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THE EFFECTS OF OIL CONTAMINATION ON THE NUCLEATE
POOL-BOILING BEHAVIOR OF R-114 FROM ENHANCED SURFACES
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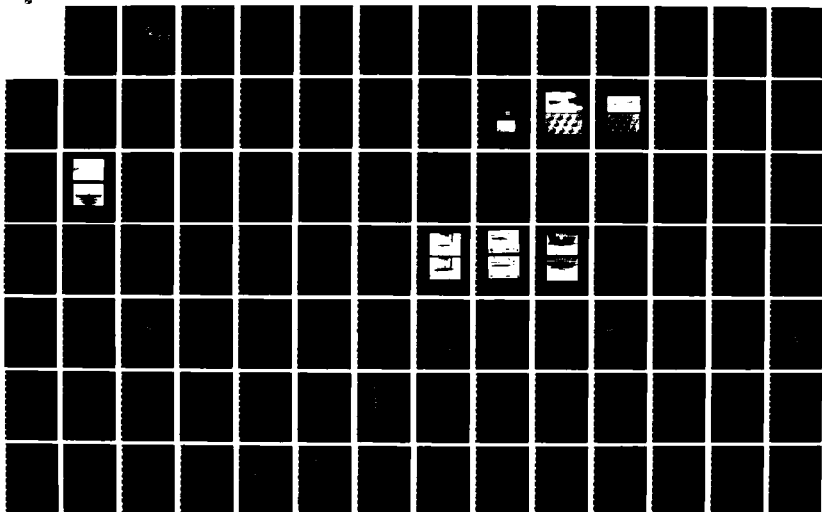
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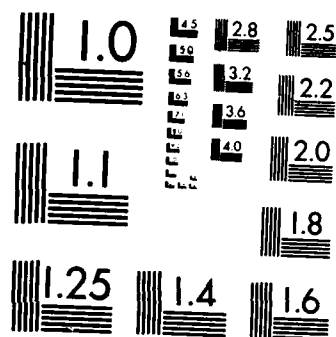
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THESIS

The Effects of Oil Contamination on
the Nucleate Pool-Boiling Behavior
of R-114 from Enhanced Surfaces

by

Lloyd M. Sawyer, Jr.

June 1986

Thesis Advisor:

P. J. Marto

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The Effect of Oil Contamination on
the Nucleate Pool-Boiling ~~Performance~~ **BEHAVIOR**
of R-111 from Enhanced Surfaces

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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June 1986

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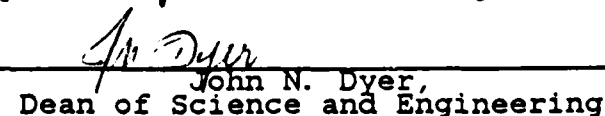

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ABSTRACT

The external nucleate pool-boiling heat-transfer coefficient of both smooth and enhanced horizontal tubes in R-114-oil mixtures (0 to 10 mass percent oil) were measured for heat fluxes from 1 to 91 kW/m² at a saturation temperature of 2.2 C. The enhanced tubes tested were a Wieland GEWA-T finned tube containing 1.02 fins/mm, a Hitachi Thermoexcel-E and a Hitachi Thermoexcel-HE tube. The Thermoexcel-E and -HE tubes with their re-entrant cavity designs were found to improve the heat-transfer coefficient over the smooth tube value at a constant heat flux by a factor of approximately 7 in oil-free R-114, while the GEWA-T tube improved the coefficient by a factor of about 4. While all of the tubes showed a generally decreasing performance with the presence of oil, the GEWA-T tube resulted in the minimum reduction. This tube showed up to 20% and 35% reduction (compared to the oil-free case) at 3 percent and 10 percent oil, respectively. The Thermoexcel-E and Thermoexcel-HE tubes showed performance reductions of up to 40% and 60%, respectively, with 3 percent oil. At a practical heat flux of about 30 kW/m² with 3 percent oil, the GEWA-T, Thermoexcel-E and Thermoexcel-HE tubes outperformed the smooth tube by factors of 4.8, 4.6 and 4.0, respectively.

TABLE OF CONTENTS

I.	INTRODUCTION	11
A.	BACKGROUND	11
B.	REVIEW OF REFRIGERANT-OIL MIXTURE BOILING BEHAVIOR	12
C.	REVIEW OF BOILING PERFORMANCE FROM SMOOTH TUBES	16
D.	REVIEW OF BOILING PERFORMANCE FROM ENHANCED SURFACES	17
	1. Surfaces with Reentrant Cavities	18
E.	THESIS OBJECTIVE	23
II.	DESCRIPTION OF EXPERIMENTAL APPARATUS	24
A.	OVERALL APPARATUS	24
B.	BOILING-TUBE CONSTRUCTION	29
C.	CONVECTION SHIELD	33
D.	DATA ACQUISITION AND REDUCTION	36
III.	EXPERIMENTAL PROCEDURES	39
A.	INSTALLATION OF TUBE IN BOILING APPARATUS	39
B.	GENERAL SYSTEM OPERATION	40
IV.	RESULTS AND DISCUSSION	50
A.	EFFECT OF CONVECTION SHIELD	50

B.	BOILING PERFORMANCE OF THE SMOOTH TUBE	54
C.	BOILING PERFORMANCE OF THE GEWA-T TUBE	62
D.	BOILING PERFORMANCE OF THE THERMOEXCEL-E TUBE	70
E.	BOILING PERFORMANCE OF THE THERMOEXCEL-HE TUBE	75
F.	COMPARISON TO REILLY'S DATA FOR THE HIGH FLUX TUBE	85
V.	CONCLUSIONS AND RECOMMENDATIONS	90
A.	CONCLUSIONS	90
B.	RECOMMENDATIONS	91
APPENDIX A:	THERMOCOUPLE CALIBRATION	92
APPENDIX B:	DATA-REDUCTION PROGRAM	96
APPENDIX C:	REPRESENTATIVE DATA RUNS	136
APPENDIX D:	UNCERTAINTY ANALYSIS	140
LIST OF REFERENCES		144
INITIAL DISTRIBUTION LIST		146

LIST OF TABLES

1.	Summary of Refrigerants	12
2.	Summary of Data Runs	42
3.	Oil Concentration Values	46
4.	Uncertainty Analysis	142

LIST OF FIGURES

1.1	Oil Concentration Gradient in a Bubble in Refrigerant-Oil mixtures [Ref. 5]	14
1.2	Schematic and Cut-away Cross-Section and Micrograph of the GEWA-T Surface	20
1.3	Surface Photograph and Enlarged Outer Surface of the Thermoexcel-E Surface	21
1.4	Surface Photograph and Enlarged Outer Surface of the Thermoexcel-HE Surface	22
2.1	Schematic of Experimental Apparatus	25
2.2	Schematic of Condensate Shield in Boiling Tee	26
2.3	Photograph of Convection Shield	27
2.4	Sectional View of Boiling Tube [Ref. 5]	31
2.5	Boiling Tube Thermocouple Channels	32
2.6	Convective Effects of Auxiliary Heaters	35
3.1	Foaming Action for Pure R-114	47
3.2	Foaming Action for R-114 with 6 Percent Oil	48
3.3	Foaming Action for R-114 with 10 Percent Oil	49
4.1	Performance Comparison for Pure R-114 Boiling from a Smooth Tube	51
4.2	Performance Comparison for R-114 with 3 Percent Oil Boiling from a Smooth Tube	52

4.3	Performance Comparison for R-114 with 10 Percent Oil Boiling from a Smooth Surface Tube.	53
4.4	Heat-Transfer Performance for Smooth Tube in 0, 3 and 10 Percent Oil	56
4.5	Reilly's [Ref. 5] Smooth Tube Data for 0, 3 and 10 Percent Oil	58
4.6	Boiling Heat-Transfer Coefficient for Smooth Tube	60
4.7	Boiling Heat-Transfer Coefficient for Reilly's Smooth Tube Data [Ref. 5]	61
4.8	Heat-Transfer Performance for GEWA-T Surface . . .	64
4.9	Boiling Heat-Transfer Coefficient for GEWA-T Surface	67
4.10	Boiling Heat-Transfer Coefficient Comparison for GEWA-T and Smooth Surface	68
4.11	Relative Effect of Oil on GEWA-T Boiling Heat- Transfer Performance	69
4.12	Heat-Transfer Performance for Thermoexcel-E Surface	71
4.13	Boiling Heat-Transfer Coefficient for Thermoexcel-E Surface	74
4.14	Boiling Heat-Transfer Coefficient for Thermoexcel-E Surface vs. Smooth Surface	76

4.15	Relative Effect of Oil on Thermoexcel-E Boiling Heat-Transfer Performance	77
4.16	Heat-Transfer Performance for Thermoexcel-HE Surface	79
4.17	Boiling Heat-Transfer Coefficient for Thermoexcel-HE	82
4.18	Boiling Heat-Transfer Coefficient Comparison for Thermoexcel-HE Surface vs. Smooth Surface . .	83
4.19	Relative Effect of Oil on Thermoexcel-HE Boiling Heat-Transfer Performance	84
4.20	Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5], GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for Pure R-114	86
4.21	Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5], GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 3 Percent Oil Content	87
4.22	Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5], GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 10 Percent Oil Content	88
A.1	Thermocouple Discrepancy Correction	95

I. INTRODUCTION

A. BACKGROUND

In the design of refrigeration systems for use aboard Naval vessels, the desire is to make the system as efficient as possible. To achieve this higher efficiency, one must consider the use of a high pressure refrigerant, since this gives a higher energy transfer per unit volume of vapor (i.e., $E_v = h_{fg}/v_g$) [Ref. 1], and results in less of a pressure drop along the vapor path for a given heat load. R-12, which is a high pressure refrigerant, has an energy transfer per unit volume of vapor of 8570 kJ/m³ [Ref. 2] and, since it is higher pressure, it requires heavier gauge components. R-11, on the other hand, is a low pressure refrigerant with a low energy transfer per unit volume of vapor of 2086 kJ/m³ and requires lighter gauge material.

