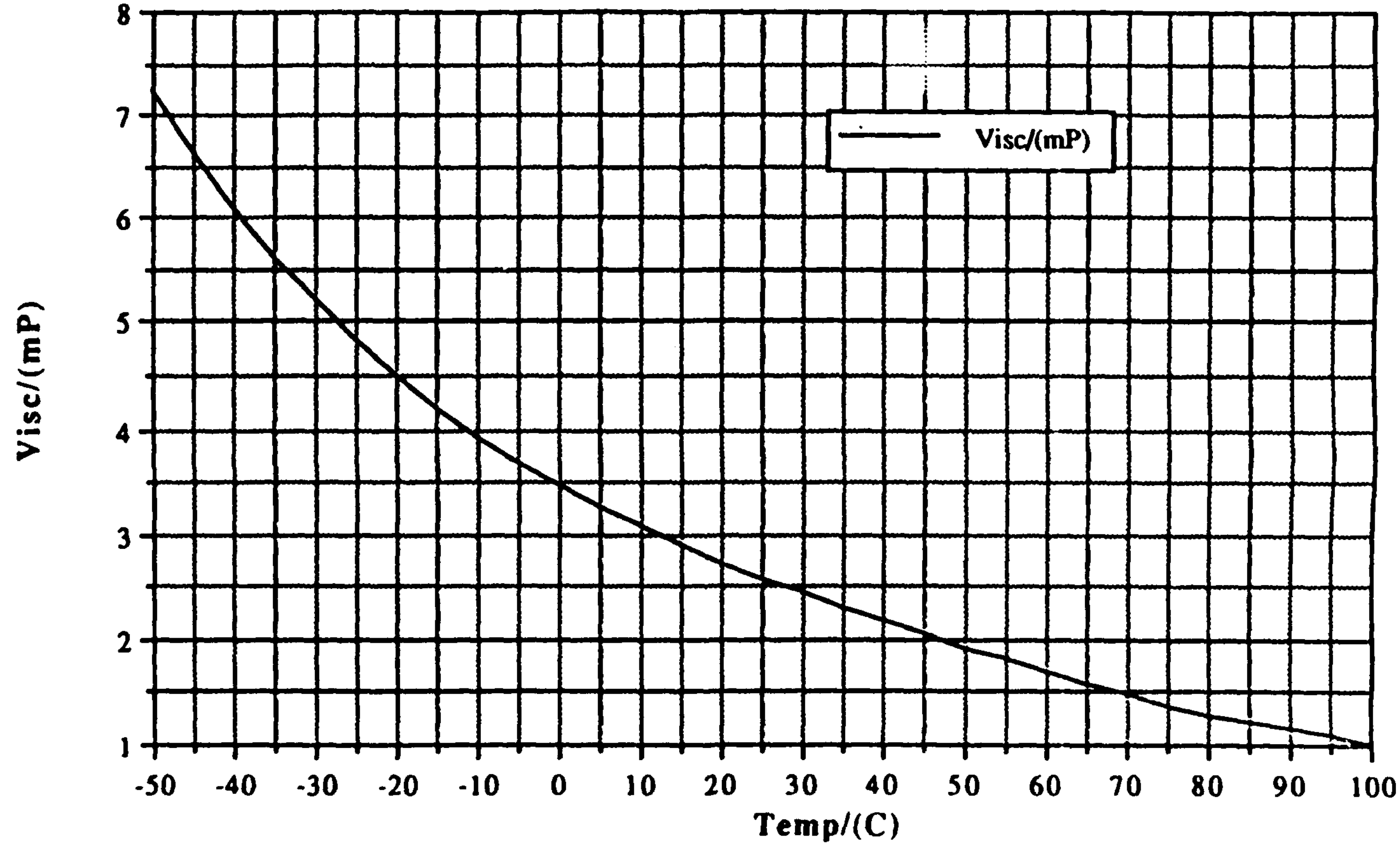


$$h_{fg}=159.93-.4609(T)-1.458\times10^{-3}(T)^2-1.3715\times10^{-5}(T)^3$$



$$Cp=1.0542+2.14\times10^{-3}(T)+1.0709\times10^{-5}(T)^2-6.4721\times10^{-8}(T)^3$$
$$-1.4324\times10^{-9}(T)^4+4.136\times10^{-11}(T)^5$$

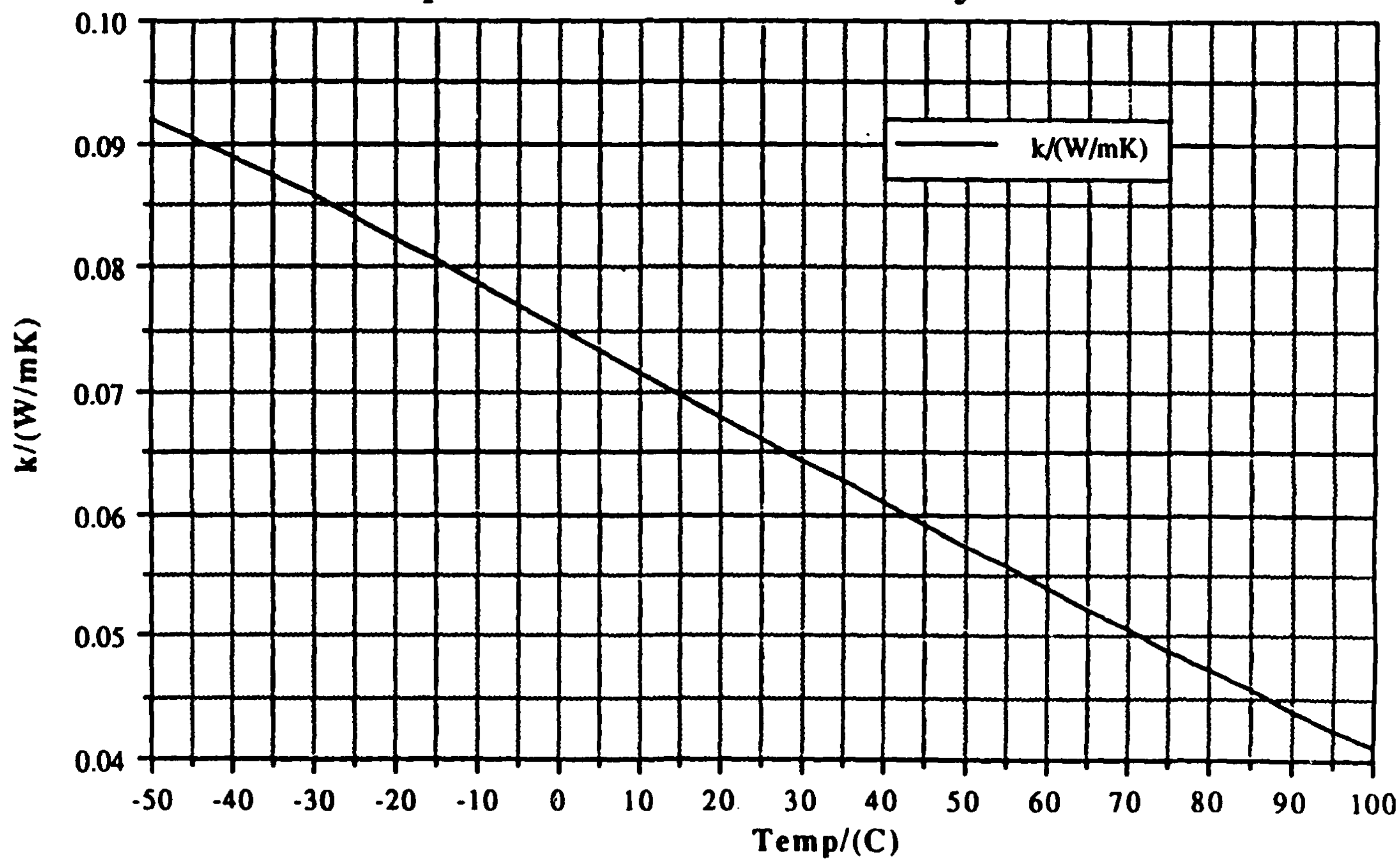
Liquid Viscosity for R-124



$$\mu = 3.4593 - 4.26\times10^{-2}(T) + 3.9458\times10^{-4}(T)^2 - 4.193\times10^{-6}(T)^3 + 2.07\times10^{-8}(T)^4$$

(note: 1mP= 1×10^{-4} kg/m s)

Liquid Thermal Conductivity for R-124



$$k = 7.5191\times10^{-2} - 3.5436\times10^{-4}(T) - 1.9545\times10^{-7}(T)^2 + 3.1835\times10^{-9}(T)^3$$

APPENDIX B. REPRESENTATIVE DATA SET

```
Date :    19 Nov 1992

NOTE: Program name : DRP6B
      Disk number  = 01

Date :    19 Nov 1992

NOTE: Program name : DRP6B
      Disk number  = 00
      New file name: D1119193
      TC are defective at locations  7    8
      Tube Number:   13

Data Set Number =   1  Bulk Oil % =  3.0
TIME:      15:40:01
TC No:     1      2      3      4      5      6      7      8
Temp :   3.23   3.38   3.31   3.20   3.06   3.32 -99.99 -99.99
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.25    2.14    2.14    2.18  10.84   -13.3
 Thetab  Htube       Qdp
  1.063  6.475E+02  6.879E+02

Data Set Number =   2  Bulk Oil % =  3.0
TIME:      15:42:22
TC No:     1      2      3      4      5      6      7      8
Temp :   3.58   3.80   3.72   3.61   3.45   3.64 -99.99 -99.99
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.63    2.22    2.24    2.25  10.91   -13.2
 Thetab  Htube       Qdp
  1.377  6.422E+02  8.845E+02

Data Set Number =   3  Bulk Oil % =  3.0
TIME:      15:45:20
TC No:     1      2      3      4      5      6      7      8
Temp :   3.85   4.35   4.36   4.19   3.87   3.95 -99.99 -99.99
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.09    2.09    2.21    2.17  10.83   -13.1
 Thetab  Htube       Qdp
  1.921  6.523E+02  1.253E+03

Data Set Number =   4  Bulk Oil % =  3.0
TIME:      15:47:12
TC No:     1      2      3      4      5      6      7      8
Temp :   4.10   5.03   5.02   4.87   4.46   4.28 -99.99 -99.99
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.62    2.15    2.27    2.27  10.92   -13.0
 Thetab  Htube       Qdp
  2.350  6.986E+02  1.642E+03
```

```
Data Set Number =   5  Bulk Oil % =  3.0
TIME:      15:49:09
TC No:     1       2       3       4       5       6       7       8
Temp :   4.30    5.75    5.76    5.44    4.68    4.56  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 5.07    2.05    2.20    2.23   10.88   -12.9
 Thetab  Htube       Qdp
 2.845   7.832E+02  2.228E+03

Data Set Number =   6  Bulk Oil % =  3.0
TIME:      15:51:30
TC No:     1       2       3       4       5       6       7       8
Temp :   4.40    6.62    6.60    6.21    5.12    4.78  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 5.61    2.12    2.16    2.28   10.93   -12.8
 Thetab  Htube       Qdp
 3.331   9.154E+02  3.049E+03

Data Set Number =   7  Bulk Oil % =  3.0
TIME:      15:54:01
TC No:     1       2       3       4       5       6       7       8
Temp :   4.75    7.39    7.27    6.75    5.38    5.22  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 6.11    2.15    2.21    2.28   10.93   -12.7
 Thetab  Htube       Qdp
 3.831   1.031E+03  3.951E+03

Data Set Number =   8  Bulk Oil % =  3.0
TIME:      15:56:43
TC No:     1       2       3       4       5       6       7       8
Temp :   5.14    8.28    8.15    7.38    5.55    5.59  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 6.66    2.24    2.27    2.35   11.00   -12.6
 Thetab  Htube       Qdp
 4.302   1.259E+03  5.418E+03

Data Set Number =   9  Bulk Oil % =  3.0
TIME:      15:59:50
TC No:     1       2       3       4       5       6       7       8
Temp :   4.78    6.89    8.17    6.85    4.88    4.46  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 5.97    2.29    2.24    2.32   10.97   -12.5
 Thetab  Htube       Qdp
 3.650   2.151E+03  7.849E+03

Data Set Number =  10  Bulk Oil % =  3.0
TIME:      16:02:33
TC No:     1       2       3       4       5       6       7       8
Temp :   4.83    5.18    5.13    4.84    4.91    4.53  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 4.86    2.30    2.25    2.28   10.93   -12.4
 Thetab  Htube       Qdp
 2.583   4.150E+03  1.072E+04

Data Set Number =  11  Bulk Oil % =  3.0
TIME:      16:17:38
TC No:     1       2       3       4       5       6       7       8
Temp :   5.14    5.66    5.59    5.22    5.25    4.77  -99.99  -99.99
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
 5.20    2.20    2.12    2.16   10.82   -11.9
 Thetab  Htube       Qdp
 3.044   5.098E+03  1.552E+04
```

```
Data Set Number =  12  Bulk Oil % =  3.0
TIME:       16:20:31
TC No:       1       2       3       4       5       6       7       8
Temp :    5.79    6.34    6.28    5.90    6.01    5.24  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  5.83    2.26     2.19    2.20   10.86   -11.9
 Thetab  Htube       Qdp
  3.630  6.328E+03  2.297E+04

Data Set Number =  13  Bulk Oil % =  3.0
TIME:       16:23:15
TC No:       1       2       3       4       5       6       7       8
Temp :    6.61    7.18    7.13    6.69    6.85    5.99  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  6.60    2.31     2.26    2.28   10.93   -11.8
 Thetab  Htube       Qdp
  4.316  7.794E+03  3.364E+04

Data Set Number =  14  Bulk Oil % =  3.0
TIME:       16:24:49
TC No:       1       2       3       4       5       6       7       8
Temp :    7.40    7.84    7.85    7.36    7.58    6.49  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  7.22    2.35     2.27    2.32   10.97   -11.8
 Thetab  Htube       Qdp
  4.895  9.726E+03  4.761E+04

Data Set Number =  15  Bulk Oil % =  3.0
TIME:       16:29:15
TC No:       1       2       3       4       5       6       7       8
Temp :    8.17    8.32    8.52    8.11    8.32    7.09  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  7.78    2.29     2.23    2.28   10.93   -11.7
 Thetab  Htube       Qdp
  5.501  1.300E+04  7.151E+04

Data Set Number =  16  Bulk Oil % =  3.0
TIME:       16:33:55
TC No:       1       2       3       4       5       6       7       8
Temp :    8.79    8.96    9.33    8.87    9.12    7.59  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  8.37    2.20     2.14    2.20   10.86   -11.4
 Thetab  Htube       Qdp
  6.169  1.553E+04  9.577E+04

Data Set Number =  17  Bulk Oil % =  3.0
TIME:       16:36:37
TC No:       1       2       3       4       5       6       7       8
Temp :    7.44    7.74    7.92    7.59    7.77    6.56  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  7.24    2.18     2.11    2.17   10.83   -11.4
 Thetab  Htube       Qdp
  5.070  1.230E+04  6.235E+04

Data Set Number =  18  Bulk Oil % =  3.0
TIME:       16:40:00
TC No:       1       2       3       4       5       6       7       8
Temp :    6.63    7.03    7.12    6.77    6.98    5.96  -99.99  -99.99
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  6.57    2.24     2.18    2.24   10.90   -11.4
 Thetab  Htube       Qdp
  4.329  9.657E+03  4.180E+04
```

```
Data Set Number =  19  Bulk Oil % =  3.0
TIME:       16:43:04
TC No:      1        2        3        4        5        6        7        8
Temp :    6.09     6.65     5.56     5.27     6.41     5.54  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  6.14     2.27     2.20     2.24   10.90    -11.5
 Thetab   Htube       Qdp
  3.859  7.859E+03  3.067E+04

Data Set Number =  20  Bulk Oil % =  3.0
TIME:       16:45:59
TC No:      1        2        3        4        5        6        7        8
Temp :    5.62     6.13     6.13     5.82     5.92     5.19  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  5.70     2.23     2.14     2.19   10.85    -11.5
 Thetab   Htube       Qdp
  3.506  6.754E+03  2.368E+04

Data Set Number =  21  Bulk Oil % =  3.0
TIME:       16:48:34
TC No:      1        2        3        4        5        6        7        8
Temp :    5.17     5.73     5.71     5.36     5.40     4.85  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  5.30     2.31     2.22     2.25   10.91    -11.7
 Thetab   Htube       Qdp
  3.045  5.555E+03  1.692E+04

Data Set Number =  22  Bulk Oil % =  3.0
TIME:       16:51:59
TC No:      1        2        3        4        5        6        7        8
Temp :    4.69     5.20     5.15     4.85     4.92     4.44  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  4.82     2.27     2.17     2.21   10.87    -11.8
 Thetab   Htube       Qdp
  2.613  4.525E+03  1.182E+04

Data Set Number =  23  Bulk Oil % =  3.0
TIME:       16:54:33
TC No:      1        2        3        4        5        6        7        8
Temp :    4.32     4.77     4.63     4.45     4.55     4.21  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  4.45     2.30     2.21     2.27   10.92    -11.9
 Thetab   Htube       Qdp
  2.186  3.653E+03  7.985E+03

Data Set Number =  24  Bulk Oil % =  3.0
TIME:       16:57:59
TC No:      1        2        3        4        5        6        7        8
Temp :    3.94     4.31     4.23     4.10     4.11     3.91  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  4.08     2.24     2.15     2.21   10.87    -12.0
 Thetab   Htube       Qdp
  1.863  2.839E+03  5.289E+03

Data Set Number =  25  Bulk Oil % =  3.0
TIME:       17:01:00
TC No:      1        2        3        4        5        6        7        8
Temp :    3.56     3.91     3.84     3.75     3.74     3.60  -99.99  -99.99
 Twa      Tliqd    Tliqd2   Tvapr    Psat     Tsump
  3.72     2.22     2.08     2.14   10.80    -12.1
 Thetab   Htube       Qdp
  1.577  2.166E+03  3.419E+03
```

```
Data Set Number =  26  Bulk Oil % =  3.0
TIME:       17:03:15
TC No:      1       2       3       4       5       6       7       8
Temp :     3.56    3.83    3.77    3.74    3.69    3.61  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.69    2.35     2.21    2.27   10.92   -12.2
 Thetab   Htube          Qdp
  1.420   1.809E+03   2.570E+03

Data Set Number =  27  Bulk Oil % =  3.0
TIME:       17:06:05
TC No:      1       2       3       4       5       6       7       8
Temp :     3.41    3.63    3.56    3.52    3.48    3.45  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.50    2.35     2.20    2.24   10.89   -12.3
 Thetab   Htube          Qdp
  1.260   1.571E+03   1.981E+03

Data Set Number =  28  Bulk Oil % =  3.0
TIME:       17:08:04
TC No:      1       2       3       4       5       6       7       8
Temp :     3.24    3.42    3.34    3.34    3.30    3.32  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.32    2.26     2.15    2.14   10.80   -12.4
 Thetab   Htube          Qdp
  1.105   1.159E+03   1.373E+03

Data Set Number =  29  Bulk Oil % =  3.0
TIME:       17:10:55
TC No:      1       2       3       4       5       6       7       8
Temp :     3.15    3.23    3.10    3.16    3.12    3.20  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.17    2.20     2.25    2.23   10.89   -12.5
 Thetab   Htube          Qdp
   .937   1.056E+03   9.893E+02

Data Set Number =  30  Bulk Oil % =  3.0
TIME:       17:13:34
TC No:      1       2       3       4       5       6       7       8
Temp :     3.20    3.40    3.36    3.33    3.29    3.20  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.30    2.21     2.00    2.10   10.77   -12.6
 Thetab   Htube          Qdp
  1.205   1.246E+03   1.501E+03

Data Set Number =  31  Bulk Oil % =  3.0
TIME:       17:16:00
TC No:      1       2       3       4       5       6       7       8
Temp :     3.15    3.25    3.20    3.16    3.13    3.23  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  3.10    2.30     2.27    2.20   10.93   -12.7
 Thetab   Htube          Qdp
   .907   9.922E+02   9.001E+02

Data Set Number =  32  Bulk Oil % =  3.0
TIME:       17:17:39
TC No:      1       2       3       4       5       6       7       8
Temp :     2.92    3.00    2.92    2.89    2.91    3.03  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  2.94    2.15     2.17    2.15   10.01   -12.7
 Thetab   Htube          Qdp
   .796   8.808E+02   7.074E+02

Data Set Number =  33  Bulk Oil % =  3.0
TIME:       17:19:16
TC No:      1       2       3       4       5       6       7       8
Temp :     2.92    2.95    2.88    2.86    2.87    2.99  -99.99  -99.99
 Twa      Tliqd   Tliqd2  Tvapr   Psat    Tsump
  2.91    2.17     2.19    2.16   10.82   -12.8
 Thetab   Htube          Qdp
   .753   7.745E+02   5.829E+02
```