Table 1 provides a short summary of some of the available refrigerants and their respective energy transfer per unit volume of vapor, their relative toxicity and their required system pressure for optimum operation. As can be seen from Table 1, R-12 and R-22 possess the highest values of energy transfer per unit volume of vapor, and therefore would provide systems of higher efficiency than the other refrigerants listed since pressure losses in the system would be less. However, since both R-12 and R-22 are

high-pressure refrigerants, their respective systems would be significantly heavier larger than those of the other refrigerants. However, R-114 being a moderate-pressure refrigerant with an energy transfer per unit volume of vapor of 3800 kJ/m³, it would allow for a relatively lighter component system than those of R-12 and R-22.

TABLE 1 [Ref. 3]
SUMMARY OF REFRIGERANTS

Refrigerant	kJ/m ³	Toxicity	Operational System Pressure
R-11	2086	moderate (Group 5)	low
R-12	8570	low (Group 6)	high
R-22	12480	moderate (Group 5)	high
R-113	1128	high (Group 4)	low
R-114	3800	moderate (Group 6)	moderate

Additionally, R-114 belongs to the refrigerant group (Group 6) having the lowest toxicity [Ref. 2], and it has also been proven fairly stable with temperature [Ref. 2]. Therefore, R-114 is a viable alternative to the higher pressure refrigerants.

B. REVIEW OF REFRIGERANT-OIL MIXTURE BOILING BEHAVIOR

The presence of oil in the evaporators of refrigeration systems is a common occurrence. This is due, in part, to the use of lubricants in the hermetically sealed refrigeration compressors. Over a period of time, a considerable amount of oil is introduced into the refrigerant, subsequently changing the physical properties of the refrigerant. Jensen and Jackman [Ref. 3]

reported that the density and the specific heat behave linearly in the refrigerant-oil mixtures, however, the viscosity and the surface tension do not. Henrici and Hesse [Ref. 4] experimentally determined in 1971 that the surface tension of mixtures first decreased for R-114-oil mixtures of up to 2.5 percent oil, and at higher oil concentrations, the surface tension increased. This non-linear behavior of the properties of the mixtures makes it difficult to explain the changes in the heat-transfer coefficient for these mixtures.

The most evident example of the addition of oil to the refrigerant is the presence of foam in the mixture when boiling takes place. With the oil concentration above 1 percent, there is a substantial amount of foam generated from the nucleate boiling surface. This foam is generated because the refrigerant in the refrigerant-oil mixture is more volatile than the oil and therefore can vaporize, creating a gas bubble surrounded by an oil-rich layer [Ref. 5]. Figure 1.1 shows the ideal model of the growth of a bubble in a refrigerant-oil mixture. These generated bubbles are at lower density than that of the surrounding refrigerant-oil mixture. The bubbles ascend to the liquid-vapor interface and collect at the interface and produce a foam layer. As reported by Henrici and Hesse [Ref. 4], the foaming action is most pronounced in refrigerant-oil

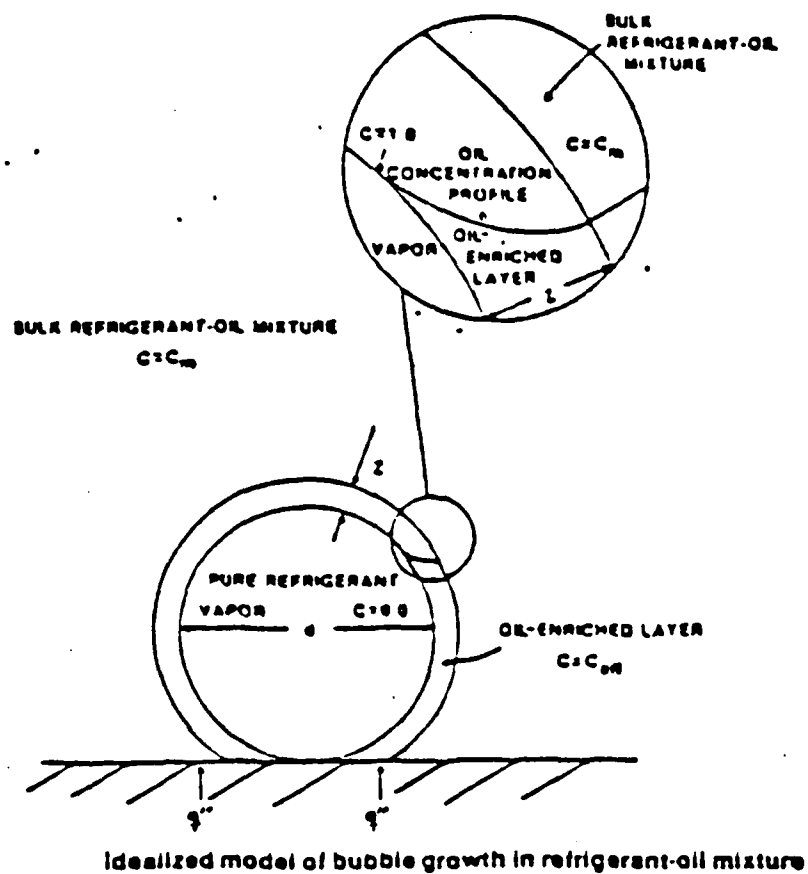


Figure 1.1 Oil Concentration Gradient in a Bubble in Refrigerant-Oil Mixtures [Ref. 5].

mixtures of 1 to 10 percent oil, and provide a the presence of oil results in a subsequent decrease in the heat-transfer performance of the boiling tube.

Numerous researchers have tried to explain the reasons for the decrease in the heat-transfer coefficient in refrigerant-oil mixtures of increasing oil content. Thome [Ref. 6], after an extensive literature search, found that, in 1956, Van Wijk et al. explained the effect as being the result of the evaporation of the more-volatile component leaving an oil-rich layer which has a higher resultant local boiling point. This increased local boiling point requires an increase in the amount of superheat necessary to continue the vaporization and bubble growth. The result is a decrease in the heat-transfer coefficient.

Stephan and Preusser [Ref. 7] determined that the work required to form bubbles in the refrigerant-oil mixtures was greater than in an equivalent amount of pure refrigerant. Therefore, the heat-transfer coefficient was lower for the refrigerant-oil mixture than for the pure refrigerant. Chongrungreong and Sauer [Ref. 8] reported that the rate of heat diffusion, which is governed by the thermal properties of the oil-rich layer, limits the bubble growth and that the effects of surface tension are negligible. Thome [Ref. 6] agreed with the above factors and concluded that the viscosity variations are important

in explaining the decrease in the heat-transfer coefficient for some refrigerant-oil mixtures.

Although researchers have not decided on any one set of factors that determine the reasons for the decrease in the heat-transfer coefficient as oil content increases in refrigerant-oil mixtures, all agreed that the physical and thermal properties are important factors in explaining the heat-transfer behavior of refrigerant-oil mixtures.

C. REVIEW OF BOILING PERFORMANCE FROM SMOOTH TUBES

The U. S. Navy attempts to reduce the size of its shipboard refrigeration systems by the use of alternate refrigerants (such as R-114). At the same time, the Navy desires to increase the performance of these systems by the use of enhanced surfaces. However, as discussed by Wanniarachchi et al. [Ref. 9], only a limited amount of data is available regarding the boiling of refrigerants in the presence of oil.

Stephan [Ref. 10] conducted experiments using a smooth horizontal plate as a boiling surface in R-12 and R-22 refrigerants and reported up to 50 percent reductions in the boiling heat-transfer coefficient with a refrigerant-oil mixture of 9 percent oil (by mass), while 50 percent oil resulted in a 90 percent reduction in the boiling heat-transfer coefficient.

In 1971, Henrici and Hesse [Ref. 4] conducted experiments involving the boiling of R-114 in the presence of oil from a smooth copper tube and reported a maximum decrease of 20 percent decrease in the boiling heat-transfer coefficient with 1 percent oil by mass. In 1981, Stephan and Mitrovic [Ref. 11] reported that for the GEWA-T tube (manufactured by the Wieland Company) in R-114-oil mixtures, the boiling heat-transfer coefficient of the enhanced surface was significantly altered by the presence of the oil. In 1985, Reilly [Ref. 5] reported a drop in the heat-transfer coefficient of 0 to 35 percent (depending on the heat flux) for a R-114-oil mixture of 10 percent oil for a smooth copper tube.

D. REVIEW OF BOILING PERFORMANCE FROM ENHANCED SURFACES

Arai et al. [Ref. 12] tested a 200-ton R-12 centrifugal water chiller. The chiller which used an enhanced-surface tube, commercially known as Thermoexcel-Em made by Hitachi, was 28 percent shorter in length and had an approximate improvement in the overall heat-transfer coefficient of 50 percent. Additional research by Yilmaz and Westwater [Ref. 13], Marto and Lepere [Ref. 14], and Carnavos [Ref. 15] on commercially available enhanced surface tubes, in various refrigerants other than R-114, indicated that a porous-coated surface exhibited the best boiling heat-transfer coefficient in a pure refrigerant.