APPENDIX C. SAMPLE CALCULATIONS

Data file number D1221SM0 was used to conduct the sample calculations. The saturation temperature was 2.28 °C with a single smooth tube heat flux of 31290 W/m^2.

A. TEST-TUBE DIMENSIONS

D_o=.015875 m

D_i=.0127 m

D_1=.01245 m

L=.2032 m

Lu=.0762 m

B. MEASURED PARAMETERS

V=141.95 volts

I=2.34 amps

T1=16.84 °C

T2=17.15 °C

T3=16.42 °C

T4=16.22 °C

T5=15.66 °C

T6=15.48 °C

T_{sat}=2.28 °C

k_c=344 W/m·K

C. OUTER WALL TEMPERATURE OF THE BOILING TUBE

$p=\pi\cdot D_o=\pi\cdot .015875\ m=.04987\ m$

$Ac=\pi(D_o^2-D_i^2)/4=\pi((.015875)^2-(.0127)^2)/4$

$Ac=7.13x10^{-5}\ m^2$

$Q_h=VI=141.95\cdot 2.34=\ 332.16\ W$

$T_{avg}=\sum Tn/n=\sum_1^6 Tn/6=16.3\ ^oC$

$T_{wo}=T_{avg}-[Q_h\cdot(\ln(D_o/D_1)/(2\pi\cdot L\cdot k_c))]$

$T_{wo}=16.3-[332.16\cdot(\ln(.015875/.01245)/(2\pi\cdot L\cdot k_c))]$

$T_{wo}=16.12\ ^oC$

$\theta=T_{wo}-T_{sat}=16.12-2.28=13.84\ ^oC$

D. PROPERTIES OF R-124 AT FILM TEMPERATURE

The thermophysical properties of R-124 were obtained from REFPROP [Ref. 12] and are shown in Appendix A.

$T_f=(T_{wo}+T_{sat})/2=(16.12+2.28)/2=\ 9.2\ ^oC$

$\mu=3.4593-(.0426)T_f+(3.9485x10^{-4})T_f^2-(4.193x10^{-6})T_f^3+$
$(2.0709x10^{-8})T_f^4$

$$\mu=3.4593-(.0426)\cdot 9.2+(3.9485\text{x}10^{-4})\cdot(9.2)^2-(4.193\text{x}10^{-6})\cdot(9.2)^3+$$
$$(2.0709\text{x}10^{-8})\cdot(9.2)^4$$
$$\mu=3.098\text{x}10^{-4}\ \text{N}\cdot\text{s/m}^2$$

$$\rho=1434.8-(2.8619)T_f-(6.7267\text{x}10^{-3})T_f^{\,2}-(7.2852\text{x}10^{-5})T_f^{\,3}$$
$$\rho=1434.8-(2.8619)\cdot 9.2-(6.7267\text{x}10^{-3})\cdot(9.2)^2-(7.2852\text{x}10^{-5})\cdot(9.2)^3$$
$$\rho=1407.84\ \text{kg/m}^3$$

$$\upsilon=\mu/\rho=3.098\text{x}10^{-4}/1407.84=\ 2.201\text{x}10^{-7}\quad \text{m}^2/\text{s}$$

$$k=7.5191\text{x}10^{-2}-(3.5436\text{x}10^{-4})T_f-(1.9545\text{x}10^{-7})T_f^{\,2}+(3.1835\text{x}10^{-9})T_f^{\,3}$$
$$k=7.5191\text{x}10^{-2}-(3.5436\text{x}10^{-4})\cdot(9.2)-(1.9545\text{x}10^{-7})\cdot(9.2)^2+$$
$$(3.1835\text{x}10^{-9})\cdot(9.2)^3$$
$$k=7.192\text{x}10^{-2}\ \text{W/m}\cdot\text{K}$$

$$c_p=1.0542+(2.1405\text{x}10^{-3})T_f+(1.0709\text{x}10^{-5})T_f^{\,2}-(6.4721\text{x}10^{-8})T_f^{\,3}-$$
$$(1.4324\text{x}10^{-9})T_f^{\,4}+(4.136\text{x}10^{-11})T_f^{\,5}$$

$$c_p=1.0542+(2.1405\text{x}10^{-3})\cdot(9.2)+(1.0709\text{x}10^{-5})\cdot(9.2)^2-(6.4721$$
$$\text{x}10^{-8})\cdot(9.2)^3-(1.4324\text{x}10^{-9})\cdot(9.2)^4+(4.136\text{x}10^{-11})\cdot(9.2)^5$$

$$c_p=1074.74\ \text{J/kg}\cdot\text{K}$$

$$\alpha=k/(\rho\cdot c_p)=\ 7.192\text{x}10^{-2}/(1407.84\cdot 1074.74)$$
$$\alpha=4.753\text{x}10^{-8}\ \text{m}^2/\text{s}$$

$\beta = -(\Delta\rho/\Delta T)/\rho = 2.094 \times 10^{-3}$ (1/K)

$Pr = \upsilon/\alpha = 4.63$

E. HEAT-FLUX CALCULATION

The average natural convection heat-transfer coefficient at the non-boiling ends of the test tube is calculated using the Churchill and Chu [Ref. 4] correlation:
For simplification let **R** represent the following in the correlation :

$$\mathbf{R} = [(g \cdot \beta \cdot D_o^3 \cdot \theta \cdot \tanh(m \cdot Lu))/(\upsilon \cdot \alpha \cdot Lu \cdot m)]^{1/6}$$

then

$$h = k/D_o[.6 + .387[\mathbf{R}/(1 + (0.559/Pr)^{9/16})^{8/27}]]^2$$

where

$$m = [(h \cdot p)/(k_c \cdot Ac)]^{1/2}$$

and an iterative process is used in program DRPGB to compute the value of h by starting with the value for h of 190 ($W/m^2 \cdot K$). The resulting values for h and m were:

$h = 265.43$ ($W/m^2 \cdot K$)

$m = 23.23$ (1/m)

therefore:

$$Q_f = (h \cdot p \cdot k_c \cdot Ac)^{1/2} \cdot \theta \cdot \tanh(m \cdot Lu) = 7.44 \text{ W}$$

F. HEAT FLUX THROUGH ACTIVE BOILING LENGTH

$Q=Q_h-2\cdot Q_f=332.16-(2\cdot 7.44)=317.28$ W

$Ab=\pi\cdot D_o\cdot L=\pi\cdot 0.015875\cdot 0.2032=1.0134\text{x}10^{-2}$ m^2

$q=Q/Ab=317.28/1.0134\text{x}10^{-2}=31{,}308$ W/m^2

$h=q/\theta=31{,}308/13.84=2262.1$ $W/m^2\cdot K$

The following results were produced by the data acquisition and reduction program DRPGB:

$q=31290$ W/m^2

$\theta=13.84$ ^oC

$h=2262$ $W/m^2\cdot {}^oK$

TABLE 5. DIMENSIONS OF BOILING TUBES TESTED

TUBE	D1 mm	D2 mm	Di mm	Do mm	L mm	Lu mm	K_c W/moK
smooth	12.4	15.9	12.7	15.9	203.2	76.2	344
GEWA-K 19 fpi	10.1	12.7	11.1	12.7	203.2	76.2	344
GEWA-K 26 fpi	10.1	12.7	11.1	12.7	203.2	76.2	344
TURBO-B	11.6	13.8	11.8	15.8	203.2	76.2	398
HIGH FLUX	12.9	15.8	13.2	15.8	203.2	76.2	45 *

* HIGH FLUX tube porous coating is on a copper/nickel base

APPENDIX D. UNCERTAINTY ANALYSIS

Using methods of uncertainty analysis outlined by Kline and McClintlock [Ref. 18] and performed by Sugiyama [Ref. 2], four data points are analyzed. The data points chosen were for a Smooth tube and HIGH FLUX tube. For each tube, there was a data point at a high heat flux and one at a low heat flux. The following is a sample uncertainty analysis calculation from data file number D1220SM0 with a Smooth tube, 0% oil, at a heat flux of 86,000 W/m^2. The results of the remaining sample points are listed in Table 6. Uncertainties are given as a percentage of the calculated parameter, i.e. a relative uncertainty.

A. UNCERTAINTY IN HEAT-TRANSFER RATE

I_s=1.99 volts V_s=9.325 volts

Estimated uncertainties in the measured quantities I and V :

$\delta I = \pm\ 0.025$ amps

$\delta V = \pm\ 0.05$ volts

$I = 1.9182 \cdot I_s = 3.82$ amps

$V = 25 \cdot V_s = 233.13$ volts $Q_h = VI$

where: δ= uncertainty in measurement

$\delta Q_h/Q_h = ((\delta V/V_s)^2 + (\delta I/I_s)^2)^{1/2}$

$\delta Q_h/Q_h = ((.05/9.325)^2 + (.025/1.99)^2)^{1/2}$

$\delta Q_h/Q_h = 1.37\ \%$

B. UNCERTAINTY IN SURFACE AREA

$Ab = \pi \cdot Do \cdot L$

$D_o = 15.88$ (mm) $\qquad \delta D_o = .1$ (mm)

$L = 203.2$ (mm) $\qquad \delta L = .1$ (mm)

$\delta Ab/Ab = ((\delta D_o/D_o)^2 + (\delta L/L)^2)^{1/2}$

$\delta Ab/Ab = ((.1/15.88)^2 + (.1/203.2)^2)^{1/2}$

$\delta Ab/Ab = .63\ \%$

C. UNCERTAINTY IN WALL SUPERHEAT

$\Delta T = T_{wo} - T_{sat}$ $\qquad T_{sat} = 2.23\ ^{o}C$ $\qquad \delta T_{sat} = .01\ ^{o}C$

$T_{wo} = T_{avg} - Q_h[\ln(D_o/D_1)/(2 \cdot \pi \cdot L \cdot k_c)]$

Tn= thermocouple readings

$T_{avg} = \Sigma Tn/n$

$T1 = 21.63\ ^{o}C$

$T2 = 21.41\ ^{o}C$

$T3 = 20.63\ ^{o}C$

$T4 = 20.94\ ^{o}C$

$T5 = 20.06\ ^{o}C$

$T6 = 20.40\ ^{o}C$

$T_{avg} = 20.85\ ^{o}C$

standard deviation= $((\Sigma(Tn-T_{avg})^2)/n)^{1/2}$

standard deviation= 0.55 °C

The logarithmic term in the equation for Two can be neglected for the uncertainty analysis as it is very small in comparison to the standard deviation.

$T_{wo}=T_{avg}=20.85$ °C

δT_{wo}=standard deviation=.55 °C

$\Delta T=18.62$ °C

$\delta\Delta T/\Delta T=((\delta T_{wo}/\Delta T)^2+(\delta T_{sat}/\Delta T)^2)^{1/2}$

$\delta\Delta T/\Delta T=((.55/18.62)^2+(.01/18.62)^2)^{1/2}$

$\delta\Delta T/\Delta T=2.95$ %

D. UNCERTAINTY IN HEAT FLUX

$q=(Q_h-2\cdot Q_f)/Ab$

$Q_h=VI$ $\quad Q_h=890.56$ W $\quad \delta Q_h=12.2$ W

assuming the same proportion in the uncertainty for Q_f:

$q=86000$ W/m^2 $\quad Ab= 0.010137$ m^2

$Q_h-2\cdot Q_f= 871.81$ W

$Q_f= 9.38$ W $\quad \delta Q_f=0.128$ W

$\delta q/q=[(\delta Q_h/(Q_h-2Q_f))^2+(2\delta Q_f/(Q_h-2Q_f))^2+(\delta Ab/Ab)^2]^{1/2}$

$\delta q/q=[(12.2/(890.56-2\cdot 9.38))^2+(2\cdot(.128)/(890.56-2\cdot 9.38))^2+$

$(6.39\times 10^{-5}/.010137)^2]^{1/2}$

$\delta q/q= 1.54$ %

E. UNCERTAINTY IN BOILING HEAT-TRANSFER COEFFICIENT

$h = q/\Delta T$

$\delta h/h = [(\delta q/q)^2 + (\delta\Delta T/\Delta T)^2]^{1/2}$

$\delta h/h = [(.0154)^2 + (.0295)^2]^{1/2}$

$\delta h/h = 3.3\ \%$

TABLE 6. UNCERTAINTY ANALYSIS OF FOUR DATA POINTS

Parameters	Smooth tube 4019 W/m^2	Smooth tube 86000 W/m^2	High Flux 2244 W/m^2	High Flux 88860 W/m^2
$\delta Q_h/Q_h$ (%)	3.52	1.37	8.11	1.36
$\delta Ab/Ab$ (%)	.63	.63	.634	.634
$\delta\Delta T/\Delta T$ (%)	5.20	2.95	17.4	12.5
$\delta q/q$ (%)	1.29	1.54	8.41	1.5
$\delta h/h$ (%)	5.4	3.3	19.3	12.6

All uncertainty analysis calculations were conducted during decreasing heat flux runs. The wall superheat uncertainty ($\delta\Delta T/\Delta T$) for the HIGH FLUX tube was significantly greater than that of the smooth tube due to a greater deviation in the thermocouple temperature readings.

APPENDIX E. SETUP PROGRAM

The following setup program was used in the preparation of the apparatus prior to commencing testing. The program was written in Hewlett-Packard Basic 5.0 for both the Hewlett-Packard 9300 and 9852A series data acquisition/control unit. The setup program performs the following:

1. Monitor the Sump temperature
2. Monitor the evaporator liquid temperature
3. Measurement and readout of all thermocouple channels.
4. Measurement and readout of the power supplied to the tube cartridge heater.
5. Measurement and readout of the power supplied to the auxiliary heaters if used.

```
1 !   PROGRAM: SETUP
2 !   DATE:  AUGUST 3,1991
4 !   PROGRAMMER: LT DEAN SUGIYAMA
5 !   MODIFIED BY LANNIE LAKE JAN 22, 1992
10    COM /Cc/ C(7)
20    DATA 0.10086091,25727.94369,-767345.8295,78025595.81,-9247486589,6.97539E+
11,-2.66192E+13
21    DATA 3.94078E+14
22    READ C(*)
23    ON KEY 1,15 GOTO 27
25    PRINTER IS 1
27    PRINT
28    PRINT
30    PRINT USING "4X,""SELECT OPTION"""
31    PRINT USING "6X,""0=MONITOR SUMP"""
32    PRINT USING "6X,""1=MONITOR LIQUID"""
33    PRINT USING "6X,""2=CHECK THERMOCOUPLES"""
34    PRINT USING "6X,""3=CHECK MAIN HEATER"""
35    PRINT USING "6X,""4=CHECK AUX HEATERS"""
36    PRINT USING "6X,""5=EXIT PROGRAM"""
37    PRINT USING "4X,""NOTE: KEY 1 = ESCAPE"""
38    BEEP
40    INPUT Ido
41    IF Ido>5 THEN Ido=5
42    IF Ido=0 THEN 50
43    IF Ido=1 THEN 155
44    IF Ido=2 THEN 173
45    IF Ido=3 THEN 195
46    IF Ido=4 THEN 195
47    IF Ido=5 THEN 231
48    PRINT
49!
50    PRINT
51    PRINT "SUMP TEMPERATURE DEG C "
53    PRINT
54    OUTPUT 709;"AR AF11 AL11 VRS"
60    OUTPUT 709;"AS SA"
70    Sum=0
80    FOR J=1 TO 5
90    ENTER 709;E
100   Sum=Sum+E
110   NEXT J
120   Eave=Sum/5
130   Temp=FNTvsv(Eave)
140   PRINT USING "4X,MDD.DD";Temp
141   BEEP
142   PRINT
150   WAIT 5
```

```
151   GOTO 50
152 !
155   PRINT
156   PRINT "LIQUID TEMPERATURE DEG C"
158   PRINT
159   OUTPUT 709;"AR AF08 AL09 VR5"
160   Sum=0
161   FOR I=1 TO 2
162   OUTPUT 709;"AS SA"
163   ENTER 709;E
164   Sum=Sum+E
165   NEXT I
166   Eave=Sum/2
167   Temp=FNTvsv(Eave)
168   PRINT USING "4X,MDD.DD";Temp
169   BEEP
170   WAIT 5
171   GOTO 155
172 !
173   PRINT
176   PRINT "CHANNEL     TEMPERATURE DEG C"
177   OUTPUT 709;"AR AF00 AL11 VR5"
178   FOR I=1 TO 12
179   OUTPUT 709;"AS SA"
180   Sum=0
181   FOR J=1 TO 5
182   ENTER 709;E
183   Sum=Sum+E
184   NEXT J
185   Eave=Sum/5
186   Temp=FNTvsv(Eave)
187   PRINT TAB(3);I;TAB(15);Temp
188   NEXT I
189   BEEP
190   WAIT 5
191   GOTO 173
194 !
195   PRINT
196   OUTPUT 709;"AR AF20 AL22 VR5"
197   FOR I=1 TO 3
198   OUTPUT 709;"AS SA"
199   Sum=0
200   FOR J=1 TO 5
201   ENTER 709;E
202   Sum=Sum+E
```

```
203   NEXT J
204   IF I=1 THEN Volt=Sum/5
205   IF I=2 AND Ido=3 THEN
209   PRINT "MAKE SURE VOLTAGE BOX IS SET TO MAIN HEATERS"
210   Amp=Sum/5
211   END IF
212   IF I=3 AND Ido=4 THEN
216   PRINT "MAKE SURE VOLTAGE BOX IS SET TO AUX HEATERS"
217   Amp=Sum/5
218   END IF
219   NEXT I
220   Amp=ABS(Amp*1.9182)
221   Volt=ABS(Volt*25)
222   Power=Volt*Amp
223   Resistence=Volt/Amp
224   PRINT
225   BEEP
226   PRINT "VOLTAGE(V) CURRENT(A) RESISTENCE(ohms) POWER(W)"
227   PRINT
228   PRINT USING "1X,5(MDDDD.DD,4X)";Volt,Amp,Resistence,Power
229   WAIT 5
230   GOTO 195
231   BEEP
232   PRINT
233   PRINT "THAT'S ALL FOLKS!"
234   END
235   DEF FNTvsv(V)
236   COM /Cc/ C(7)
237   T=C(0)
238   FOR I=1 TO 7
239   T=T+C(I)*V^I
240   NEXT I
241   T=T+8.526897E-2+T*(3.761199E-3-T*5.0689259E-5)
242   RETURN T
250   FNEND
```