Comparisons by Reilly [Ref. 5] indicated that in R-114, Union Carbide's "High Flux" tube with a porous-coated surface resulted in an improvement of at least a factor of seven over a smooth copper tube at the same operational parameters. Reilly's findings complemented the research of Yilmaz and Westwater [Ref. 13]. Additionally, Reilly reported that for a porous-coated surface in an R-114-oil mixtures of 1 percent oil, the oil was seen to degrade the nucleate pool-boiling heat-transfer performance by about 20 percent.

1. Surfaces with Reentrant Cavities

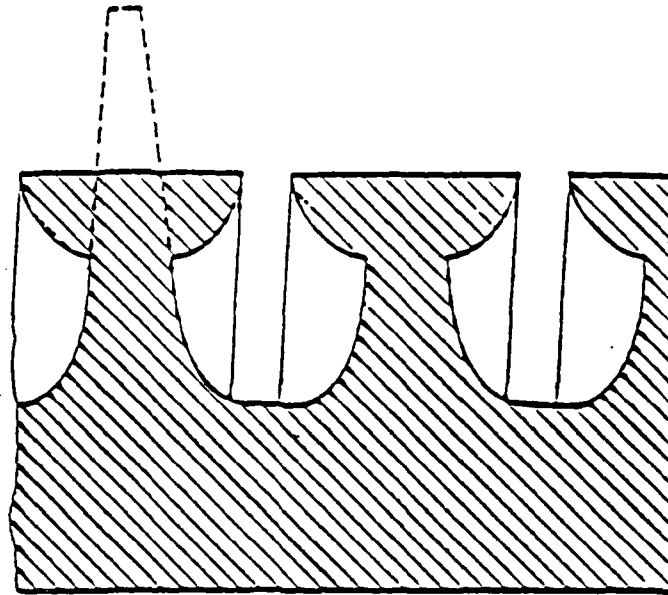
Reentrant cavities have been investigated for a considerable period of time. Griffith and Wallis [Ref. 15] determined that the reentrant cavity geometry is important in the generation of nucleate boiling sites in two ways; (1) the diameter of the reentrant cavity mouth determines the amount of superheat required to initiate boiling, and (2) the cavity shape determines the stability once the boiling has begun. Webb [Ref. 16] stated that the key to the high performance of the reentrant grooved structures can be attributed to three factors: (1) reentrant cavity within a critical size range, (2) interconnected cavities, and (3) nucleation sites of a reentrant shape. If the cavities are interconnected, adjacent cavities can activate each other. Webb [Ref. 16]

also stated that reentrant cavities provide a stable vapor trap, which can remain active at low values of superheat.

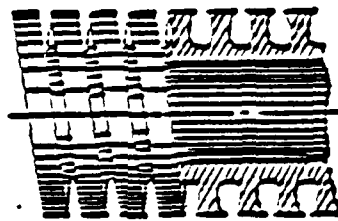
The GEWA-T (1.02 fins/mm) enhanced-surface tube, manufactured by Wieland-Werke AG, is a copper tube with spiral fins of a T-shaped profile. It has a reentrant-type cavity formed by cold working an integral finned tube. The two adjacent T-fins form a spiral cavity with an opening of 0.25-mm (see Figure 1.2).

The Thermoexcel-E and Thermoexcel-HE enhanced-surface tubes are made by the Hitachi Company. Like the GEWA-T tube, the Thermoexcel-E (Figure 1.3) and Thermoexcel-HE (Figure 1.4) tubes are also formed by cold working integral fins; however, these tubes have low fins which have a small space cut out at the fin tips, giving the appearance of a sawtooth. These sawtooth fins are bent parallel to the tube axis, to a horizontal position, forming tunnels with evenly spaced surface pores. This cold working procedure results in a high area density of reentrant nucleation sites. The Thermoexcel-HE tube is a variation of the Thermoexcel-E tube, designed for improved performance in low-heat-flux regions.

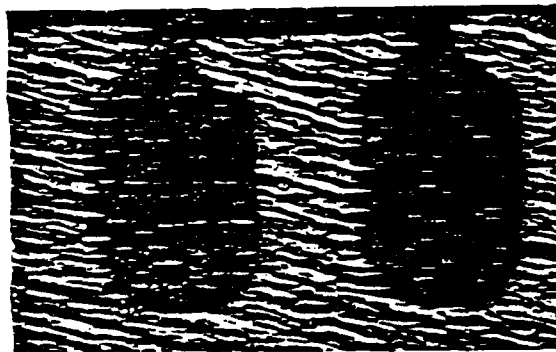
Experimental data showing the effect of oil concentrations on the heat-transfer coefficient of the GEWA-T, the Thermoexcel-E and Thermoexcel-HE tubes in R-114 are lacking. In an effort to gain more understanding of



(a) Schematic of GEWA-T Surface Cross Section



(b) Cutaway of the GEWA-T Surface



(c) Micrograph of the GEWA-T Surface

Figure 1.2 Schematic, Cut-away Cross Section and Micrograph of the GEWA-T Surface.

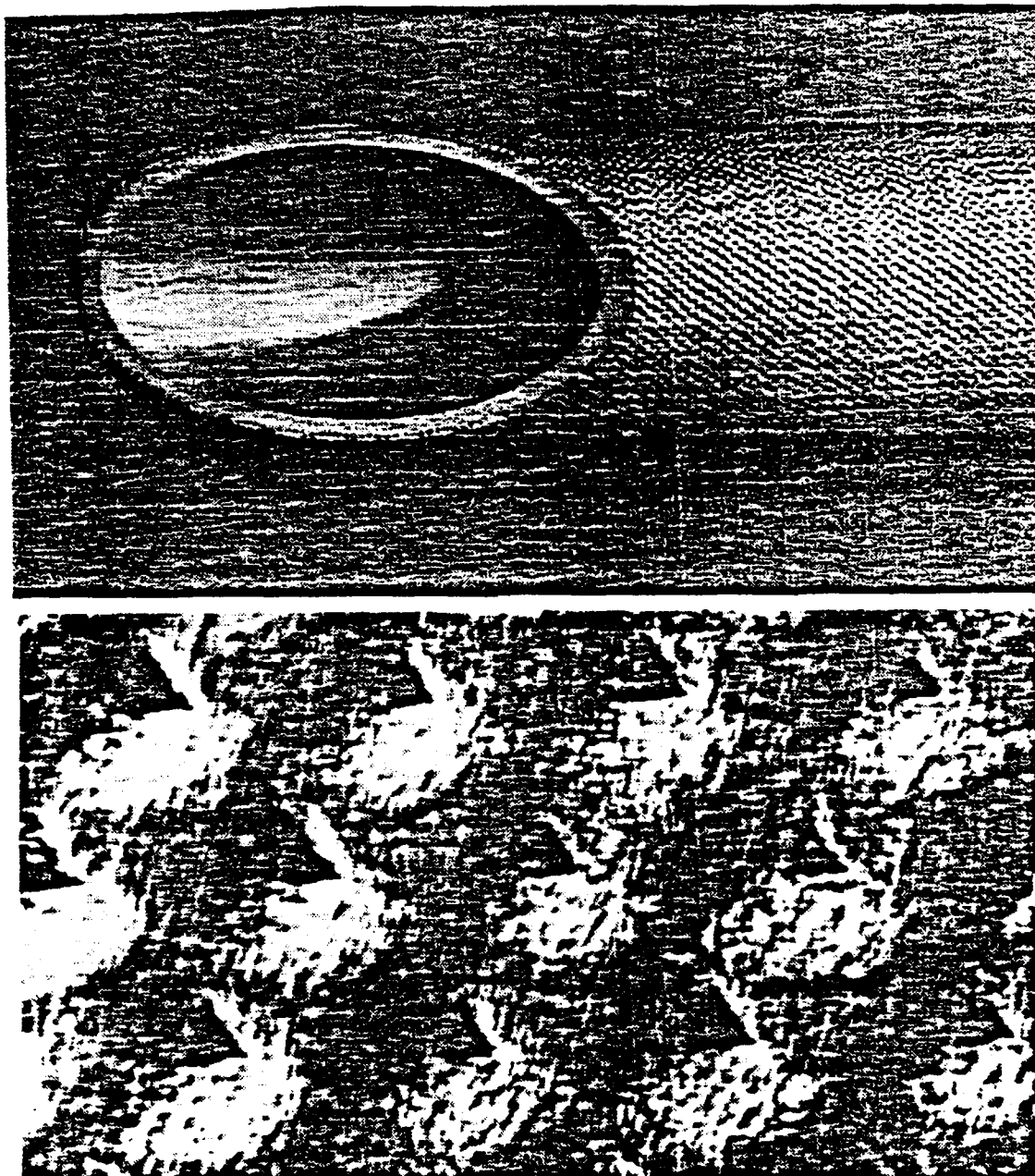


Figure 1.3 Surface Photograph and Enlarged Outer
Surface of the Thermoexcel-E Surface.