APPENDIX F. PROGRAM DRPGB

The data acquisition and reduction program DRPGB is written in Hewlett-Packard Basic 5.0 for the HP 9300 series computer and listed on the following pages.

```
10  ! FILE NAME: DRPGB
20  ! DATE:       October 19, 1984
30  ! REVISED:    July 11, 1991 BY Dean Sugiyama
41  ! REVISED:    Aug  18, 1992 BY George Bertsch (including R-124 properties)
50    COM /Idp/ Idp
60    PRINTER IS 1
70    CALL Select
80    INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
90    IF Isel=1 THEN GOTO 70
100   BEEP
110   BEEP
120   PRINTER IS 1
130   PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
140   END
150   SUB Main
151   COM /Iprop/ Ift
160   COM /Idp/ Idp
170   COM /Cc/ C(7),Ical
180   COM /Wil/ D2,Di,Do,L,Lu,Kcu
190   DIM Emf(12),T(12),D1a(13),D2a(13),Dia(13),Doa(13),La(13),Lua(13),Kcua(13),
Et(19),Tn$(4)[15]
200   DATA 0.10086091,25727.94369,-767345.8295,78025595.81
210   DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
220   READ C(*)
230 ! DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
240   DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
250   READ Tn$(*)
260   PRINTER IS 701
270   BEEP
280   IF Idp=4 THEN PRINTER IS 1
290   IF Idp=4 THEN GOTO 2660
300 ! INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
310 ! OUTPUT 709;"TD";Date$
320 ! OUTPUT 709;"TD"
330 ! ENTER 709;Date$
340   PRINT
350 ! PRINT "          Month, date and time :";Date$
351   PRINT "          Date :",DATE$(TIMEDATE)
360   PRINT
370   PRINT USING "10X,""NOTE: Program name : DRPGB"""
380   BEEP
390   INPUT "ENTER DISK NUMBER",Dn
400   PRINT USING "16X,""Disk number  = "",ZZ";Dn
410   BEEP
420   INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
430   BEEP
431   Ift=0
432   INPUT "SELECT FLUID (0=114,1=124)",Ift
433   BEEP
440   INPUT "SELECT HEATING MODE (0=ELEC; 1=WATER)",Ihm
450   BEEP
460   INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
470   IF Im=0 THEN
480   BEEP
490   INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_file$
500   PRINT USING "16X,""New file name: "",14A";D2_file$
510   Size1=20
520   CREATE BDAT D2_file$,Size1
530   ASSIGN @File2 TO D2_file$
540 !
550 ! DUMMY FILE UNTIL Nrun KNOWN
```

```
560  D1_file$="DUMMY"
570  CREATE BDAT D1_file$,Size1
580  ASSIGN @File1 TO D1_file$
590  OUTPUT @File1;Date$
600  IF Ihm=0 THEN
610  BEEP
620  INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT, 4 MAX.)",Idtc
630  IF Idtc=0 THEN
640  Ldtc1=0
650  Ldtc2=0
651  Ldtc3=0
652  Ldtc4=0
660  PRINT USING "16X,""No defective TCs exist"""
670  END IF
680  IF Idtc=1 THEN
690  BEEP
700  INPUT "ENTER DEFECTIVE TC LOCATION (1-8)",Ldtc1
710  PRINT USING "16X,""TC is defective at location "",DD";Ldtc1
720  Ldtc2=0
721  Ldtc3=0
722  Ldtc4=0
730  END IF
740  IF Idtc=2 THEN
750  BEEP
760  INPUT "ENTER DEFECTIVE TC LOCATIONS (1-8)",Ldtc1,Ldtc2
770  PRINT USING "16X,""TC are defective at locations "",DD,4X,DD";Ldtc1,Ldtc2
771  Ldtc3=0
772  Ldtc4=0
780  END IF
781  IF Idtc=3 THEN
782  BEEP
783  INPUT "ENTER DEFECTIVE TC LOCATION (1-8)",Ldtc1,Ldtc2,Ldtc3
784  PRINT USING "16X,""TC is defective at location "",3(4X,DD)";Ldtc1,Ldtc2,Ld
tc3
785  Ldtc4=0
786  END IF
787  IF Idtc=4 THEN
788  BEEP
789  INPUT "ENTER DEFECTIVE TC LOCATION (1-8)",Ldtc1,Ldtc2,Ldtc3,Ldtc4
790  PRINT USING "16X,""TC is defective at location "",4(4X,DD)";Ldtc1,Ldtc2,Ld
tc3,Ldtc4
792  END IF
793  IF Idtc>4 THEN
800  BEEP
810  PRINTER IS 1
820  BEEP
830  PRINT "INVALID ENTRY"
840  PRINTER IS 701
850  GOTO 610
860  END IF
870  END IF
880  OUTPUT @File1;Ldtc1,Ldtc2,Ldtc3,Ldtc4
890 ! Im=1 option
900  ELSE
910  BEEP
920  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_file$
930  PRINT USING "16X,""Old file name: "",14A";D2_file$
940  ASSIGN @File2 TO D2_file$
950  ENTER @File2;Nrun
960  ENTER @File2;Dold$
970  PRINT USING "16X,""This data set taken on : "",14A";Dold$
980  ENTER @File2;Ldtc1,Ldtc2,Ldtc3,Ldtc4
990  IF Ldtc1>0 OR Ldtc2>0 OR Ldtc3>0 OR Ldtc4>0 THEN
1000 PRINT USING "16X,""Thermocouples were defective at locations:"",4(3D,4X)";
Ldtc1,Ldtc2,Ldtc3,Ldtc4
1010 END IF
```

```
1020  ENTER @File2;Itt
1030  END IF
1040  Idtc=0
1050  IF Ldtc1>0 THEN Idtc=Idtc+1
1060  IF Ldtc2>0 THEN Idtc=Idtc+1
1061  IF Ldtc3>0 THEN Idtc=Idtc+1
1062  IF Ldtc4>0 THEN Idtc=Idtc+1
1070  IF Im=0 AND Ihm=1 THEN 1595
1080  BEEP
1090  INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1100  IF Iplot=1 THEN
1110  BEEP
1120  INPUT "GIVE NAME FOR PLOT FILE",P_file$
1130  CREATE BDAT P_file$,4
1140  ASSIGN @Plot TO P_file$
1150  END IF
1160  IF Ihm=1 THEN
1170  BEEP
1180  INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1190  IF Iuf=1 THEN
1200  BEEP
1210  INPUT "ENTER Uo FILE NAME",Ufile$
1220  CREATE BDAT Ufile$,4
1230  ASSIGN @Ufile TO Ufile$
1240  END IF
1250  BEEP
1260  INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1270  IF Ire=1 THEN
1280  BEEP
1290  INPUT "ENTER Re FILE NAME",Refile$
1300  CREATE BDAT Refile$,10
1310  ASSIGN @Refile TO Refile$
1320  END IF
1330  END IF
1340  PRINTER IS 1
1350  IF Im=0 THEN
1360  BEEP
1370  PRINT USING "4X,""Select tube number"""
1380  IF Ihm=0 THEN
1390  PRINT USING "6X,""0  Smooth 4 inch Ref"""
1400  PRINT USING "6X,""1  Smooth 4 inch Cu (Press/Slide)"""
1410  PRINT USING "6X,""2  Soft Solder 4 inch Cu"""
1420  PRINT USING "6X,""3  Soft Solder 4 inch HIGH FLUX"""
1430  PRINT USING "6X,""4  Wieland Hard 8 inch"""
1440  PRINT USING "6X,""5  HIGH FLUX 8 inch"""
1450  PRINT USING "6X,""6  GEWA-K 40 Fins/in"""
1460  PRINT USING "6X,""7  GEWA-K 26 Fins/in"""
1470  PRINT USING "6X,""8  GEWA-T 19 Fins/in"""
1480  PRINT USING "6X,""9  GEWA-T OR GEWA-TY 26 Fins/in"""
1490  PRINT USING "6X,""10 THERMOEXCEL-E"""
1500  PRINT USING "6X,""11 THERMOEXCEL-HE"""
1510  PRINT USING "6X,""12 TURBO-B"""
1520  PRINT USING "6X,""13 GEWA-K 19 Fins/in"""
1530  ELSE
1540  PRINT USING "6X,""0  Smooth tube"""
1550  PRINT USING "6X,""1  High Flux"""
1560  PRINT USING "6X,""2  Turbo-B"""
1570  PRINT USING "6X,""3  High Flux Mod"""
1580  PRINT USING "6X,""4  Turbo-B Mod"""
1590  END IF
1600  INPUT Itt
1610  OUTPUT @File1;Itt
1620  END IF
1630  PRINTER IS 701
1640  IF Itt<10 THEN PRINT USING "16X,""Tube Number:   "",D";Itt
1650  IF Itt>9 THEN PRINT USING "16X,""Tube Number:   "",DD";Itt
```

```
1660  IF Inm=1 THEN PRINT USING "16X,""Tube Type:        [illegible]
1670  BEEP
1680  INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iov
1690  BEEP
1700  INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilqv
1710!
1720! DIMENSIONS FO TESTED TUBES
1730! ELECTRIC HEATED MODE
1740! D1=Diameter at thermocouple positions
1750  DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
1760  DATA .0100965,.01157,.01157,.01157,.01157,.01157,.0100965
1770  READ D1a(*)
1780  D1=D1a(Itt)
1790!
1800! D2=Diameter of test section to the base of fins
1810  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270
1820  DATA .0127,.0138,.0138,.0138,.0138,.0138,.0127
1830  READ D2a(*)
1840!
1850! Di=Inside diameter of unenhanced ends
1860  DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125
1870  DATA .0118,.0118,.0118,.0118,.0118,.0111125
1880  READ Dia(*)
1890!
1900! Do=Outside diameter of unenhanced ends
1910  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270
1920  DATA .01331,.01331,.01331,.01331,.0158,.0127
1930  READ Doa(*)
1940!
1950! L=Length of enhanced surface
1960  DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32,.2032,.2032
1970  READ La(*)
1980!
1990! Lu=Length of unenhanced surface at the ends
2000  DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62,.0762,.0762
2010  READ Lua(*)
2020!
2030! Kcu=Thermal Conductivity of tube
2040  DATA 398,344,344,45,344,45,344,344,398,398,398,398,398,344
2050  READ Kcua(*)
2060  IF Inm=1 THEN
2070!
2080! Data statements for water heating mode
2090!
2100  DATA 0.015875,0.015875,0.0169,0.0138,0.0169,0,0,0,0,0
2110  READ D2a(*)
2120  DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
2130  READ Dia(*)
2140  DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
2150  READ Doa(*)
2160  DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
2170  READ La(*)
2180  DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
2190  READ Lua(*)
2200  DATA 398,45,398,45,398,0,0,0,0,0
2210  READ Kcua(*)
2220  END IF
2230  D2=D2a(Itt)
2240  Di=Dia(Itt)
2250  Do=Doa(Itt)
2260  L=La(Itt)
2270  Lu=Lua(Itt)
2280  Kcu=Kcua(Itt)
2290  Xn=.8
```

```
2300  Fr=.3
2310  IF Itt=0 THEN Cf=1.70E+9
2320  IF Itt>0 THEN Cf=3.7037E+10
2330  A=PI*(Do^2-Di^2)/4
2340  P=PI*Do
2350  IF Ihm=1 THEN
2360  BEEP
2370  INPUT "TUBE INITIATION MODE. (1=HOT WATER,2=STEAM,3=COLD WATER)",Itim
2380  IF Itim=1 THEN PRINT USING "16X,""Tube Initiate: Hot Water"""
2390  IF Itim=2 THEN PRINT USING "16X,""Tube Initiate: Steam"""
2400  IF Itim=3 THEN PRINT USING "16X,""Tube Initiate: Cold Water"""
2410  INPUT "TEMP/VEL MODE: (0=T-CONST,V-DEC;1=T-DEC,V-CONST; 2=T-INC,V-CONST)",
Itv
2420  IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing"""
2430  IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant"""
2440  IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant"""
2450  INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iwil
2460  IF Ihm=1 AND Iwil=0 THEN
2470  IF Itt=0 THEN Ci=.032
2480  IF Itt=1 OR Itt=3 THEN Ci=.059
2490  IF Itt=2 OR Itt=4 THEN Ci=.062
2500  BEEP
2510  INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
2520  PRINT USING "16X,""Sieder-Tate """
2530  PRINT USING "16X,""  Constant    = "",Z.4D";Ci
2540  END IF
2550  END IF
2560  IF Ihm=1 AND Im=1 AND Iwil=1 THEN

2570  IF Itt=0 THEN Ci=.032
2580  IF Itt=1 OR Itt=3 THEN Ci=.059
2590  IF Itt=2 OR Itt=4 THEN Ci=.062
2600  ASSIGN @File2 TO *
2610  CALL Wilson(Cf,Ci)
2620  ASSIGN @File2 TO D2_file$
2630  ENTER @File2;Nrun,Dold$,Ldtc1,Ldtc2,Ldtc3,Ldtc4,Itt
2640  END IF
2650  Nsub=0
2660  IF Idp=4 THEN Ihm=1
2670  IF Ihm=1 THEN Nsub=8
2680  Ntc=6
2690  IF Ihm=0 THEN Ntc=12
2700  J=1
2710  Sx=0
2720  Sy=0
2730  Sxs=0
2740  Sxy=0
2750 Repeat: !
2760  IF Im=0 THEN
2780  Ido=2
2790  ON KEY 1,15 RECOVER 2750
2800  PRINTER IS 1
2810  PRINT USING "4X,""SELECT OPTION"""
2820  PRINT USING "6X,""0=TAKE DATA"""
2830  IF Ihm=0 THEN PRINT USING "6X,""1=SET HEAT FLUX"""
2840  IF Ihm=1 THEN PRINT USING "6X,""1=SET WATER FLOW RATE"""
2850  PRINT USING "6X,""2=SET Tsat"""
2860  PRINT USING "4X,""NOTE: KEY 1 = ESCAPE"""
2870  BEEP
2880  INPUT Ido
2890  IF Ido>2 THEN Ido=2
2900  IF Ido=0 THEN 4440
2910!
2920! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
2930  IF Ido=1 THEN
2940  IF Ihm=0 THEN
```

```
2950  OUTPUT 709;"AR AF20 AL21 VR5"
2960  BEEP
2970  INPUT "ENTER DESIRED Qdp",Dqdp
2980  PRINT USING "4X,""DESIRED Qdp  ACTUAL Qdp"""
2990  Err=1000
3000  FOR I=1 TO 2
3010  OUTPUT 709;"AS SA"
3020  Sum=0
3030  FOR J1=1 TO 5
3040  ENTER 709;E
3050  Sum=Sum+E
3060  NEXT J1
3070  IF I=1 THEN Volt=Sum/5
3080  IF I=2 THEN Amp=Sum/5
3090  NEXT I
3091  PRINT "Vs:",Volt
3092  PRINT "Is:",Amp
3100  Amp=ABS(Amp*1.9182)
3110  Volt=ABS(Volt*25)
3120  Aqdp=Volt*Amp/(PI*D2*L)
3130  IF ABS(Aqdp-Dqdp)>Err THEN
3140  IF Aqdp>Dqdp THEN
3150  BEEP 4000,.2
3160  BEEP 4000,.2
3170  BEEP 4000,.2
3180  ELSE
3190  BEEP 250,.2
3200  BEEP 250,.2
3210  BEEP 250,.2
3220  END IF
3230  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
3240  WAIT 2
3250  GOTO 3000
3260  ELSE
3270  BEEP
3280  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
3290  Err=500
3300  WAIT 2
3310  GOTO 3000
3320  END IF
3330  ELSE
3340  BEEP
3350  INPUT "ENTER FLOWMETER SETTING",Fms
3360  GOTO 2810
3370  END IF
3380  END IF
3390!
3400! LOOP TO SET Tsat
3410  IF Ido=2 THEN
3420  IF Ikdt=1 THEN 3470
3430  BEEP
3440  INPUT "ENTER DESIRED Tsat",Dtld
3450! PRINT USING "4X,"" DTsat  ATsat   Rate     Tv      Rate"""
3460  Ikdt=1
3470  Old1=0
3480  Old2=0
3490  Nn=1
3500  Nrs=Nn MOD 15
3510  Nn=Nn+1
3520  IF Nrs=1 THEN
3530  IF Ihm=0 THEN PRINT USING "4X,""  Tsat     Tld1     Tld2     Tv     Tsump"""
3540  IF Ihm=1 THEN PRINT USING "4X,""  Tsat   Tld1     Tld2     Tv    Tsump  Tinle
t   Tpile  Tout"""
3550  END IF
3560  IF Ihm=0 THEN OUTPUT 709;"AR AF09 AL11 VR5"
3570  IF Ihm=1 THEN OUTPUT 709;"AR AF0 AL5 VR5"
```

```
3580  FOR I=1 TO 6
3590  IF Ihm=0 AND I>4 THEN 3860
3600  Sum=0
3610  OUTPUT 709;"AS SA"
3620  FOR Ji=1 TO 20
3630  ENTER 709;Eliq
3640  Sum=Sum+Eliq
3650  NEXT Ji
3660  Eliq=Sum/20
3670  Tld=FNTvsv(Eliq)
3680  IF I=1 THEN Tld1=Tld
3690  IF I=2 THEN Tld2=Tld
3700  IF I=3 THEN Tv=Tld
3710  IF I=4 THEN Tsump=Tld
3720  IF I=5 THEN Tinlet=Tld
3730  IF I=6 THEN Tout=Tld
3740  NEXT I
3750  IF Ihm=1 THEN
3760  OUTPUT 709;"AR AF00 AL00 VRS"
3770  OUTPUT 709;"AS SA"
3780  Sum=0
3790  FOR Kk=1 TO 20
3800  ENTER 709;E
3810  Sum=Sum+E
3820  NEXT Kk
3830  Emf(7)=ABS(Sum/20)
3840  Tpile=Emf(7)/3.96E-4
3850  END IF
3860  Atld=(Tld1+Tld2)*.5
3870  IF ABS(Atld-Dtld)>.2 THEN
3880  IF Atld>Dtld THEN