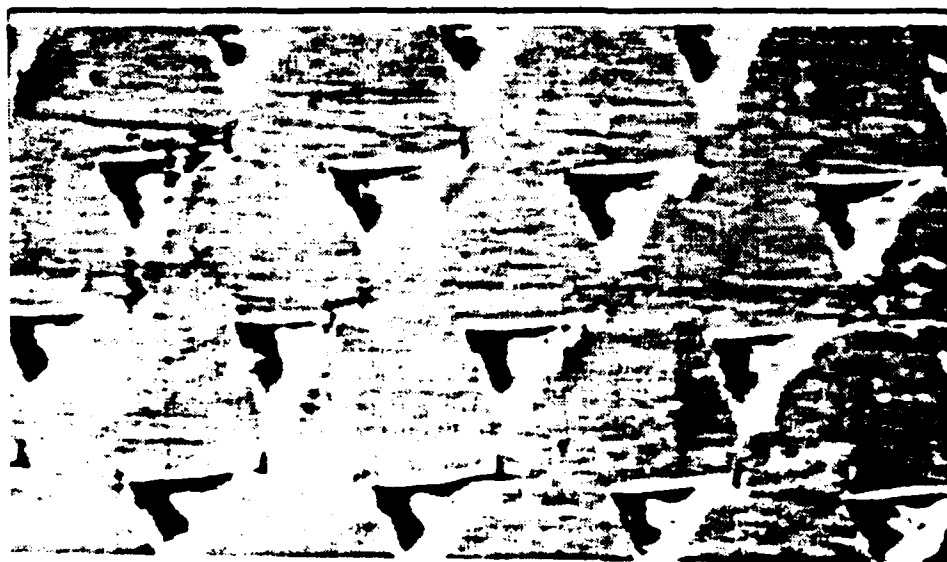
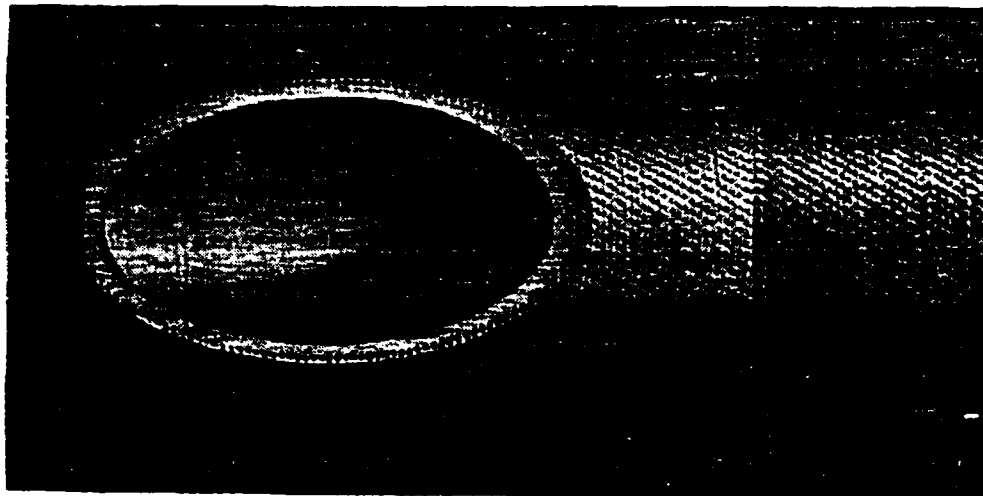


Figure 1.4 Surface Photograph and Enlarged Outer
Surface of the Thermoexcel-HE Surface.

the pool-boiling performance of these tubes, the David W. Taylor Naval Ship Research and Development Center sponsored this investigation. The smooth copper tube and the GEWA-T tube were provided by the Wieland Company. The Thermoexcel-E and Thermoexcel-HE tubes were provided by the Hitachi Company.

E. THESIS OBJECTIVE

The objectives of this thesis are:

1. take data on a smooth tube with the use of auxiliary heaters together with a convection shield to enable the collection of more data with a minimum of operator effort,
2. take boiling data on a smooth copper tube in R-114 to provide a baseline for follow-on comparison for enhanced tubes at oil concentrations of 0, 1, 2, 3, 6 and 10 percent (by mass) at a boiling temperature of 2.2 C and a heat-flux range from 500 W/m² to 91 kW/m².
3. take data on the following tubes for the above-mentioned conditions:
 - a. GEWA-T (1.02 fins/mm),
 - b. Thermoexcel-E, and
 - c. Thermoexcel-HE.

II. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. OVERALL APPARATUS

The equipment used for this study consisted of nine basic components: (a) a Pyrex-glass tee for the pool boiling of the R-114 liquid; (b) a Pyrex-glass tee for the condensing of the R-114 vapor; (c) an R-114 liquid reservoir; (d) a water-ethylene glycol mixture sump; (e) an R-12 refrigeration system with an external proportioning valve; (f) oil reservoir; (g) a vacuum pump; (h) instrumentation and data-acquisition system; and (i) a convection shield. Figure 2.1 shows schematically the arrangement of the various components. Complete details of the design, construction and operation of the apparatus are provided by Karasabun [Ref. 17], Reilly [Ref. 5] and Wanniarachchi et al. [Ref. 1]. The original design of Karasabun was modified by the inclusion of the convection shield in the pool-boiling section as shown in Figures 2.2 and 2.3.

The operation of the apparatus consisted of the boiling of R-114 liquid in the lower glass tee (1), and condensing of the R-114 vapor in the upper glass tee (2). The resultant condensate was fed to the distribution tube within the boiling section by gravity. A water-ethylene glycol mixture from a 30-gallon

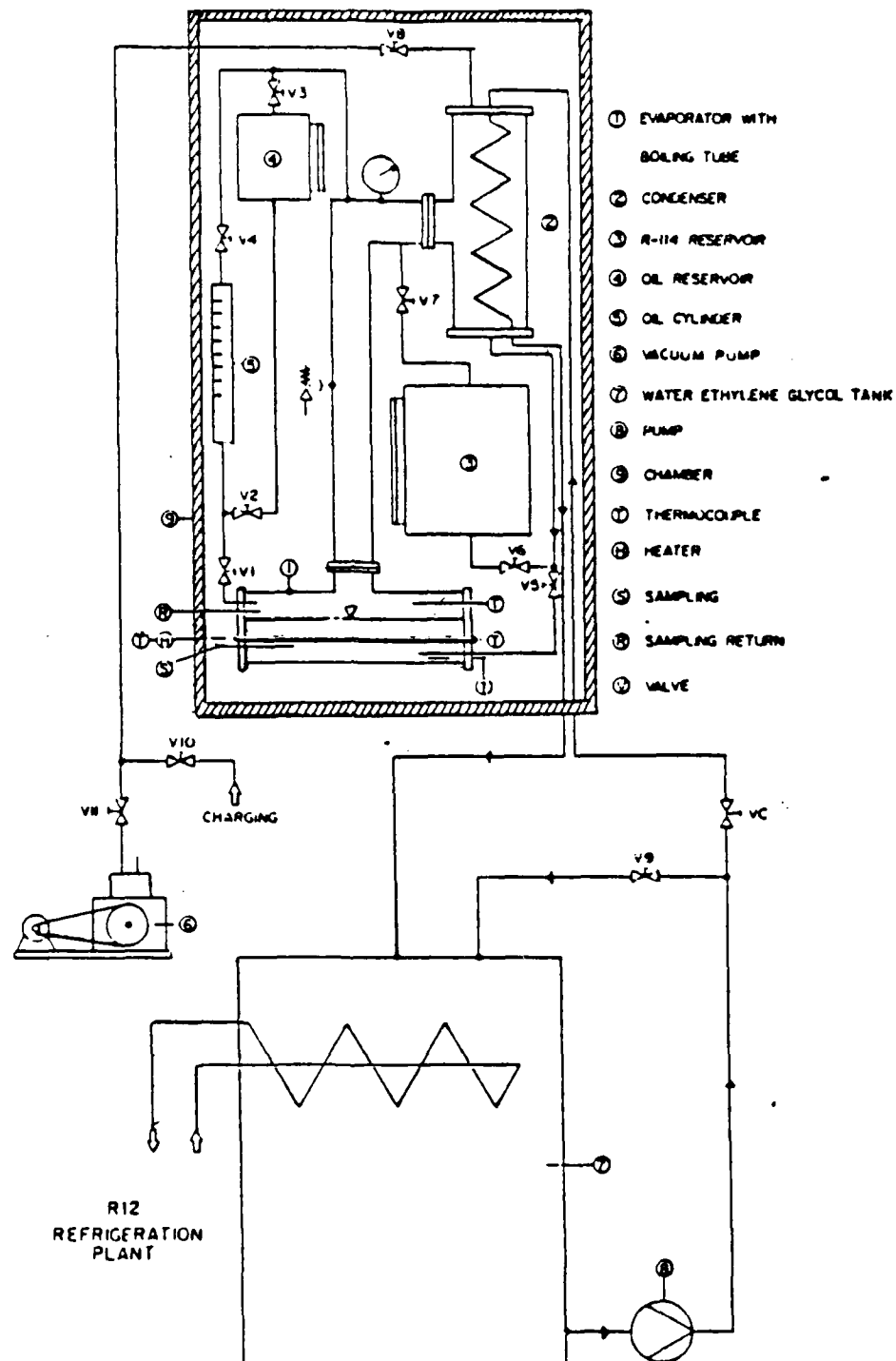


Figure 2.1 Schematic of Experimental Apparatus.

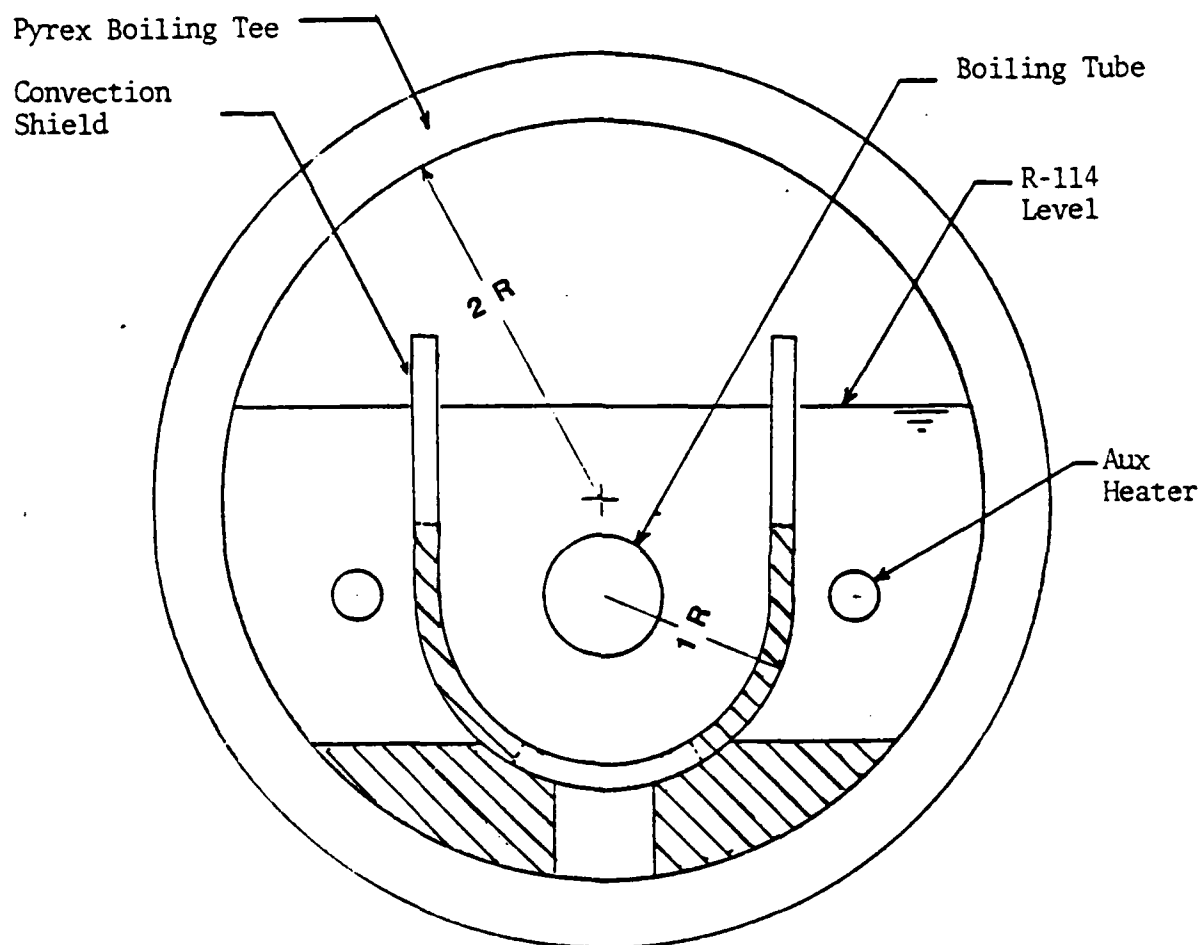
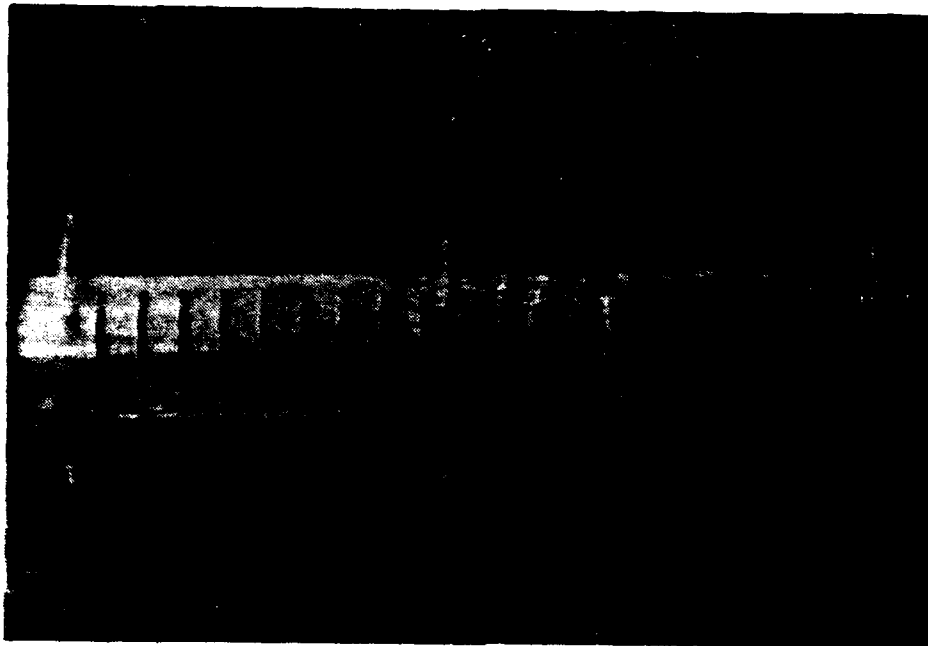
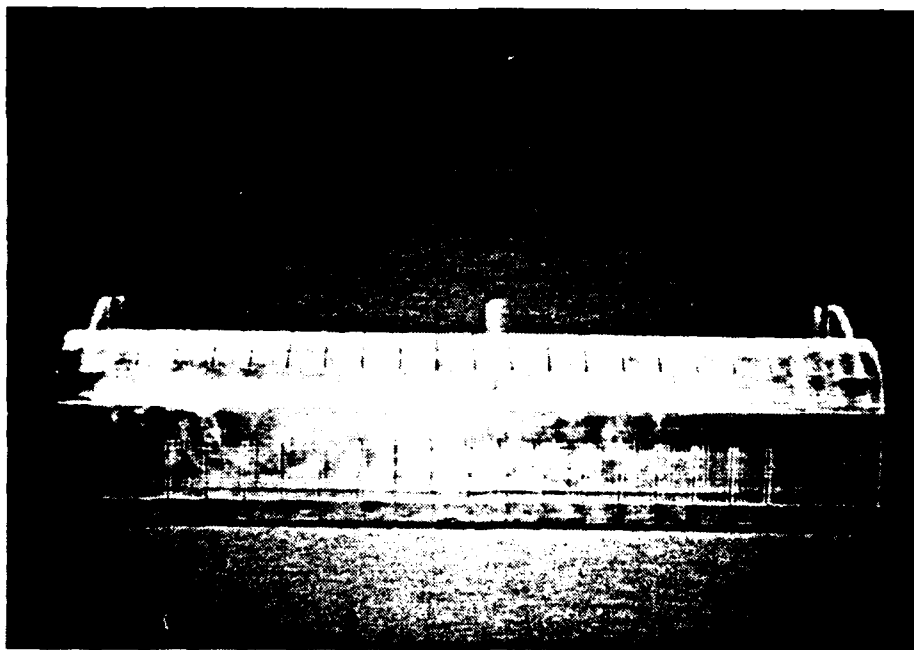


Figure 2.2 Schematic of Convection Shield in
Pyrex Boiling Tee.



(a) Bottom View



(b) Side View

Figure 2.3 Photograph of Convection Shield.

sump was used to cool the copper condensing coil, thereby condensing the R-114 vapor. This water-ethylene glycol mixture sump was maintained between -18 and -14 C by a one-half ton R-12 air-conditioning system. The mixture was pumped through the condensing coil and controlled manually with valve VC.

Valve VC controls the amount of the water-ethylene glycol mixture to the condensing coil, thereby controlling the pressure within the test loop. For example, the opening of valve VC allows more of the water-ethylene glycol mixture to pass through the condensing coil, resulting in additional condensing of the R-114, and subsequently lowering the temperature and pressure within the entire system.

As the subcooled R-114 condensate enters the boiling section of the apparatus through the distribution tube, it strikes the convection shield. This shield provides increased mixing of the subcooled R-114 condensate with the remaining R-114 (or R-114/oil mixture) in the lower portion of the boiling section. The shield deflects the incoming condensate away from the boiling surface and allows for further mixing of the condensate and the existing R-114 liquid by means of the auxiliary cartridge heaters. This deflection of the incoming condensate allowed for a more even temperature distribution of the liquid R-114 and therefore decreased the previously reported temperature

gradients within the liquid region. This additional mixing of the liquid R-114, coupled with the ability to use auxiliary cartridge heaters in the liquid and allowed for the timely achievement of steady-state conditions without the previously observed thermal gradients in the liquid region of the tests done without the aid of the convection shield. It was also observed throughout the operation of the apparatus that the data obtained using the convection shield had a higher degree of repeatability than the data obtained without the shield.