3890  BEEP 4000,.2
3900  BEEP 4000,.2
3910  BEEP 4000,.2
3920  ELSE
3930  BEEP 250,.2
3940  BEEP 250,.2
3950  BEEP 250,.2
3960  END IF
3970  Err1=Atld-Old1
3980  Old1=Atld
3990  Err2=Tv-Old2
4000  Old2=Tv
4010  IF Tld1>100. THEN 4060
4020  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
4030  IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Ts
ump,Tinlet,Tpile
4040  IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,2X)";Dtld,Tl
d1,Tld2,Tv,Tsump,Tinlet,Tpile,Tout
4050  WAIT 2
4060  GOTO 3500
4070  ELSE
4080  IF ABS(Atld-Dtld)>.1 THEN
4090  IF Atld>Dtld THEN
4100  BEEP 3000,.2
4110  BEEP 3000,.2
4120  ELSE
4130  BEEP 800,.2
4140  BEEP 800,.2
4150  END IF
4160  Err1=Atld-Old1
4170  Old1=Atld
4180  Err2=Tv-Old2
4190  Old2=Tv
4200  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
```

```
4210  IF Ihm=1 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,1X)";Dtld,Tld1,Tld2,Tv
,Tsump,Tinlet,Tpile,Tout
4220  WAIT 2
4230  GOTO 3500
4240  ELSE
4250  BEEP
4260  Err1=Atld-Old1
4270  Old1=Atld
4280  Err2=Tv-Old2
4290  Old2=Tv
4300  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
4310  IF Ihm=1 THEN PRINT USING "4X,8(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump,Tinlet
,Tpile,Tout
4320  WAIT 2
4330  GOTO 3500
4340  END IF
4350  END IF
4360  END IF
4370! ERROR TRAP FOR Ido OUT OF BOUNDS
4380  IF Ido>2 THEN
4390  BEEP
4400  GOTO 2810
4410  END IF
4420!
4430! TAKE DATA IF Im=0 LOOP
4440  IF Ikol=1 THEN 4480
4450  BEEP
4460  INPUT "ENTER BULK OIL %",Bop
4470  Ikol=1
4480  IF Ihm=0 THEN OUTPUT 709;"AR AF00 AL11 VRS"
4490  IF Ihm=1 THEN OUTPUT 709;"AR AF0 AL5 VRS"
4500  IF Ihm=0 THEN Ntc=12
4510  FOR I=1 TO Ntc
4520  OUTPUT 709;"AS SA"
4530  Sum=0
4540  FOR Ji=1 TO 20
4550  ENTER 709;E
4560  Sum=Sum+E
4570  IF I=(9-Nsub) OR I=(10-Nsub) THEN Et(Ji-1)=E
4580  NEXT Ji
4590  Kdl=0
4600  IF I=(9-Nsub) OR I=(10-Nsub) THEN
4610  Eave=Sum/20
4620  Sum=0.
4630  FOR Jk=0 TO 19
4640  IF ABS(Et(Jk)-Eave)<5.0E-6 THEN
4650  Sum=Sum+Et(Jk)
4660  ELSE
4670  Kdl=Kdl+1
4680  END IF
4690  NEXT Jk
4700  IF I=(9-Nsub) OR I=(10-Nsub) THEN PRINT USING "4X,""Kdl = "",DD";Kdl
4710  IF Kdl>10 THEN
4720  BEEP
4730  BEEP
4740  PRINT USING "4X,""Too much scattering in data - repeat data set"""
4750  GOTO 2800
4760  END IF
4770  END IF
4780  Emf(I)=Sum/(20-Kdl)
4790  NEXT I
4800  IF Ihm=1 THEN
4810  OUTPUT 709;"AR AF00 AL00 VRS"
4820  OUTPUT 709;"AS SA"
4830  Sum=0
4840  FOR Kk=1 TO 20
```

```
4852  ENTER 709;E
4860  Sum=Sum+E
4870  NEXT Kk
4880  Emf(7)=ABS(Sum)/20
4890  END IF
4900  IF Ihm=0 THEN
4910  OUTPUT 709;"AR AF20 AL21 VRS"
4920  FOR I=1 TO 2
4930  OUTPUT 709;"AS SA"
4940  Sum=0
4950  FOR J1=1 TO 5
4960  ENTER 709;E
4970  Sum=Sum+E
4980  NEXT J1
4990  IF I=1 THEN Vr=Sum/5
5000  IF I=2 THEN Ir=Sum/5
5010  NEXT I
5020  END IF
5030  ELSE
5040  IF Ihm=0 THEN ENTER @File2;Bop,Told$,Emf(*),Vr,Ir
5050  IF Ihm=1 THEN ENTER @File2;Bop,Told$,Emf(*),Fms
5060  END IF
5070!
5080! CONVERT emf'S TO TEMP,VOLT,CURRENT
5090  Twa=0
5100  FOR I=1 TO Ntc
5110  IF Idtc>0 THEN
5120  IF I=Ldtc1 OR I=Ldtc2 OR I=Ldtc3 OR I=Ldtc4 THEN
5130  T(I)=-99.99
5140  GOTO 5240
5150  END IF
5160  END IF
5170  IF Itt<4 AND Ihm=0 THEN
5180  IF I>4 AND I<9 THEN
5190  T(I)=-99.99
5200  GOTO 5240
5210  END IF
5220  END IF
5230  T(I)=FNTvsv(Emf(I))
5240  NEXT I
5250  IF Itt<4 THEN
5251!   WARNING: 4 BAD THERMOCOUPLES ARE NOT POSSIBLE FOR ITT<4
5260  FOR I=1 TO 4
5270  IF I=Ldtc1 OR I=Ldtc2 THEN
5280  Twa=Twa
5290  ELSE
5300  Twa=Twa+T(I)
5310  END IF
5320  NEXT I
5330  Twa=Twa/(4-Idtc)
5340  ELSE
5350  IF Ihm=1 THEN 5450
5360  FOR I=1 TO 8
5370  IF I=Ldtc1 OR I=Ldtc2 OR I=Ldtc3 OR I=Ldtc4 THEN
5380  Twa=Twa
5390  ELSE
5400  Twa=Twa+T(I)
5410  END IF
5420  NEXT I
5430  Tw=Twa/(8-Idtc)
5440  END IF
5450  Tld=T(9-Nsub)
5460  Tld2=T(10-Nsub)
5470  Tlda=(Tld+Tld2)*.5
5480  Tv=T(11-Nsub)
5490  IF Itt<3 AND Ihm=0 THEN
```

```
5500  Tld2=-99.99
5510  Tv=(T(10)+T(11))/2
5520  END IF
5530  Tsump=T(12-Nsub)
5540  IF Ihm=0 THEN 5570
5550  Tinlet=T(13-Nsub)
5560  Tout=T(14-Nsub)
5570  IF Ihm=0 THEN
5580  Amp=ABS(Ir*1.9182)
5590  Volt=ABS(Vr)*25
5600  Q=Volt*Amp
5610  END IF
5620  IF Itt=0 AND Ihm=0 THEN
5630  Kcu=FNKcu(Tw)
5640  ELSE
5650  Kcu=Kcua(Itt)
5660  END IF
5670!
5680! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
5690  IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
5700  IF Ilqv=0 THEN Tsat=Tlda
5710  IF Ilqv=1 THEN Tsat=(Tlda+Tv)*.5
5720  IF Ilqv=2 THEN Tsat=Tv
5730  IF Ihm=1 THEN
5740  Tavg=Tinlet
5750  Grad=37.9853+.104388*Tavg
5760  Tdrop=ABS(Emf(7))*1.E+6/(10*Grad)
5770  Tavgc=Tinlet-Tdrop*.5
5780  IF ABS(Tavg-Tavgc)>.01 THEN
5790  Tavg=(Tavg+Tavgc)*.5
5800  GOTO 5750
5810  END IF
5820!
5830! COMPUTE WATER PROPERTIES
5840  IF Ihm=1 THEN
5850  Kw=FNKw(Tavg)
5860  Muwa=FNMuw(Tavg)
5870  Cpw=FNCpw(Tavg)
5880  Prw=FNPrw(Tavg)
5890  Rhow=FNRhow(Tavg)
5900  Twi=Tavg
5910!
5920! Compute MDOT
5930  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
5940! Mdot=Mdot*(1.0365-Tinlet*(1.96644E-3-Tinlet*5.252E-6))/1.0037
5950  Kdt=0
5960  Q=Mdot*Cpw*Tdrop
5970  Lmtd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
5980  Uo=Q/(PI*Do*L*Lmtd)
5990  Rw=Do*LOG(Do/Di)/(2.*Kcu)
6000  Tw=Tsat+Fr*Lmtd
6010  Vw=Mdot/(Rhow*PI*Di^2/4)
6020  Rew=Rhow*Vw*Di/Muwa
6030  Hi=Ci*Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
6040  Twic=Tavg-Q/(PI*Do*L*Hi)
6050  IF ABS(Twi-Twic)>.01 THEN
6060  Twi=(Twi+Twic)*.5
6070  GOTO 6030
6080  END IF
6090  Twi=(Twi+Twic)*.5
6100  Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
6110  END IF
6120  END IF
6130  IF Ihm=1 THEN
6140  Thetab=Q/(Ho*PI*Do*L)
```

```
6150  Tw=Tsat+Thetab
6160  ELSE
6170  Thetab=Tw-Tsat
6180  END IF
6190  IF Thetab<0 THEN
6200  BEEP
6210  INPUT "TWALL<TSAT (0=CONTINUE, 1=END)",Iev
6220  IF Iev=0 THEN GOTO 2760
6230  IF Iev=1 THEN 7220
6240  END IF
6250!
6260! COMPUTE VARIOUS PROPERTIES
6270  Tfilm=(Tw+Tsat)*.5
6280  Rho=FNRho(Tfilm)
6290  Mu=FNMu(Tfilm)
6300  K=FNK(Tfilm)
6310  Cp=FNCp(Tfilm)
6320  Beta=FNBeta(Tfil
6330  Hfg=FNHfg(Tsat)
6340  Ni=Mu/Rho
6350  Alpha=K/(Rho*Cp)
6360  Pr=Ni/Alpha
6370  Psat=FNPsat(Tsat)
6380!
6381  PRINT "Rho:",Rho
6382  PRINT "Mu:",Mu
6383  PRINT "K:",K
6384  PRINT "Cp:",Cp
6385  PRINT "Tfilm:",Tfilm
6386  PRINT "Hfg:",Hfg
6387  PRINT "Psat:",Psat
6388  PRINT "Tsat:",Tsat
6390! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
6400! FOR UNENHANCED END(S)
6410  Hbar=190
6420  Fe=(Hbar*P/(Kcu*A))^.5*Lu
6430  Tanh=FNTanh(Fe)
6440  Theta=Thetab*Tanh/Fe
6450  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
6460  Yy=(1+(.559/Pr)^(9/16))^(8/27)
6470  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
6480  IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
6490  Hbar=(Hbar+Hbarc)*.5
6500  GOTO 6420
6510  END IF
6511  PRINT "NAT CONV h:",Hbar
6520!
6530! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
6540  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
6550  Qc=Q-2*Q1
6560  As=PI*D2*L
6570!
6580! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
6590  Qdp=Qc/As
6600  Htube=Qdp/Thetab
6610  Csf=(Cp*Thetab/Hfg)/(Qdp/(Mu*Hfg)*(.014/(9.81*Rho)^.5)^(1/3.)*Pr^1.7)
6620!
6630! RECORD TIME OF DATA TAKING
6640  IF Im=0 THEN
6650  OUTPUT 709;"TD"
6660  ENTER 709;Told$
6670  END IF
6680!
6690! OUTPUT DATA TO PRINTER
6700  PRINTER IS 701
6710  IF Iov=0 THEN
```

```
6720  PRINT
6730! PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D,5X,1
4A";J,Bop,Told$
6731  PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D";J,B
op
6732  PRINT "            TIME:",TIME$(TIMEDATE)
6740  IF Ihm=0 THEN
6750  PRINT USING "10X,""TC No:    1      2      3      4      5      6      7
    8"""
6760  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
6770  PRINT USING "10X,"" Twa    Tliqd   Tliqd2  Tvapr  Psat   Tsump"""
6780  PRINT USING "10X,2(MDD.DD,1X),1X,MDD.DD,1X,2(1X,MDD.DD),2X,MDD.D";Tw,Tld,T
ld2,Tv,Psat,Tsump
6790  PRINT USING "10X,"" Thetab  Htube      Qdp"""
6800  PRINT USING "10X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE";Thetab,Htube,Qdp
6810  ELSE
6820  PRINT USING "10X,"" Fms    Vw    Tsat  Tinl Tdrop Thetab     q          Uo
       Ho"""
6830  PRINT USING "10X,4(2D.DD,1X),Z.3D,1X,DD.DD,1X,3(MZ.3DE,1X)";Fms,Vw,Tsat,Ti
nlet,Tdrop,Thetab,Qdp,Uo,Ho
6840  END IF
6850  END IF
6860  IF Iov=1 THEN
6870  IF J=1 THEN
6880  PRINT
6890  IF Ihm=0 THEN
6900  PRINT USING "10X,"" RUN No  Oil%  Tsat    Htube      Qdp       Thetab"""
6910  ELSE
6920  PRINT USING "10X,""  FMS    OIL%  TSAT    HTUBE      QDP       THETAB"""
6930  END IF
6940  END IF
6950  IF Ihm=0 THEN
6960  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
6970  ELSE
6980  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
6990  END IF
7000  END IF
7010  IF Im=0 THEN
7020  BEEP
7030  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
7040  END IF
7050  IF Ok=1 OR Im=1 THEN J=J+1
7060  IF Ok=1 AND Im=0 THEN
7070  IF Ihm=0 THEN OUTPUT @File1;Bop,Told$,Emf(*),Vr,Ir
7080  IF Ihm=1 THEN OUTPUT @File1;Bop,Told$,Emf(*),Fms
7090  END IF
7100  IF Iuf=1 THEN OUTPUT @Ufile;Vw,Uo
7110  IF Ire=1 THEN OUTPUT @Refile;Fms,Rew
7120  IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot;Qdp,Thetab
7130  IF Im=0 THEN
7140  BEEP
7150  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
7160  Nrun=J
7170  IF Go_on=0 THEN 7220
7180  IF Go_on<>0 THEN Repeat
7190  ELSE
7200  IF J<Nrun+1 THEN Repeat
7210  END IF
7220  IF Im=0 THEN
7230  BEEP
7240  PRINT USING "10X,""NOTE: "",ZZ,"" data runs were stored in file "",10A";J-
1,D2_file$
7250  ASSIGN @File1 TO *
```

```
7260  OUTPUT @File2;Nrun-1
7270  ASSIGN @File1 TO D1_file$
7280  ENTER @File1;Date$,Ldtc1,Ldtc2,Itt
7290  OUTPUT @File2;Date$,Ldtc1,Ldtc2,Itt
7300  FOR I=1 TO Nrun-1
7310  IF Ihm=0 THEN
7320  ENTER @File1;Bop,Told$,Emf(*),Vr,Ir
7330  OUTPUT @File2;Bop,Told$,Emf(*),Vr,Ir
7340  ELSE
7350  ENTER @File1;Bop,Told$,Emf(*),Fms
7360  OUTPUT @File2;Bop,Told$,Emf(*),Fms
7370  END IF
7380  NEXT I
7390  ASSIGN @File1 TO *
7400  PURGE "DUMMY"
7410  END IF
7420  BEEP
7430  PRINT
7440  IF Iplot=1 THEN PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in
 plot data file "",10A";J-1,P_file$
7450  ASSIGN @File2 TO *
7460  ASSIGN @Plot TO *
7470  IF Iuf=1 THEN ASSIGN @Ufile TO *
7480  IF Ire=1 THEN ASSIGN @Refile TO *
7490  CALL Stats
7500  BEEP
7510  INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
7520  IF Ok=1 THEN CALL Plot
7530  SUBEND
7540!
7550! CURVE FITS OF PROPERTY FUNCTIONS
7560  DEF FNKcu(T)
7570! OFHC COPPER 250 TO 300 K
7580  Tk=T+273.15      !C TO K
7590  K=434-.112*Tk .
7600  RETURN K
7610  FNEND
7620  DEF FNMu(T)
7621  COM /Iprop/ Ift
7622  IF Ift=0 THEN
7630! 170 TO 360 K CURVE FIT OF VISCOUSITY
7640  Tk=T+273.15      !C TO K
7650  Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
7651  END IF
7652  IF Ift=1 THEN
7653! 223 TO 373 K
7657  Mu=3.4593-4.26E-2*T+3.9485E-4*T^2-4.193E-6*T^3+2.0709E-8*T^4
7658  Mu=Mu*1.0E-4
7659  END IF
7660  RETURN Mu
7670  FNEND
7680  DEF FNCp(T)
7681  COM /Iprop/ Ift
7682  IF Ift=0 THEN
7690! 180 TO 400 K CURVE FIT OF Cp
7700  Tk=T+273.15      !C TO K
7710  Cp=.40188+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3
7720  Cp=Cp*1000
7721  END IF
7722  IF Ift=1 THEN
7723! 223 TO 373 K CURVE FIT Cp(R124)
7725  Cp=1.0542+2.1405E-3*T+1.0709E-5*T^2-6.4721E-8*T^3-1.4324E-9*T^4+4.136E-11*
T^5
7726  Cp=Cp*1000
7727  END IF
7730  RETURN Cp
```

```
7740  FNEND
7750  DEF FNRho(T)
7751  COM /Iprop/ Ift
7752  IF Ift=0 THEN
7760  Tk=T+273.15     !C TO K
7770  X=1-(1.8*Tk/753.95)  !K TO R
7780  Ro=36.32+61.146414*X^(1/3)+16.418015*X+17.476838*X^.5+1.119828*X^2
7790  Ro=Ro/.062428
7791  END IF
7792  IF Ift=1 THEN
7793! 223 TO 373 K (R-124)
7796  Ro=1434.8-2.8619*T-6.7267E-3*T^2-7.2852E-5*T^3
7797  END IF
7800  RETURN Ro
7810  FNEND
7820  DEF FNPr(T)
7830  Pr=FNCp(T)*FNMu(T)/FNK(T)
7840  RETURN Pr
7850  FNEND
7860  DEF FNK(T)
7861  COM /Iprop/ Ift
7862  IF Ift=0 THEN
7870! T<360 K WITH T IN C
7880  K=.071-.000261*T
7881  END IF
7882  IF Ift=1 THEN
7883! 223 TO 373 K  (R-124)
7885  K=7.5191E-2-3.5436E-4*T-1.9545E-7*T^2+3.1835E-9*T^3
7886  END IF
7890  RETURN K
7900  FNEND
7910  DEF FNTanh(X)
7920  P=EXP(X)
7930  Q=1/P
7940  Tanh=(P-Q)/(P+Q)
7950  RETURN Tanh
7960  FNEND
7970  DEF FNTvsv(V)
7980  COM /Cc/ C(7),Ical
7990  T=C(0)
8000  FOR I=1 TO 7
8010  T=T+C(I)*V^I
8020  NEXT I
8030  IF Ical=1 THEN
8040  T=T-6.7422934E-2+T*(9.0277043E-3-T*(-9.3259917E-5))
8050  ELSE
8060  T=T+8.626897E-2+T*(3.76199E-3-T*5.0689259E-5)
8070  END IF
8080  RETURN T
8090  FNEND
8100  DEF FNBeta(T)
8110  Rop=FNRho(T+.1)
8120  Rom=FNRho(T-.1)
8130  Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
8140  RETURN Beta
8150  FNEND
8160  DEF FNHfg(T)
8161  COM /Iprop/ Ift
8162  IF Ift=0 THEN
8170  Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
8171  END IF
8172  IF Ift=1 THEN
8173! 223 TO 373 K CURVE FIT (R124)