B. BOILING-TUBE CONSTRUCTION

The tubes tested during the course of this study were the smooth copper tube, the GEWA-T (1.02 fins/mm), the Thermoexcel-E and the Thermoexcel-HE tubes. All of these tubes had an active test section (i.e., heated) of length of 203.2-mm (8 in), with an outside diameter of 15.9 mm (5/8 in) and an inside diameter of 12.7 mm (1/2 in). The remaining 114.3-mm section on either side of the heated test section was smooth and unheated and did not nucleate under any heat flux or any oil concentration condition. Figure 1.2 shows the schematic of the GEWA-T finned surface. Karasabun [Ref. 17] described the analysis used in the data-reduction program, allowing for the two end surfaces to be treated as extended fins from the center section and subsequently accounting for the heat losses.

The center section of each tube tested was heated by a 1000-W 240-V stainless steel cartridge heater inserted in the center section of each tube. The cartridge heater was inserted in the boiling tube and surrounded by a copper sleeve with eight 1.3 mm by 1.3 mm thermocouple channels. Figure 2.4 shows the layout of the installed tube in the boiling section. Figure 2.5 shows the details of the thermocouple layout. The thermocouple hot junctions were inserted into the copper sleeve and the copper sleeve was then tinned; and heat was maintained to keep the solder in a molten state as the sleeve was inserted and positioned in the center section of the boiling tube. Upon completion of the thermocouple installation, calibration of the thermocouples was achieved. Reilly [Ref. 5] determined in the course of his investigation that since the data-reduction program utilized the differences between the thermocouples in all computations, such as wall temperatures minus saturation temperatures, the corrections provided by the thermocouple calibration were basically unnecessary since the calibration procedures were only necessary for items dependent on absolute temperature. Appendix A summarizes the procedure used by Karasabun [Ref. 17] and Reilly [Ref. 5] to calibrate the thermocouples.

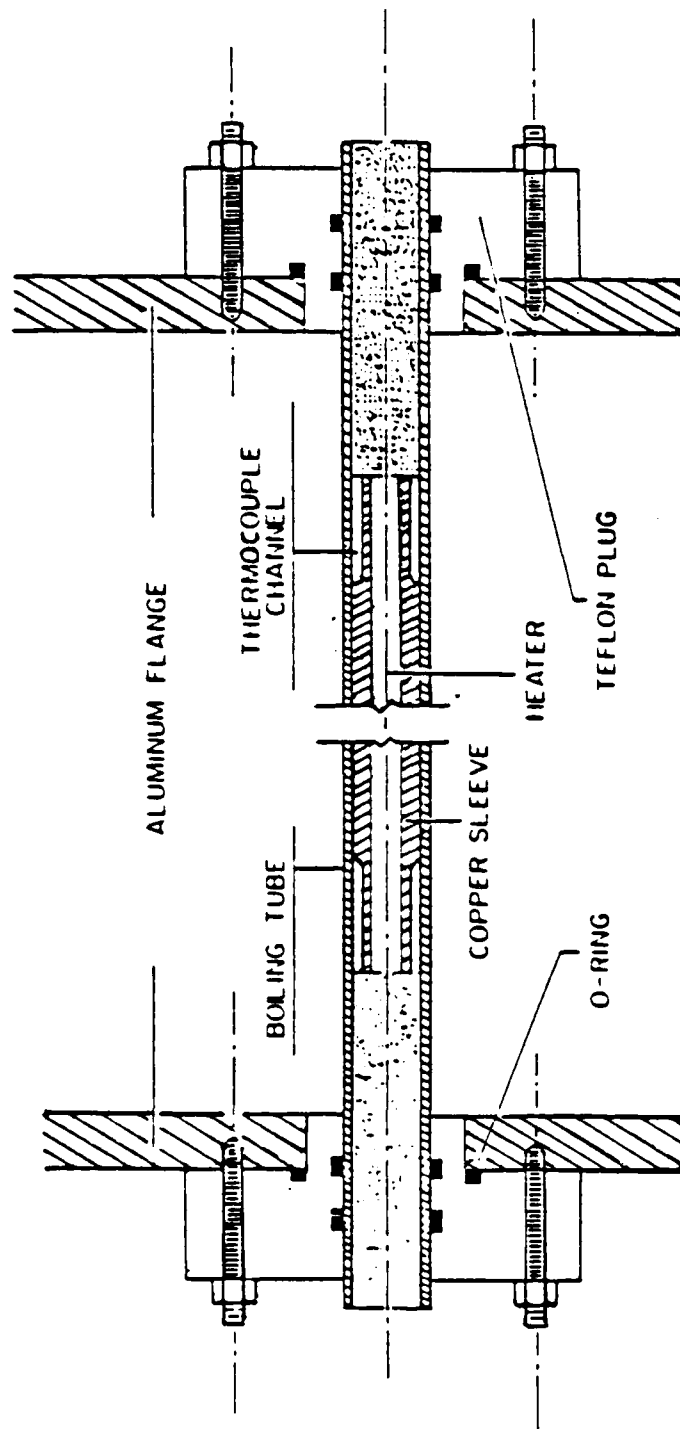
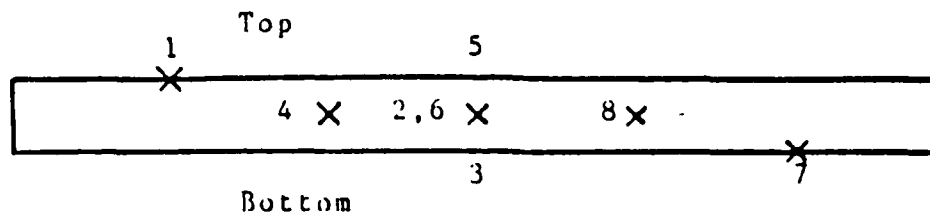
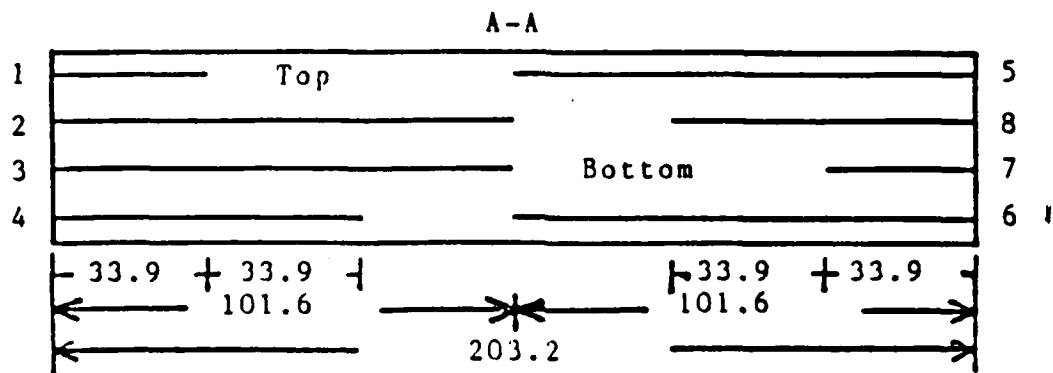


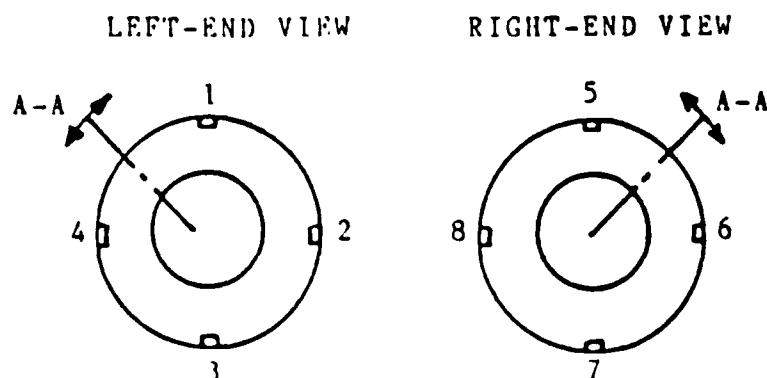
Figure 2.4 Sectional View of Boiling Tube



(a) View of the boiling tube thermocouple locations as seen from the front of the experimental apparatus.



(b) Thermocouple sleeve unwrapped (at section A-A) to show the relative locations of the thermocouple channels (all dimensions in millimeters).



(c) End views of the boiling tube.

Figure 2.5 Boiling Tube Thermocouples Channels.

C. CONVECTION SHIELD

Initial tests on the smooth copper tube revealed an axial thermal gradient in the liquid over the length of the boiling tube. This thermal gradient increased with increasing oil concentration and with increasing heat flux, with the thermal gradient ranging from 0.5 K to 1.5 K over the length of the boiling section. This thermal gradient resulted in questionable data since steady-state conditions could not be maintained over the course of the individual data runs.

During the early stages of this investigation, it was found that the steady-state conditions were fairly difficult to achieve. This was especially true after making a step change in the heat flux. For example, if the heat flux was increased, the cooling flow rate to the condenser must be increased to maintain the system pressure. Since the system showed about a 30-second time lag between the change of the valve position and the subsequent system response, the pressure was often seen to undergo cyclic variations. With considerable experience of the operator, it was possible to achieve steady-state conditions within 5 to 10 minutes, as demonstrated by Reilly [Ref. 5].