8176  Hfg=159.93-.4609*T-1.458E-3*T^2-1.3715E-5*T^3
8177  Hfg=Hfg*1000
8178  END IF
```

```
8180  RETURN Hfg
8190  FNEND
8200  DEF FNPsat(Tc)
8201  COM /Iprop/ Ift
8202  IF Ift=0 THEN
8210! 0 TO 80 deg F CURVE FIT OF Psat
8220  Tf=1.8*Tc+32
8230  Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
8240  Pg=Pa-14.7
8241  END IF
8242  IF Ift=1 THEN
8243! 223 TO 373 K  (R-124)
8245  Pa=(162.68+5.946*Tc+9.2081E-2*Tc^2+6.9359E-4*Tc^3)*.14504
8247  Pg=Pa-14.7
8248  END IF
8250  IF Pg>0 THEN       ! +=PSIG,-=in Hg
8260  Psat=Pg
8270  ELSE
8280  Psat=Pg*29.92/14.7
8290  END IF
8300  RETURN Psat
8310  FNEND
8320  DEF FNHsmooth(X,Bop,Isat)
8330  DIM A(5),B(5),C(5),D(5)
8340  DATA .20526,.25322,.319048,.55322,.79909,1.00258
8350  DATA .74515,.72992,.73189,.71225,.68472,.64197
8360  DATA .41092,.17726,.25142,.54806,.81916,1.0845
8370  DATA .71403,.72913,.72565,.696691,.665867,.61889
8380  READ A(*),B(*),C(*),D(*)
8390  IF Bop<6 THEN I=Bop
8400  IF Bop=6 THEN I=4
8410  IF Bop=10 THEN I=5
8420  IF Isat=1 THEN
8430  Hs=EXP(A(I)+B(I)*LOG(X))
8440  ELSE
8450  Hs=EXP(C(I)+D(I)*LOG(X))
8460  END IF
8470  RETURN Hs
8480  FNEND
8490  DEF FNPoly(X)
8500  COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
8510  X1=X
8520  Poly=B(0)
8530  FOR I=1 TO Nop
8540  IF Ilog=1 THEN X1=LOG(X)
8550  Poly=Poly+B(I)*X1^I
8560  NEXT I
8570  IF Ilog=1 THEN Poly=EXP(Poly)
8580  RETURN Poly
8590  FNEND
8600  SUB Poly
8610  DIM R(10),S(10),Sy(12),Sx(12),Xx(100),Yy(100)
8620  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
8630  COM /Xxyy/ Xp(25),Yp(25)
8640  FOR I=0 TO 4
8650  B(I)=0
8660  NEXT I
8670  BEEP
8680  INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",Im
8690  Im=Im+1
8700  BEEP
8710  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
8720  IF Im=1 THEN
8730  BEEP
8740  INPUT "ENTER DATA FILE NAME",D_file$
8750  BEEP
```

```
8760 INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
8770 IF Ied=1 THEN
8780 BEEP
8790 INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
8800 END IF
8810 ASSIGN @File TO D_file$
8820 ELSE
8830 BEEP
8840 INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
8850 IF Yes=1 THEN
8860 BEEP
8870 INPUT "GIVE A NAME FOR DATA FILE",D_file$
8880 CREATE BDAT D_file$,5
8890 ASSIGN @File TO D_file$
8900 END IF
8910 END IF
8920 BEEP
8930 INPUT "ENTER THE ORDER OF POLYNOMIAL",N
8940 FOR I=0 TO N*2
8950 Sy(I)=0
8960 Sx(I)=0
8970 NEXT I
8980 IF Ied=1 AND Im=1 THEN
8990 FOR I=1 TO Ipex
9000 ENTER @File;X,Y
9010 NEXT I
9020 END IF
9030 FOR I=1 TO Np
9040 IF Im=1 THEN
9050 IF Opo=2 THEN ENTER @File;X,Y
9060 IF Opo<2 THEN ENTER @File;Y,X
9070 IF Opo=1 THEN Y=Y/X
9080 IF Ilog=1 THEN
9090 IF Opo=2 THEN Xt=X/Y
9100 X=LOG(X)
9110 IF Opo=2 THEN Y=LOG(Xt)
9120 IF Opo<2 THEN Y=LOG(Y)
9130 END IF
9140 END IF
9150 IF Im=2 THEN
9160 BEEP
9170 INPUT "ENTER NEXT X-Y PAIR",X,Y
9180 IF Yes=1 THEN OUTPUT @File;X,Y
9190 END IF
9200 IF Im<3 THEN
9210 Xx(I)=X
9220 Yy(I)=Y
9230 ELSE
9240 X=Xp(I-1)
9250 Y=Yp(I-1)
9260 END IF
9270 R(0)=Y
9280 Sy(0)=Sy(0)+Y
9290 S(1)=X
9300 Sx(1)=Sx(1)+X
9310 FOR J=1 TO N
9320 R(J)=R(J-1)*X
9330 Sy(J)=Sy(J)+R(J)
9340 NEXT J
9350 FOR J=2 TO N*2
9360 S(J)=S(J-1)*X
9370 Sx(J)=Sx(J)+S(J)
9380 NEXT J
9390 NEXT I
9400 IF Yes=1 AND Im=2 THEN
9410 BEEP
```

```
9420  PRINT USING "12X,DD,"" x-y pairs were stored in file    ,"0A":Np,D_file$
9430  END IF
9440  Sx(0)=Np
9450  FOR I=0 TO N
9460  C(I)=Sy(I)
9470  FOR J=0 TO N
9480  A(I,J)=Sx(I+J)
9490  NEXT J
9500  NEXT I
9510  FOR I=0 TO N-1
9520  CALL Divide(I)
9530  CALL Subtract(I+1)
9540  NEXT I
9550  B(N)=C(N)/A(N,N)
9560  FOR I=0 TO N-1
9570  B(N-1-I)=C(N-1-I)
9580  FOR J=0 TO I
9590  B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
9600  NEXT J
9610  B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
9620  NEXT I
9630 !PRINTER IS 701
9640 !PRINT B(*)
9650 !PRINTER IS 705
9660  IF Iprnt=0 THEN
9670  PRINT USING "12X,""EXPONENT    COEFFICIENT"""
9680  FOR I=0 TO N
9690  PRINT USING "15X,DD,5X,MD.7DE";I,B(I)
9700  NEXT I
9710  PRINT " "
9720  PRINT USING "12X,""DATA POINT       X              Y        Y(CALCULATED) DISCR
EPANCY"""
9730  FOR I=1 TO Np
9740  Yc=B(0)
9750  FOR J=1 TO N
9760  Yc=Yc+B(J)*Xx(I)^J
9770  NEXT J
9780  D=Yy(I)-Yc
9790  PRINT USING "15X,3D,4X,4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
9800  NEXT I
9810  END IF
9820  ASSIGN @File TO *
9830  SUBEND
9840  SUB Divide(M)
9850  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
9860  FOR I=M TO N
9870  Ao=A(I,M)
9880  FOR J=M TO N
9890  A(I,J)=A(I,J)/Ao
9900  NEXT J
9910  C(I)=C(I)/Ao
9920  NEXT I
9930  SUBEND
9940  SUB Subtract(K)
9950  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
9960  FOR I=K TO N
9970  FOR J=K-1 TO N
9980  A(I,J)=A(K-1,J)-A(I,J)
9990  NEXT J
10000 C(I)=C(K-1)-C(I)
10010 NEXT I
10020 SUBEND
10030 SUB Plin
10040 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
10050 COM /Xxyy/ Xx(25),Yy(25)
10060 PRINTER IS 705
```

```
10070 BEEP
10080 INPUT "WANT TO PLOT Uo vs Vw? (1=Y,0=N)",Iuo
10090 IF Iuo=0 THEN
10100 BEEP
10110 INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
10120 BEEP
10130 INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrat
10140 IF Ihrat=0 THEN
10150 BEEP
10160 INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
10170 END IF
10180 Xmin=0
10190 Xmax=10
10200 Xstep=2
10210 IF Irt=0 THEN
10220 Ymin=0
10230 Ymax=1.4
10240 Ystep=.2
10250 ELSE
10260 Ymin=0
10270 Ymax=15
10280 Ystep=5
10290 END IF
10300 ELSE
10310 Opo=2
10320 Ymin=0
10330 Ymax=12
10340 Ystep=3
10350 Xmin=0
10360 Xmax=4
10370 Xstep=1
10380 END IF
10390 IF Ihrat=1 THEN
10400 Ymin=0
10410 Ymax=18
10420 Ystep=3
10430 Xmin=0
10440 Xmax=9
10450 Xstep=2
10460 END IF
10470 BEEP
10480 PRINT "IN;SP1;IP 2300,2200,8300,6800;"
10490 PRINT "SC 0,100,0,100;TL 2,0;"
10500 Sfx=100/(Xmax-Xmin)
10510 Sfy=100/(Ymax-Ymin)
10520 PRINT "PU 0,0 PD"
10530 FOR Xa=Xmin TO Xmax STEP Xstep
10540 X=(Xa-Xmin)*Sfx
10550 PRINT "PA";X,",0; XT;"
10560 NEXT Xa
10570 PRINT "PA 100,0;PU;"
10580 PRINT "PU PA 0,0 PD"
10590 FOR Ya=Ymin TO Ymax STEP Ystep
10600 Y=(Ya-Ymin)*Sfy
10610 PRINT "PA 0,";Y,"YT"
10620 NEXT Ya
10630 PRINT "PA 0,100 TL 0 2"
10640 FOR Xa=Xmin TO Xmax STEP Xstep
10650 X=(Xa-Xmin)*Sfx
10660 PRINT "PA";X,",100; XT"
10670 NEXT Xa
10680 PRINT "PA 100,100 PU PA 100,0 PD"
10690 FOR Ya=Ymin TO Ymax STEP Ystep
10700 Y=(Ya-Ymin)*Sfy
10710 PRINT "PD PA 100,",Y,"YT"
10720 NEXT Ya
```

```
10730 PRINT "PA 100,100 PU"
10740 PRINT "PA 0,-2 SR 1.5,2"
10750 FOR Xa=Xmin TO Xmax STEP Xstep
10760 X=(Xa-Xmin)*Sfx
10770 PRINT "PA";X,",0;"
10780 IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;""
10790 IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;""
10800 NEXT Xa
10810 PRINT "PU PA 0,0"
10820 FOR Ya=Ymin TO Ymax STEP Ystep
10830 IF ABS(Ya)<1.E-5 THEN Ya=0
10840 Y=(Ya-Ymin)*Sfy
10850 PRINT "PA 0,";Y,""
10860 IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;""
10870 IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;""
10880 NEXT Ya
10890 Xlabel$="Oil Percent"
10900 IF Iuo=0 THEN
10910 IF Irt=0 THEN
10920 Ylabel$="h/h0%"
10930 ELSE
10940 Ylabel$="h/hsmooth"
10950 END IF
10960 PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
10970 PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
10980 PRINT "CP 0,0"
10990 ELSE
11000 PRINT "SP0;SP2"
11010 PRINT "SR 1.2,2.4;PU PA -8,35;DI 0,1;LBU;PR 1,0.5;LBo;PR -1,0.5;LB (kW/m
"
11020 PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
11030 PRINT "PA 42,-10;DI 1,0;LBV;PR .4,-1;LBw;PR 1,.5;LB(m/s)"
11040 PRINT "SP0;SP1"
11050 END IF
11060 Ipn=0
11070 BEEP
11080 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Okp
11090 Icn=0
11100 IF Okp=1 THEN
11110 BEEP
11120 INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
11130! IF Iuo=0 THEN
11140 BEEP
11150 INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)",Ilog
11160! END IF
11170 ASSIGN @File TO D_file$
11180 BEEP
11190 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
11200 BEEP
11210 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
11220 IF Iuo=0 AND Ihrat=0 THEN
11230 BEEP
11240 INPUT "ENTER DESIRED HEAT FLUX",Q
11250 END IF
11260 BEEP
11270 PRINTER IS 1
11280 PRINT USING "4X,""Select a symbol:"""
11290 PRINT USING "4X,""1  Star   2  Plus sign"""
11300 PRINT USING "4X,""3  Circle 4  Square"""
11310 PRINT USING "4X,""5  Rombus"""
11320 PRINT USING "4X,""6  Right-side-up triangle"""
11330 PRINT USING "4X,""7  Up-side-down triangle"""
11340 INPUT Sym
11350 PRINTER IS 705
11360 PRINT "PU DI"
11370 IF Sym=1 THEN PRINT "SM*"
```

```
11380 IF Sym=2 THEN PRINT "SM+"
11390 IF Sym=3 THEN PRINT "SMo
11400 Nn=4
11410 IF Ilog=1 THEN Nn=1
11420 IF Md>1 THEN
11430 FOR I=1 TO (Md-1)
11440 ENTER @File;Xa,Ya
11450 NEXT I
11460 END IF
11470 IF Ihrat=0 THEN
11480 Q1=Q
11490 IF Ilog=1 THEN Q=LOG(Q)
11500 END IF
11510 FOR I=1 TO Npairs
11520 IF Iuo=0 AND Ihrat=0 THEN
11530 ENTER @File;Xa,B(*)
11540 Ya=B(0)
11550 FOR K=1 TO Nn
11560 Ya=Ya+B(K)*Q^K
11570 NEXT K
11580 END IF
11590 IF Iuo=1 OR Ihrat=1 THEN
11600 ENTER @File;Xa,Ya
11610 IF Iuo=1 THEN Ya=Ya/1000
11620 END IF
11630 IF Iuo=0 AND Ihrat=0 THEN
11640 IF Ilog=1 THEN Ya=EXP(Ya)
11650 IF Ilog=0 THEN Ya=Q1/Ya
11660 IF Irt=0 THEN
11670 IF Xa=0 THEN
11680 Yo=Ya
11690 Ya=1
11700 ELSE
11710 Ya=Ya/Yo
11720 END IF
11730 ELSE
11740 Hsm=FNHsmooth(Q,Xa,Isat)
11750 Ya=Ya/Hsm
11760 END IF
11770 END IF
11780 Xx(I-1)=Xa
11790 Yy(I-1)=Ya
11800 X=(Xa-Xmin)*Sfx
11810 Y=(Ya-Ymin)*Sfy
11820 IF Sym>3 THEN PRINT "SM"
11830 IF Sym<4 THEN PRINT "SR 1.4,2.4"
11840 PRINT "PA",X,Y,""
11850 IF Sym>3 THEN PRINT "SR 1.2,1.6"
11860 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0,;"
11870 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
11880 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
11890 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
11900 NEXT I
11910 BEEP
11920 ASSIGN @File TO *
11930 END IF
11940 PRINT "PU SM"
11950 BEEP
11960 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
11970 IF Okp=1 THEN
11980 BEEP
11990 PRINTER IS 1
12000 PRINT USING "4X,""Select line type:"""
12010 PRINT USING "6X,""0     Solid line"""
12020 PRINT USING "6X,""1     Dashed"""
12030 PRINT USING "6X,""2,..,5 Longer line - dash"""
```

```
12040 INPUT Ipn
12050 PRINTER IS 705
12060 BEEP
12070 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
12080 Iprnt=1
12090 CALL Poly
12100 IF Iuo=1 THEN
12110 BEEP
12120 INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
12130 IF Ixlim=0 THEN
12140 Xll=0
12150 Xul=7
12160 END IF
12170 IF Ixlim=1 THEN
12180 BEEP
12190 INPUT "ENTER X Lower Limit",Xll
12200 BEEP
12210 INPUT "ENTER X Upper Limit",Xul
12220 END IF
12230 END IF
12240 FOR Xa=Xll TO Xul STEP Xstep/25
12250 Icn=Icn+1
12260 Ya=FNPoly(Xa)
12270 IF Iuo=1 THEN Ya=Ya/1000
12280 Y=(Ya-Ymin)*Sfy
12290 X=(Xa-Xmin)*Sfx
12300 IF Y<0 THEN Y=0
12310 IF Y>100 THEN GOTO 12410
12320 Pu=0
12330 IF Ipn=1 THEN Idf=Icn MOD 2
12340 IF Ipn=2 THEN Idf=Icn MOD 4
12350 IF Ipn=3 THEN Idf=Icn MOD 8
12360 IF Ipn=4 THEN Idf=Icn MOD 16
12370 IF Ipn=5 THEN Idf=Icn MOD 32
12380 IF Idf=1 THEN Pu=1
12390 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
12400 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
12410 NEXT Xa
12420 PRINT "PU"
12430 GOTO 11070
12440 END IF
12450 BEEP
12460 INPUT "WANT TO QUIT (1=Y,0=N)?",Iquit
12470 IF Iquit=1 THEN 12490
12480 GOTO 11070
12490 PRINT "PU SP0"
12500 SUBEND
12510 SUB Stats
12520 PRINTER IS 701
12530 J=0
12540 K=0
12550 BEEP
12560 IF Iplot=1 THEN ASSIGN @File TO P_file$
12570 BEEP
12580 INPUT "LAST RUN No?(0=QUIT)",Nn
12590 IF Nn=0 THEN 12950
12600 Nn=Nn-J
12610 Sx=0
12620 Sy=0
12630 Sz=0
12640 Sxs=0
12650 Sys=0
12660 Szs=0
12670 FOR I=1 TO Nn
12680 J=J+1
12690 ENTER @File;Q,T
```

```
12700 H=Q/T
12710 Sx=Sx+Q
12720 Sxs=Sxs+Q^2
12730 Sy=Sy+T
12740 Sys=Sys+T^2
12750 Sz=Sz+H
12760 Szs=Szs+H^2
12770 NEXT I
12780 Qave=Sx/Nn
12790 Tave=Sy/Nn
12800 Have=Sz/Nn
12810 Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
12820 Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
12830 Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
12840 Sh=100*Sdevh/Have
12850 Sq=100*Sdevq/Qave
12860 St=100*Sdevt/Tave
12870 IF K=1 THEN 12930
12880 PRINT
12890 PRINT USING "11X,""DATA FILE:"",14A";File$
12900 PRINT
12910 PRINT USING "11X,""RUN Htube      SdevH   Qdp         SdevQ    Thetab SdevT""
"
12920 K=1
12930 PRINT USING "11X,DD,2(2X,D.3DE,1X,3D.2D),2X,DD.3D,1X,3D.2D";J,Have,Sh,Qave
,Sq,Tave,St
12940 GOTO 12570
12950 ASSIGN @File1 TO *
12960 PRINTER IS 1
12970 SUBEND
12980 SUB Coef
12990 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
13000 BEEP
13010 INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
13020 CREATE BDAT Cpf$,2
13030 ASSIGN @File TO Cpf$
13040 BEEP
13050 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
13060 BEEP
13070 INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
13080 IF Bop<0 THEN 13120
13090 CALL Poly
13100 OUTPUT @File;Bop,B(*)
13110 GOTO 13060
13120 ASSIGN @File TO *
13130 SUBEND
13140 SUB Wilson(Cf,Ci)
13150 COM /Wil/ D2,Di,Do,L,Lu,Kcu
13160 DIM Emf(12)
13170! WLISON PLOT SUBROUTINE DETERMINE CF AND CI
13180 BEEP
13190 INPUT "ENTER DATA FILE NAME",File$
13200 BEEP
13210 PRINTER IS 1
13220 PRINT USING "4X,""Select option:"""
13230 PRINT USING "4X,""  0 Vary Cf and  Ci"""
13240 PRINT USING "4X,""  1 Fix  Cf Vary Ci"""
13250 PRINT USING "4X,""  2 Vary Cf Fix  Ci"""
13260 INPUT "ENTER OPTION",Icfix
13270 PRINTER IS 701
13280 IF Icfix=0 THEN 13320
13290 IF Icfix>0 THEN BEEP
13300 IF Icfix=1 THEN INPUT "ENTER Cf",Caf
13310 IF Icfix=2 THEN INPUT "ENTER CI",Ci
13320 PRINTER IS 1
13330 INPUT "Want To Vary Coeff?(1=Y,0=N)",Iccoef
```

```
13340 IF Iccoef=1 THEN INPUT "ENTER COEFF",R
13350 PRINTER IS 701
13360 IF Icfix=0 OR Icfix=2 THEN Cfa=.004
13370 IF Icfix=1 THEN Cfa=Csf
13380 Cia=Ci
13390 Xn=.8
13400 Fr=.3
13410 Jj=0
13420 Rr=3.
13430 IF Iccoef=1 THEN Rr=R
13440 PRINTER IS 1
13450 PRINT Do,Di,Kcu
13460 ASSIGN @File TO File$
13470 ENTER @File;Nrun,Date$,Ldtc1,Ldtc2,Itt
13480 Rw=Do*LOG(Do/Di)/(2*Kcu)
13490 Sx=0
13500 Sy=0
13510 Sxy=0
13520 Sx2=0
13530 Sy2=0
13540 FOR I=1 TO Nrun
13550 ENTER @File;Bop,Told$,Emf(*),Fms
13560! CONVERT EMF'S TO TEMPERATURE
13570 FOR J=1 TO 5
13580 T(J)=FNTvsv(Emf(J))
13590 NEXT J
13600 Tsat=(T(1)+T(2))*.5
13610 Tavg=T(5)
13620 Grad=37.9853+.104388*Tavg
13630 Tdrop=Emf(7)*1.E+6/(10.*Grad)
13640 Tavgc=T(5)-Tdrop*.5
13650 IF ABS(Tavg-Tavgc)>.01 THEN
13660 Tavg=(Tavg+Tavgc)*.5
13670 GOTO 13620
13680 END IF
13690!
13700! Compute properties of water
13710 Kw=FNKw(Tavg)
13720 Muwa=FNMuw(Tavg)
13730 Cpw=FNCpw(Tavg)
13740 Prw=FNPrw(Tavg)
13750 Rhow=FNRhow(Tavg)
13760!
13770! Compute properties of Freon-114
13780 Lmtd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
13790 IF Jj=0 THEN
13800 Tw=Tsat+Fr*Lmtd
13810 Thetab=Tw-Tsat
13820 Jj=1
13830 END IF
13840 Tf=(Tw+Tsat)*.5
13850 Rho=FNRho(Tf)
13860 Mu=FNMu(Tf)
13870 K=FNK(Tf)
13880 Cp=FNCp(Tf)
13890 Beta=FNBeta(Tf)
13900 Hfg=FNHfg(Tsat)
13910 Ni=Mu/Rho
13920 Alpha=K/(Rho*Cp)
13930 Pr=Ni/Alpha
13940!
13950! Analysis
13960! COMPUTE MDOT
13970 A=PI*(Do^2-Di^2)/4
13980 P=PI*Do
13990 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82806E-6-Fms*(1.23688E-7-Fms*4.31897
```

```
E-10)))
14000 Q=Mdot*Cpw*Tdrop
14010! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
14020! FOR UNENHANCED END(S)
14030 Hbar=190
14040 Fe=(Hbar*P/(Kcu*A))^.5*Lu
14050 Tanh=FNTanh(Fe)
14060 Theta=Thetab*Tanh/Fe
14070 Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
14080 Yy=(1+(.559/Pr)^(9/16))^(8/27)
14090 Hbarc=K/Do*(.6+.387*Xx/Yy)^2
14100 IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
14110 Hbar=(Hbar+Hbarc)*.5
14120 GOTO 14040
14130 END IF
14140!
14150! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
14160 Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
14170 Qc=Q-2*Q1
14180 As=PI*D2*L
14190! COMPUTE ACTUAL HEAT FLUX
14200 Qdp=Qc/As
14210 IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf^(1./Rr)
14220 Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))^.5)^(1/Rr)*Pr^1.7
14230 Ho=Qdp/Thetab
14240 Omega=Ho/Cf
14250 Uo=Q/(PI*Do*L*Lmtd)
14260 Vw=Mdot/(Rhow*PI*Di^2/4)
14270 Rew=Rhow*Vw*Di/Muwa
14280 Twi=Tw+Q*Rw/(PI*Do*L)
14290 Gama=Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
14300! PRINTER IS 1
14310 Yw=(1./Uo-Rw)*Omega
14320 Xw=Omega*Do/(Gama*Di)
14330 Sx=Sx+Xw
14340 Sy=Sy+Yw
14350 Sxy=Sxy+Yw*Xw
14360 Sx2=Sx2+Xw*Xw
14370 Sy2=Sy2+Yw*Yw
14380 NEXT I
14390 ASSIGN @File TO *
14400 M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
14410 C=(Sy-Sx*M)/Nrun
14420 IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
14430 Cic=1/M
14440 Cfc=1/C
14450 END IF
14460 IF Icfix=1 THEN
14470 Cic=1/M
14480 Cfc=Cf
14490 END IF
14500 IF Icfix=2 THEN
14510 Cic=Ci
14520 Cfc=1/C
14530 END IF
14540 IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
14550 Ci=(Ci+Cic)*.5
14560 Cf=(Cf+Cfc)*.5
14570 PRINTER IS 1
14580 PRINT USING "2X,"" Csf = "",MZ.3DE,2X,"" Ci = "",MZ.3DE";Csf,Ci
14590 PRINTER IS 701
14600 GOTO 13460
14610 END IF
14620 PRINT
14630 PRINTER IS 701
14640 PRINT USING "23X,""  Cf           Ci"""
```

```
14650 PRINT USING "8X,""ASSUMED        "",MZ.3DE,3X,MZ.3DE";Cfa,Cia
14660 PRINT USING "8X,""CALCULATED     "",MZ.3DE,3X,MZ.3DE";Csf,Ci
14670 PRINT
14680 Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
14690 PRINT USING "10X,""Sum of Squares = "",Z.3DE";Sum2
14700 PRINT USING "10X,""Coefficient = "",D.DDD";Rr
14710 SUBEND
14720 DEF FNMuw(T)
14730 A=247.8/(T+133.15)
14740 Mu=2.4E-5*10^A
14750 RETURN Mu
14760 FNEND
14770 DEF FNCpw(T)
14780 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
14790 RETURN Cpw*1000
14800 FNEND
14810 DEF FNRhow(T)
14820 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
14830 RETURN Ro
14840 FNEND
14850 DEF FNPrw(T)
14860 Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
14870 RETURN Prw
14880 FNEND
14890 DEF FNKw(T)
14900 X=(T+273.15)/273.15
14910 Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
14920 RETURN Kw
14930 FNEND
14940 SUB Plot
14950 COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
14960 DIM Bs(3)
14970 INTEGER Ii
14980 PRINTER IS 1
14990 Idv=0
15000 BEEP
15010 INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
15020 Opo=0
15030 BEEP
15040 PRINT USING "4X,""Select Option:"""
15050 PRINT USING "6X,""0  q versus delta-T"""
15060 PRINT USING "6X,""1  h versus delta-T"""
15070 PRINT USING "6X,""2  h versus q"""
15080 INPUT Opo
15090 BEEP
15100 INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
15110 PRINTER IS 705
15120 IF Idv<>1 THEN
15130 BEEP
15140 INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
15150 BEEP
15160 INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
15170 BEEP
15180 INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
15190 BEEP
15200 INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
15210 ELSE
15220 IF Opo=0 THEN
15230 Cy=3
15240 Cx=3
15250 Xmin=.1
15260 Ymin=100
15270 END IF
15280 IF Opo=1 THEN
15290 Cy=2
15300 Cx=2
```

```
15310 Xmin=.1
15320 Ymin=100
15330 END IF
15340 IF Opo=2 THEN
15350 IF Iun=0 THEN
15360 Cy=3
15370 Cx=2
15380 Xmin=1000
15390 Ymin=100
15400 ELSE
15410 Cy=3
15420 Cx=3
15430 Xmin=100
15440 Ymin=10
15450 END IF
15460 END IF
15470 END IF
15480 BEEP
15490 PRINT "IN;SP1;IP 2300,2200,8300,6800;"
15500 PRINT "SC 0,100,0,100;TL 2,0;"
15510 Sfx=100/Cx
15520 Sfy=100/Cy
15530 BEEP
15540 INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
15550 IF Ibyp=1 THEN 16790
15560 PRINT "PU 0,0 PD"
15570 Nn=9
15580 FOR I=1 TO Cx+1
15590 Xat=Xmin*10^(I-1)
15600 IF I=Cx+1 THEN Nn=1
15610 FOR J=1 TO Nn
15620 IF J=1 THEN PRINT "TL 2 0"
15630 IF J=2 THEN PRINT "TL 1 0"
15640 Xa=Xat*J
15650 X=LGT(Xa/Xmin)*Sfx
15660 PRINT "PA";X,",0; XT;"
15670 NEXT J
15680 NEXT I
15690 PRINT "PA 100,0;PU;"
15700 PRINT "PU PA 0,0 PD"
15710 Nn=9
15720 FOR I=1 TO Cy+1
15730 Yat=Ymin*10^(I-1)
15740 IF I=Cy+1 THEN Nn=1
15750 FOR J=1 TO Nn
15760 IF J=1 THEN PRINT "TL 2 0"
15770 IF J=2 THEN PRINT "TL 1 0"
15780 Ya=Yat*J
15790 Y=LGT(Ya/Ymin)*Sfy
15800 PRINT "PA 0,";Y,"YT"
15810 NEXT J
15820 NEXT I
15830 PRINT "PA 0,100 TL 0 2"
15840 Nn=9
15850 FOR I=1 TO Cx+1
15860 Xat=Xmin*10^(I-1)
15870 IF I=Cx+1 THEN Nn=1
15880 FOR J=1 TO Nn
15890 IF J=1 THEN PRINT "TL 0 2"
15900 IF J>1 THEN PRINT "TL 0 1"
15910 Xa=Xat*J
15920 X=LGT(Xa/Xmin)*Sfx
15930 PRINT "PA";X,",100; XT"
15940 NEXT J
15950 NEXT I
15960 PRINT "PA 100,100 PU PA 100,0 PD"
```

```
15970 Nn=9
15980 FOR I=1 TO Cy+1
15990 Yat=Ymin*10^(I-1)
16000 IF I=Cy+1 THEN Nn=1
16010 FOR J=1 TO Nn
16020 IF J=1 THEN PRINT "TL 0 2"
16030 IF J>1 THEN PRINT "TL 0 1"
16040 Ya=Yat*J
16050 Y=LGT(Ya/Ymin)*Sfy
16060 PRINT "PD PA 100,",Y,"YT"
16070 NEXT J
16080 NEXT I
16090 PRINT "PA 100,100 PU"
16100 PRINT "PA 0,-2 SR 1.5,2"
16110 I1=LGT(Xmin)
16120 FOR I=1 TO Cx+1
16130 Xa=Xmin*10^(I-1)
16140 X=LGT(Xa/Xmin)*Sfx
16150 PRINT "PA";X,",0;"
16160 IF I1>=0 THEN PRINT "CP -2,-2;LB10;PR -2,2;LB";I1;""
16170 IF I1<0 THEN PRINT "CP -2,-2;LB10;PR 0,2;LB";I1;""
16180 I1=I1+1
16190 NEXT I
16200 PRINT "PU PA 0,0"
16210 I1=LGT(Ymin)
16220 Y10=10
16230 FOR I=1 TO Cy+1
16240 Ya=Ymin*10^(I-1)
16250 Y=LGT(Ya/Ymin)*Sfy
16260 PRINT "PA 0,";Y,""
16270 PRINT "CP -4,-.25;LB10;PR -2,2;LB";I1;""
16280 I1=I1+1
16290 NEXT I
16300 BEEP
16310 INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Idl
16320 IF Idl<>1 THEN
16330 BEEP
16340 INPUT "ENTER X-LABEL",Xlabel$
16350 BEEP
16360 INPUT "ENTER Y-LABEL",Ylabel$
16370 END IF
16380 IF Opo<2 THEN
16390 PRINT "SR 1,2;PU PA 40,-14;"
16400 PRINT "LB(T;PR -1.6,3 PD PR 1.2,0 PU;PR .5,-4;LBwo;PR .5,1;"
16410 PRINT "LB-T;PR .5,-1;LBsat;PR .5,1;"
16420 IF Iun=0 THEN
16430 PRINT "LB) (K)"
16440 ELSE
16450 PRINT "LB) (F)"
16460 END IF
16470 END IF
16480 IF Opo=2 THEN
16490 IF Iun=0 THEN
16500 PRINT "SR 1.5,2;PU PA 40,-14;LBq (W/m;SR 1,1.5;PR 0.5,1;LB2;SR 1.5,2;PR
0.5,-1;LB)"
16510 ELSE
16520 PRINT "SR 1.5,2;PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.;PR .5,-.5;"
16530 PRINT "LBft;PR .5,1;SR 1,1.5;LB2;SR 1.5,2;PR .5,-1;LB);"
16540 END IF
16550 END IF
16560 IF Opo=0 THEN
16570 IF Iun=0 THEN
16580 PRINT "SR 1.5,2;PU PA -12,40;DI 0,1;LBq (W/m;PR -1,0.5;SR 1,1.5;LB2;SR 1
.5,2;PR 1,.5;LB)"
16590 ELSE
16600 PRINT "SR 1.5,2;PU PA -12,32;DI 0,1;LBq (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
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```
16610 PRINT "LBft;SR 1,1.5;PR -1,.5;LB2;PR 1,.5;SR 1.5,2;LB "
16620 END IF
16630 END IF
16640 IF Opo>0 THEN
16650 IF Iun=0 THEN
16660! PRINT "SR 1.5,2;PU PA -12,38;DI 0,1;LBh (W/m;PR -1,.5;SR 1,1.5;LB2;SR 1
.5,2;PR .5,.5;"
16670 PRINT "SR 1.2,2.4;PU PA -12,37;DI 0,1;LBh;PR 1,0.5;LBo;PR -1,0.5;LB (W/m
*
16680 PRINT "PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
16690 ELSE
16700 PRINT "SR 1.5,2;PU PA -12,28;DI 0,1;LBh (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
16710 PRINT "LBft;PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,.5;LBF)"
16720 END IF
16730 END IF
16740 IF Idl=0 THEN
16750 PRINT "SR 1.5,2;PU PA 50,-16 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
16760 PRINT "PA -14,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
16770 PRINT "CP 0,0 DI"
16780 END IF
16790 Ipn=0
16800 Xll=1.E+6
16810 Xul=-1.E+6
16820 Icn=0
16830 Ifn=0
16840 Ijoin=1
16850 BEEP
16860 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Ok
16870 IF Ok=1 THEN
16880 BEEP
16890 INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
16900 ASSIGN @File TO D_file$
16910 BEEP
16920 BEEP
16930 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
16940 BEEP
16950 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
16960! BEEP
16970! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?",Icl
16980 BEEP
16990 PRINTER IS 1
17000 PRINT USING "4X,""Select a symbol:"""
17010 PRINT USING "6X,""1  Star      2  Plus sign"""
17020 PRINT USING "6X,""3  Circle    4  Square"""
17030 PRINT USING "6X,""5  Rombus"""
17040 PRINT USING "6X,""6  Right-side-up triangle"""
17050 PRINT USING "6X,""7  Up-side-down triangle"""
17060 INPUT Sym
17070 PRINTER IS 705
17080 PRINT "PU DI"
17090 IF Sym=1 THEN PRINT "SM*"
17100 IF Sym=2 THEN PRINT "SM+"
17110 IF Sym=3 THEN PRINT "SMo"
17120 IF Md>1 THEN
17130 FOR I=1 TO (Md-1)
17140 ENTER @File;Ya,Xa
17150 NEXT I
17160 END IF
17170 FOR I=1 TO Npairs
17180 ENTER @File;Ya,Xa
17190 IF I=1 THEN Q1=Ya
17200 IF I=Npairs THEN Q2=Ya
17210 IF Opo=1 THEN Ya=Ya/Xa
17220 IF Opo=2 THEN
17230 Q=Ya
17240 Ya=Ya/Xa
```

```
17250 Xa=0
17260 END IF
17270 IF Xa<Xll THEN Xll=Xa
17280 IF Xa>Xul THEN Xul=Xa
17290 IF Iun=1 THEN
17300 IF Opo<2 THEN Xa=Xa*1.8
17310 IF Opo>0 THEN Ya=Ya*.1761
17320 IF Opo=0 THEN Ya=Ya*.317
17330 IF Opo=2 THEN Xa=Xa*.317
17340 END IF
17350 X=LGT(Xa/Xmin)*Sfx
17360 Y=LGT(Ya/Ymin)*Sfy
17370 Kj=0
17380 CALL Symb(X,Y,Sym,Icl,Kj)
17390 GOTO 17520
17400 IF Sym>3 THEN PRINT "SM"
17410 IF Sym<4 THEN PRINT "SR 1.4,2.4"
17420 IF Icl=0 THEN
17430 PRINT "PA",X,Y,""
17440 ELSE
17450 PRINT "PA",X,Y,"PD"
17460 END IF
17470 IF Sym>3 THEN PRINT "SR 1.2,1.6"
17480 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
17490 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
17500 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
17510 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
17520 NEXT I
17530 PRINT "PU"
17540 BEEP
17550 INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
17560 IF Ilab=1 THEN
17570 PRINT "SP0;SP2"
17580 BEEP
17590 IF Klab=0 THEN
17600 Xlab=5
17610 Ylab=85
17620 INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
17630 Xtt=Xlab-5
17640 Ytt=Ylab+8
17650 PRINT "SR 1,1.5"
17660 PRINT "SM;PA",Xtt,Ytt,"LB       %   Heat  File"
17670 Ytt=Ytt-3
17680 PRINT "PA",Xtt,Ytt,"LB      Oil  Flux  Name"
17690 IF Sym=1 THEN PRINT "SM*"
17700 IF Sym=2 THEN PRINT "SM+"
17710 IF Sym=3 THEN PRINT "SMo"
17720 Klab=1
17730 END IF
17740 Kj=1