In order to minimize the efforts necessary by the operator, two 600-W auxiliary cartridge heaters were installed within the boiling tee. With this arrangement, steady-state conditions could be maintained very easily by

maintaining the total heat load in the boiling tee at a constant value. For example, if the heat duty for the boiling tube was increased, the heat duty on the auxiliary heaters must be decreased by the same magnitude. In this manner, steady-state conditions could be maintained with minimum attention. However, this arrangement required that the heat duty on the auxiliary heaters be a maximum when the heat duty on the boiling tube is at a minimum. As determined by the early data runs (see Figure 2.6), the convective effects created by the bubbles of the auxiliary heaters created an artificially enhanced heat-transfer coefficient at low heat-flux settings.

In order to alleviate the problem discussed above, while maintaining the advantages offered by the auxiliary heaters, the present investigator considered the use of a convection shield. As shown in Figure 2.2, this shield was positioned around the test tube, thus isolating it from the convective bubble effects created by the auxiliary heaters.

The convection shield also provided increased mixing of the refrigerant and condensate without interfering with the boiling phenomenon of the boiling tube or the circulation of the oil-refrigerant mixture in the boiling section by both the boiling tube and the auxiliary heaters.

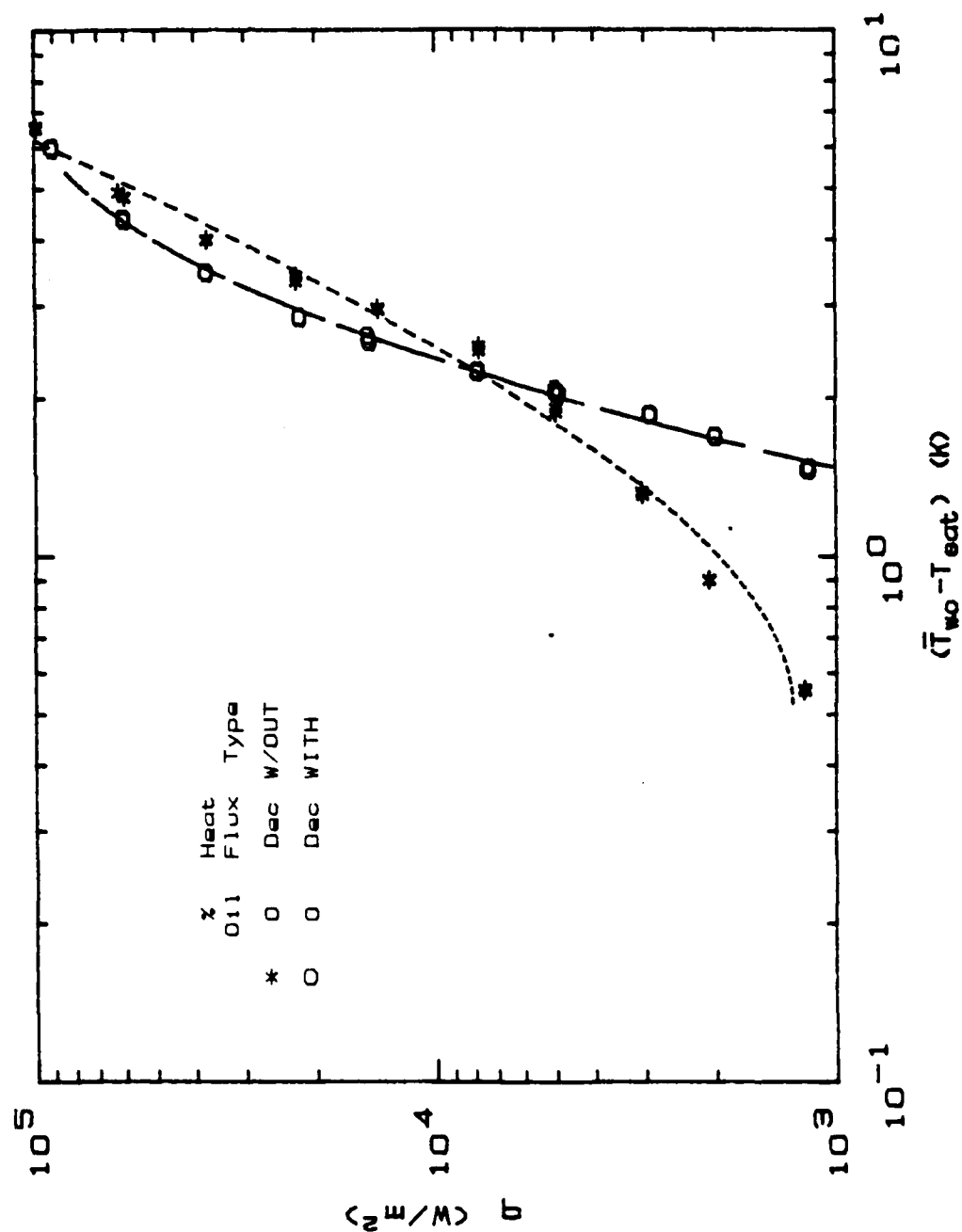


Figure 2.6 Convective effects of Auxiliary Heaters
with and without Convective Shield

D. DATA ACQUISITION AND REDUCTION

The data-acquisition system used for this research was a Hewlett-Packard 9826A computer and a Hewlett-Packard 3497A Automatic Data Acquisition Unit. The HP-9826A computer was used to control the HP-3497A, to provide hard-copy storage capacity and to analyze the data obtained during this investigation.

The data-acquisition system provided the means by which the researcher was able to review system performance and stability prior to the taking of any data. System parameters were monitored on the video screen following the scanning of all of the channels by the HP-3497A. Following the automatic scanning of all of the channels, the computer would display the desired saturation temperature (2.2°C), the observed saturation temperature, the liquid temperature at both ends of the boiling section and their average, the vapor temperature, and the temperature of the water-ethylene glycol mixture sump (-15 to -18°C). Once the steady-state conditions were met for the required saturation temperature within the prescribed variance ($\pm 0.1\text{ K}$) of the desired saturation temperature, the data-acquisition system was initiated for the individual data run. Since there was a time lag in the request for the taking of data and the actual printing of the data due to the sampling of each channel twenty times before recording the data, the data-acquisition system would print the data,

allowing the researcher to review the results prior to storing the data. If, during the sampling of the data, a transient trend was observed due to the cycling of the R-12 refrigerant system or the temperature difference between the thermocouples measuring the liquid R-114 was not within the specified temperature range, the researcher had the capability to reject the affected data set. This capability allowed the researcher to apply a cursory analysis of each data point and ascertain if the temperatures measured during that individual data set were within the prescribed limits of variance.

The information scanned on each channel of the HP-3497A were thermal emf's provided by copper-constantan (type-T) thermocouples made of 0.25-mm-diameter (30 gauge) wire. Two additional measurements were provided to the HP-3497A by the power-sensing device, as described by Karasabun [Ref. 17], which converted the AC voltage dialed into the variac of the main boiling tube heater into a DC signal, allowing the HP-3497A to accurately scan the converted value and then allow the HP-9826A to automatically apply this value to the analysis calculation.

Upon the initiation of the command to take data, the data-acquisition system would sample each channel and then compute, according to the step-wise procedure outlined by Karasabun [Ref. 17] and print the results. Appendix B contains a summary of the data-acquisition program and a

listing of the data-reduction program utilized during the course of this research. Appendix C contains a representative sample of the data printout received for each data run.

III. EXPERIMENTAL PROCEDURES

A. INSTALLATION OF TUBE IN BOILING APPARATUS

The external surfaces of each of the boiling tubes were cleaned with Nitol (2 percent nitric acid and 98 percent ethyl alcohol) solution and then rinsed with acetone to ensure tube cleanliness. This treatment was also effective in the removal of oil and grease residues from the tube surfaces.

After air drying, the individual tube to be tested was installed in the boiling section of the apparatus. The system was sealed and then evacuated to approximately 29 inHg by means of a portable mechanical vacuum pump (6), shown in Figure 2.1. The apparatus remained under the evacuated condition for a period of about one hour to check if there were any major leaks. System pressure was measured by means of a Marsh pressure gauge (30 inHg to 150 psi range with ± 2.5 inHg and ± 0.5 psi accuracy, respectively). If there was not a noticeable drop in the vacuum reading as observed on the pressure gauge, the system was charged with R-114 vapor, which was condensed by the water-ethylene glycol mixture and then the absolute pressure was raised to approximately 0.186 MPa (27 psi). Upon reaching this pressure, an Automatic Halogen Leak

Detector, TIF 5000, with a sensitivity of 3 ppm concentration, was used to check for system leaks.

Upon successful completion of the leak-detection tests and taking the necessary steps to fix any leaks found, the R-114 liquid level was adjusted to be 20 mm above the top of the boiling tube surface. Liquid-level adjustments were made by either boiling off the excess refrigerant to the R-114 reservoir (3), or drawing the required amount of refrigerant liquid into the system from the R-114 reservoir. The required liquid level for boiling was maintained constant for all tubes tested by means of a permanent scribe mark on the inside of the oil intake endbell of the boiling section. At this initial refrigerant level, the system was now ready for boiling tests in pure refrigerant.

B. GENERAL SYSTEM OPERATION

Table 2 provides a summary of all of the 83 data runs made during this investigation. Each data run is annotated to indicate the conditions involved in the respective run. The data runs were numbered sequentially with an indicator code for each tube preceding the number of the data run. Since this research is a follow up of previous research, the initial data run was indicated as number 168. All data runs were undertaken at a saturation temperature of 2.2°C.