17750 CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
17760 PRINT "SR 1,1.5;SM"
17770 IF Sym<4 THEN PRINT "PR 2,0"
17780 BEEP
17790 INPUT "ENTER BOP",Bop
17800 IF Bop<10 THEN PRINT "PR 2,0;LB";Bop;""
17810 IF Bop>9 THEN PRINT "PR .5,0;LB";Bop;""
17820 Ihf=0
17830 IF Q1>Q2 THEN Ihf=1
17840 IF Ihf=0 THEN PRINT "PR 4,0;LBInc"
17850 IF Ihf=1 THEN PRINT "PR 4,0;LBDec"
17860 PRINT "PR 2,0;LB";D_file$;""
17870 PRINT "SP0;SP1;SR 1.5,2"
17880 Ylab=Ylab-5
17890 END IF
17900 BEEP
```

```
17910 ASSIGN @File TO *
17920 Xll=Xll/1.2
17930 Xul=Xul*1.2
17940! GOTO 8040
17950 END IF
17960 PRINT "PU SM"
17970 BEEP
17980 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
17990 IF Go_on=1 THEN
18000 BEEP
18010 PRINTER IS 1
18020 PRINT USING "4X,""Select line type:"""
18030 PRINT USING "6X,""0     Solid line"""
18040 PRINT USING "6X,""1     Dashed"""
18050 PRINT USING "6X,""2,.,5 Longer line - dash"""
18060 INPUT Ipn
18070 PRINTER IS 705
18080 BEEP
18090 INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
18100 Iprnt=1
18110 CALL Poly
18120 IF Ifn=0 THEN
18130 BEEP
18140 INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
18150 END IF
18160 Ijoin=0
18170 IF Ifn<Njoin THEN Ijoin=1
18180 IF Ifn=0 OR Ijoin=1 THEN
18190 FOR Ij=0 TO 3
18200 Bs(Ij)=Bs(Ij)+B(Ij)
18210 NEXT Ij
18220 Ifn=Ifn+1
18230 END IF
18240 IF Njoin=Ifn THEN
18250 FOR Ij=0 TO 3
18260 B(Ij)=Bs(Ij)/Njoin
18270 Bs(Ij)=0
18280 NEXT Ij
18290 Ifn=0
18300 ELSE
18310 GOTO 16850
18320 END IF
18330 BEEP
18340 INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
18350 FOR Xx=0 TO Cx STEP Cx/200
18360 Xa=Xmin*10^Xx
18370 IF Xa<Xll OR Xa>Xul THEN 18640
18380 Icn=Icn+1
18390 Pu=0
18400 IF Ipn=1 THEN Idf=Icn MOD 2
18410 IF Ipn=2 THEN Idf=Icn MOD 4
18420 IF Ipn=3 THEN Idf=Icn MOD 8
18430 IF Ipn=4 THEN Idf=Icn MOD 16
18440 IF Ipn=5 THEN Idf=Icn MOD 28
18450 IF Idf=1 THEN Pu=1
18460 IF Opo=0 THEN Ya=FNPoly(Xa)
18470 IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
18480 IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
18490 IF Opo=1 THEN Ya=FNPoly(Xa)
18500 IF Ya<Ymin THEN 18640
18510 IF Ya<Yll OR Ya>Yul THEN 18640
18520 IF Iun=1 THEN
18530 IF Opo<2 THEN Xa=Xa*1.8
18540 IF Opo>0 THEN Ya=Ya*.1761
18550 IF Opo=0 THEN Ya=Ya*.317
18560 IF Opo=2 THEN Xa=Xa*.317
```

```
18570 END IF
18580 Y=LGT(Ya/Ymin)*Sfy
18590 X=LGT(Xa/Xmin)*Sfx
18600 IF Y<0 THEN Y=0
18610 IF Y>100 THEN GOTO 18640
18620 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
18630 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
18640 NEXT Xx
18650 PRINT "PU"
18660 GOTO 16850
18670 END IF
18680 BEEP
18690 INPUT "WANT TO PLOT REILLY'S DATA? (1=Y,0=N)",Irly
18700 IF Opo=0 OR Opo=1 THEN
18710 Xll=3
18720 Xul=20
18730 END IF
18740 IF Opo=2 THEN
18750 Xll=10000
18760 Xul=100000
18770 END IF
18780 IF Irly=1 THEN
18790 Yll=20
18800 Yul=70
18810 BEEP
18820 INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
18830 FOR Xx=0 TO Cx STEP Cx/200
18840 Xa=Xmin*10^Xx
18850 IF Xa<Xll OR Xa>Xul THEN 18980
18860 Xl=LOG(Xa)
18870 IF Opo=0 THEN Yl=-2.5402837E-1+Xl*(4.9720151-Xl*2.5134787E-1)
18880 IF Opo=1 THEN Yl=-2.5402837E-1+Xl*(3.9720151-Xl*2.5134787E-1)
18890 IF Opo=2 THEN Yl=-3.7073801E-1+Xl*(8.7259190E-1-Xl*6.8826842E-3)
18900 Ya=EXP(Yl)
18910 Y=LGT(Ya/Ymin)*Sfy
18920 X=LGT(Xa/Xmin)*Sfx
18930 Ipu=0
18940 IF Y<Yll THEN Ipu=1
18950 IF Y>Yul THEN GOTO 18980
18960 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
18970 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
18980 NEXT Xx
18990 PRINT "PU"
19000 END IF
19010 BEEP
19020 INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
19030 IF Irohs=1 THEN
19040 Yll=15
19050 Yul=80
19060 BEEP
19070 INPUT "ENTER Tsat (Deg C)",Tsat
19080 Csf=.0040
19090 BEEP
19100 INPUT "ENTER Csf (DEF=0.004)",Csf
19110 Tf=Tsat+2
19120 FOR Xx=0 TO Cx STEP Cx/200
19130 Xa=Xmin*10^Xx
19140 IF Xa<Xll OR Xa>Xul THEN 19420
19150 Xl=LOG(Xa)
19160 IF Opo<2 THEN Tf=Tsat+Xa/2
19170 Rho=FNRho(Tf)
19180 K=FNK(Tf)
19190 Mu=FNMu(Tf)
19200 Cp=FNCp(Tf)
19210 Hfg=FNHfg(Tsat)
19220 Ni=Mu/Rho
```

```
19230 Pr=Cp*Mu/k
19240 Omega=Csf*Hfg/Cp*((.014/(9.81*Rnc ... .5/(Mu*Hfg ...
19250 IF Opo=0 THEN Ya=(Xa/Omega)^3
19260 IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
19270 IF Opo=2 THEN Ya=Xa^(2./3)/Omega
19280 IF Opo=2 THEN
19290 Tfc=Tsat+Xa/Ya*.5
19300 IF ABS(Tf-Tfc)>.01 THEN
19310 Tf=(Tf+Tfc)*.5
19320 GOTO 19170
19330 END IF
19340 END IF
19350 Y=LGT(Ya/Ymin)*Sfy
19360 X=LGT(Xa/Xmin)*Sfx
19370 Ipu=0
19380 IF Y<Yll THEN Ipu=1
19390 IF Y>Yul THEN 19420
19400 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
19410 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
19420 NEXT Xx
19430 PRINT "PU"
19440 END IF
19450 BEEP
19460 INPUT "WANT TO QUIT (1=Y,0=N)",Iqt
19470 IF Iqt=1 THEN 19490
19480 GOTO 16800
19490 PRINT "PU PA 0,0 SP0"
19500 SUBEND
19510 SUB Symb(X,Y,Sym,Icl,Kj)
19520 IF Sym>3 THEN PRINT "SM"
19530 IF Sym<4 THEN PRINT "SR 1.4,2.4"
19540 Yad=0
19550 IF Kj=1 THEN Yad=.8
19560 IF Icl=0 THEN
19570 PRINT "PA",X,Y+Yad,""
19580 ELSE
19590 PRINT "PA",X,Y+Yad,"PD"
19600 END IF
19610 IF Sym>3 THEN PRINT "SR 1.2,1.6"
19620 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
19630 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
19640 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
19650 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
19660 IF Kj=1 THEN PRINT "SM;PR 0,-.8"
19670 SUBEND
19680 SUB Purg
19690 BEEP
19700 INPUT "ENTER FILE NAME TO BE DELETED",File$
19710 PURGE File$
19720 GOTO 19690
19730 SUBEND
19740 SUB Tdcn
19750 COM /Cc/ C(7),Ical
19760 DIM Emf(1)
19770 DATA 0.10086091,25727.94369,-767345.8295,78025595.81
19780 DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
19790 READ C(*)
19800 BEEP
19810 INPUT "GIVE A NAME FOR FILE TO BE CREATED",File$
19820 BEEP
19830 INPUT "SELECT TUBE (0=WH,1=HF,2=WT)",Itt
19840 BEEP
19850 INPUT "SELECT THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
19860 IF Itt<2 THEN Di=.0127
19870 CREATE BDAT File$,4
19880 ASSIGN @File TO File$
```

```
19890 OUTPUT @File;Itt
19900 J=0
19910 BEEP
19920 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
19930 OUTPUT 709;"TD";Date$
19940 OUTPUT 709;"TD"
19950 ENTER 709;Date$
19960 PRINTER IS 1
19970 PRINT
19980 PRINT "          Month, date and time: ";Date$
19990 PRINT
20000 PRINT USING "10X,"" Fms      Tin      Tev      Vw^2     Tdrop"""
20010 IF K=0 THEN
20020 PRINTER IS 701
20030 PRINT
20040 PRINT "          Month, date and time: ";Date$
20050 IF Itt=0 THEN PRINT USING "10X,""Tube Type:           Wieland Smooth"""
20060 IF Itt=1 THEN PRINT USING "10X,""Tube Type:           High Flux"""
20070 IF Itt=2 THEN PRINT USING "10X,""Tube Type:           Turbo-B"""
20080 PRINT
20090 PRINT USING "10X,"" Fms      Tin      Tev      Vw^2      Tdrop"""
20100 PRINTER IS 1
20110 K=1
20120 END IF
20130 BEEP
20140 INPUT "ENTER FLOWMETER READING",Fms
20150 OUTPUT 709;"AR AF0 AL4 VR1"
20160 FOR L=0 TO 4
20170 OUTPUT 709;"AS SA"
20180 IF L>0 AND L<4 THEN 20260
20190 S=0
20200 FOR I=0 TO 9
20210 ENTER 709;E
20220 S=S+E
20230 NEXT I
20240 IF L=0 THEN Emf(0)=ABS(S/10)
20250 IF L=4 THEN Emf(1)=ABS(S/10)
20260 NEXT L
20270 OUTPUT 709;"AR AF00 AL00 VR1"
20280 OUTPUT 709;"AS SA"
20290 Etp=0
20300 FOR I=0 TO 9
20310 ENTER 709;Et
20320 Etp=Etp+Et
20330 NEXT I
20340 Etp=Etp/10
20350 Tin=FNTvsv(Emf(1))
20360 Tev=FNTvsv(Emf(0))
20370 Grad=37.9853+.104388*Tin
20380 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
20390 Vw=Mdot/(1000*PI*Di^2)*4
20400 Tdrop=Etp*1.E+6/(10*Grad)
20410 PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
20420 BEEP
20430 INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
20440 J=J+1
20450 IF Ok=0 THEN
20460 J=J-1
20470 GOTO 20130
20480 ELSE
20490 OUTPUT @File;Fms,Emf(*),Etp
20500 PRINTER IS 701
20510 PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
20520 PRINTER IS 1
20530 BEEP
```

```
20540 INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
20550 IF Go_on=1 THEN 20130
20560 END IF
20570 ASSIGN @File TO *
20580 PRINTER IS 701
20590 PRINT
20600 PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";J,F
ile$
20610 PRINTER IS 1
20620 SUBEND
20630 SUB Uoprt
20640 PRINTER IS 1
20650 BEEP
20660 INPUT "Enter Uo File Name",File$
20670 BEEP
20680 INPUT "Number of Data Runs",Nrun
20690 INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
20700 BEEP
20710 IF Iplot=1 THEN
20720 INPUT "Give Plot File Name",P_file$
20730 CREATE BDAT P_file$,4
20740 ASSIGN @Plot TO P_file$
20750 END IF
20760 PRINTER IS 701
20770 PRINT
20780 PRINT
20790 PRINT USING "10X,""   Water Vel        Uo"""
20800 ASSIGN @File TO File$
20810 IF Iplot=1 THEN ASSIGN @File1 TO P_file$
20820 FOR I=1 TO Nrun
20830 ENTER @File;Vw,Uo
20840 IF Iplot=1 THEN OUTPUT @File1;Vw,Uo
20850 PRINT USING "15X,D.DD,6X,MZ.3DE";Vw,Uo
20860 NEXT I
20870 ASSIGN @File TO *
20880 ASSIGN @File1 TO *
20890 PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";Nru
n,File$
20900 IF Iplot=1 THEN
20910 PRINT USING "10X,""NOTE: "",ZZ,"" X-Y Pairs are stored in file "",15A";Nru
n,P_file$
20920 END IF
20930 PRINTER IS 1
20940 SUBEND
20950 SUB Select
20960 COM /Idp/ Idp
20970 BEEP
20980 PRINTER IS 1
20990 PRINT USING "4X,""Select option:"""
21000 PRINT USING "6X,"" 0 Taking data or re-processing previous data"""
21010 PRINT USING "6X,"" 1 Plotting data on Log-Log """
21020 PRINT USING "6X,"" 2 Plotting data on Linear"""
21030 PRINT USING "6X,"" 3 Make cross-plot coefft file"""
21040 PRINT USING "6X,"" 4 Re-circulate water"""
21050 PRINT USING "6X,"" 5 Purge"""
21060 PRINT USING "6X,"" 6 T-Drop correction"""
21070 PRINT USING "6X,"" 7 Print Uo File"""
21080 PRINT USING "6X,"" 8 Modify X-Y file"""
21090 PRINT USING "6X,"" 9 Move"""
21100 PRINT USING "6X,""10 Comb/Fixup"""
21110 INPUT Idp
21120 IF Idp=0 THEN CALL Main
21130 IF Idp=1 THEN CALL Plot
21140 IF Idp=2 THEN CALL Plin
21150 IF Idp=3 THEN CALL Coef
21160 IF Idp=4 THEN CALL Main
```

```
21170 IF Idp=5 THEN CALL Purg
21180 IF Idp=6 THEN CALL Tdcn
21190 IF Idp=7 THEN CALL Uoprt
21200 IF Idp=8 THEN CALL Xymod
21210 IF Idp=9 THEN CALL Move
21220 IF Idp=10 THEN CALL Comb
21230 SUBEND
21240 SUB Xymod
21250 PRINTER IS 1
21260 BEEP
21270 INPUT "ENTER FILE NAME",File$
21280 ASSIGN @File1 TO File$
21290 BEEP
21300 INPUT "ENTER NUMBER OF X-Y PAIRS",Np
21310 BEEP
21320 INPUT "ENTER NEW FILE NAME",File2$
21330 CREATE BDAT File2$,5
21340 ASSIGN @File2 TO File2$
21350 BEEP
21360 INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
21370 IF Ndel=0 THEN 21410
21380 FOR I=1 TO Ndel
21390 BEEP
21400 INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
21410 NEXT I
21420 FOR J=1 TO Np
21430 ENTER @File1;X,Y
21440 FOR I=1 TO Ndel
21450 IF Nd(I)=J THEN 21490
21460 NEXT I
21470 OUTPUT @File2;X,Y
21480 PRINT J,X,Y
21490 NEXT J
21500 PRINTER IS 701
21510 ASSIGN @File1 TO *
21520 ASSIGN @File2 TO *
21530 SUBEND
21540 SUB Move
21550! FILE NAME: MOVE
21560!
21570 DIM Bop(66),A(66),B(66),C(66),D(66),E(66),F(66),G(66),H(66),J(66),K(66),L(
66),M(66)
21580 DIM Told$(66)[14],N(66),Vr(66),Ir(66)
21590 BEEP
21600 INPUT "OLD FILE TO MOVE",O2_file$
21610 ASSIGN @File2 TO O2_file$
21620 ENTER @File2;Nrun,Date$,Ldtc1,Ldtc2,Itt
21630 FOR I=1 TO Nrun
21640 ENTER @File2;Bop(I),Told$(I)
21650 ENTER @File2;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
21660 ENTER @File2;Vr(I),Ir(I)
21670 NEXT I
21680 ASSIGN @File2 TO *
21690 BEEP
21700 INPUT "SHIFT DISK AND HIT CONTINUE",Ok
21710 BEEP
21720 INPUT "INPUT BDAT SIZE",Size
21730 CREATE BDAT O2_file$,Size
21740 ASSIGN @File1 TO O2_file$
21750 OUTPUT @File1;Nrun,Date$,Ldtc1,Ldtc2,Itt
21760 FOR I=1 TO Nrun
21770 OUTPUT @File1;Bop(I),Told$(I)
21780 OUTPUT @File1;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),
N(I)
21790 OUTPUT @File1;Vr(I),Ir(I)
```

```
21800 NEXT I
21810 ASSIGN @File1 TO *
21820! RENAME "TEST" TO D2_file$
21830 BEEP 2000,.2
21840 BEEP 4000,.2
21850 BEEP 4000,.2
21860 PRINT "DATA FILE MOVED"
21870 SUBEND
21880 SUB Comb
21890! FILE NAME: COMB
21900!
21910 DIM Emf(12)
21920 BEEP
21930 INPUT "OLD FILE TO FIXUP",D2_file$
21940 ASSIGN @File2 TO D2_file$
21950 D1_file$="TEST"
21960 CREATE BDAT D1_file$,20
21970 ASSIGN @File1 TO D1_file$
21980 ENTER @File2;Nrun,Date$,Ldtc1,Ldtc2,Itt
21990 Nrunm=20
22000 IF K=0 THEN OUTPUT @File1;Nrunm,Date$,Ldtc1,Ldtc2,Itt
22010 FOR I=1 TO Nrun
22020 ENTER @File2;Bop,Told$,Emf(*),Vr,Ir
22030 OUTPUT @File1;Bop,Told$,Emf(*),Vr,Ir
22040 NEXT I
22050 ASSIGN @File2 TO *
22060! RENAME "TEST" TO D2_file$
22070 BEEP 2000,.2
22080 BEEP 4000,.2
22090 BEEP 4000,.2
22100 BEEP
22110 INPUT "WANT TO ADD ANOTHER FILE (1=Y,0=N)?",Oka
22120 IF Oka=1 THEN
22130 K=1
22140 BEEP
22150 INPUT "GIVE NEW FILE NAME",Nfile$
22160 ASSIGN @File2 TO Nfile$
22170 GOTO 21980
22180 END IF
22190 ASSIGN @File2 TO *
22200 SUBEND
```

Date : 19 Jan 1993

NOTE: Program name : DRP68
Disk number = 00

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