A listing of the boiling tube indicator codes for Table 2 is as follows:

WH -- Wieland Hard Copper Smooth Tube
GTB -- Wieland Gewa-T (1.02 fins per mm)
TXE -- Hitachi Thermoexcel-E
THE -- Hitachi Thermoexcel-HE.

Initially, all data runs were taken over a range of nine different heat-flux settings, ranging from 2 kW/m² to 91 kW/m². Additional heat fluxes of 0.5, 0.8, 1.2 kW/m² were later included for all tubes with enhanced surfaces to study the onset of nucleate boiling in the oil-refrigerant mixtures and to study the effects of hysteresis on these tubes. The initiation of all data runs was carried out in the same manner to ensure consistency in the obtained data. Each run was started by an initial system "warm-up" period allowing the R-12 refrigeration system to obtain a minimum coolant starting temperature of about -15°C. This was accomplished by lighting off of the R-12 system in conjunction with the effluent recirculation/cooling pump (8) and slight opening of the control valve VC. This procedure allowed the system to gradually decrease system temperature and pressure, while minimizing the adverse effects of shocking the boiling tube. The system was operated in this condition until a stable condition was established with the saturation temperature of 2.2°C. This operation was most critical when the testing sequence involved increasing heat-flux conditions since

TABLE 2
Summary of Data Runs

Run No.	% Oil	Heat Flux	No. of Data Points	Auxiliary Heater	Convection Shield
WH168	0	DEC	20	off	without
WH169	0	INC	22	off	without
WH170	1	DEC	20	off	without
WH171	1	INC	22	off	without
WH172	2	DEC	20	off	without
WH173	2	INC	20	off	without
WH174	3	DEC	20	off	without
WH175	3	INC	22	off	without
WH176	3	DEC	20	off	without
WH177	6	DEC	20	off	without
WH178	6	INC	21	off	without
WH179	10	DEC	18	off	without
WH180	10	INC	13	off	without
WH181	10	INC	12	off	without
GTB182	0	DEC	24	on	with
GTB183	0	INC	23	on	with
GTB184	0	DEC	22	on	with
GTB185	1	DEC	20	on	with
GTB186	1	INC	22	on	with
GTB187	2	DEC	34	on	with
GTB188	2	INC	18	on	with
GTB189	3	INC	22	on	with
GTB190	3	DEC	20	on	with
GTB191	6	DEC	27	on	with
GTB192	6	INC	20	on	with
GTB193	10	INC	20	on	with
GTB194	10	DEC	21	on	with
WH195	0	INC	22	on	with
WH196	0	DEC	20	on	with
WH197	0	DEC	17	on	with
WH198	0	INC	22	on	with
WH199	1	INC	20	on	with
WH200	1	DEC	20	on	with
WH201	2	INC	20	on	with
WH202	2	DEC	20	on	with
WH203	3	INC	20	on	with
WH204	3	INC	20	on	with
WH205	3	DEC	20	on	with
WH206	3	INC	21	on	with
WH207	6	DEC	20	on	with
WH208	6	INC	20	on	with
WH209	10	INC	20	on	with

TABLE 2
Summary of Data Runs (cont'd)

Run No.	% Oil	Heat Flux	No. of Data Points	Auxiliary Heater	Convection Shield
WH210	10	DEC	21	on	with
TXE210	0	DEC	18	on	with
TXE211	0	DEC	12	on	with
TXE212	0	DEC	12	on	with
TXE213	0	DEC	14	on	with
TXE214	0	DEC	12	on	with
TXE215	0	INC	27	on	with
TXE216	0	DEC	14	on	with
TXE217	1	INC	27	on	with
TXE218	1	DEC	14	on	with
TXE219	2	DEC	16	on	with
TXE220	2	DEC	16	on	with
TXE221	2	INC	25	on	with
TXE222	3	DEC	15	on	with
TXE223	3	INC	22	on	with
TXE224	3	INC	24	on	with
TXE225	6	INC	30	on	with
TXE226	6	DEC	16	on	with
TXE227	6	INC	25	on	with
TXE228	10	INC	24	on	with
TXE229	10	DEC	25	on	with
TXE230	10	INC	20	on	with
THE231	0	INC	20	on	with
THE232	0	DEC	12	on	with
THE233	1	DEC	14	on	with
THE234	1	INC	24	on	with
THE235	1	INC	27	on	with
THE236	2	DEC	14	on	with
THE237	2	INC	12	on	with
THE238	2	INC	8	on	with
THE240	3	DEC	14	on	with
THE241	3	INC	18	on	with
THE242	3	INC	8	on	with
THE243	3	INC	5	on	with
THE244	3	INC	5	on	with
THE245	6	DEC	14	on	with
THE246	6	INC	24	on	with
THE247	6	INC	18	on	with
THE248	10	DEC	14	on	with
THE249	10	INC	24	on	with

failure to strictly adhere to this would result in premature nucleate boiling and the subsequent purging of the data. This initial warm-up period required a minimum of one hour to ensure adequate system performance.

Upon reaching stable conditions, the initial heat flux for the boiling tube was set by means of the resistor variac. Also, the heat flux for the auxiliary cartridge heaters was set by a second variac. The heat flux of the auxiliary cartridge heaters was limited to settings that allowed the heating of the liquid R-114 without creating excess turbulence on the boiling tube. As discussed earlier, the boiling tube was shielded from the effects of the auxiliary heater by means of the convection shield. As the oil concentration of the refrigerant-oil mixture increased, the heat-flux setting for the auxiliary heater was additionally limited to lower heat fluxes. This precluded the generated oil foam from carrying over the sides of the convection shield and interfering with the operation of the boiling tube.

After setting of the desired heat flux for the data run, the system was monitored for the vapor temperature, sump temperature and the liquid refrigerant temperature (two readings; left side and right side of the boiling tube). Control valve VC was adjusted to allow the system to reach steady-state conditions. Additionally, the liquid refrigerant temperatures were compared to ensure minimum

variance. After fulfilling the requirements of the steady-state conditions, the data-acquisition system was initiated to take data.

The data-acquisition system would scan each assigned channel, compute the heat-transfer coefficient and print the results for operator viewing. If the data were within the prescribed limits, they were stored on a floppy disk for permanent records. A representative sample of a data printout is contained in Appendix B.

After each run was completed, oil was added to the boiling section by means of a graduated cylinder through valve V1. Table 3 contains the listing of the required volume of oil added to obtain the proper mass percent of oil for each series of data runs. Mixing of the oil and refrigerant liquid was accomplished by means of the auxiliary heater, to ensure a homogeneous mixture. Foaming of the oil-refrigerant mixtures was observed over the entire heat-flux range of each data run, although carryover of the foam over the convection shield was limited to the highest heat flux. As the oil concentration increased, carryover increased, but was limited to the vertical section of the apparatus. Carryover oil was not observed in the condenser section of the apparatus. Figures 3.1 to 3.3 demonstrate the foaming action of

the oil-refrigerant mixtures at a heat flux of 37 kW/m² for oil concentrations of 0, 6 and 10 percent.

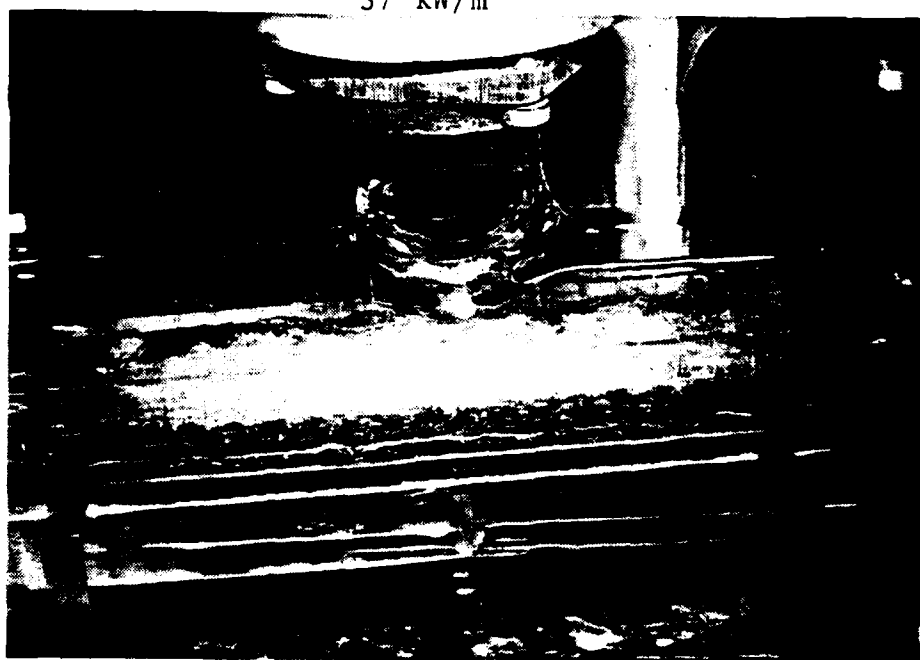
Data runs were made for each boiling tube tested with pure R-114 and followed by runs of oil-refrigerant mixtures of increasing oil content. Oil-refrigerant mixtures of 1, 2, 3, 6 and 10 percent oil by mass were used for all tubes.

TABLE 3
OIL CONCENTRATIONS VALUES

Percent Oil	Total Volume (cc) of Oil	Step Change (cc) in Volume of Oil
0	---	---
1	26.8	26.8
2	54.2	27.4
3	82.2	28.0
6	169.6	87.4
10	295.2	125.6

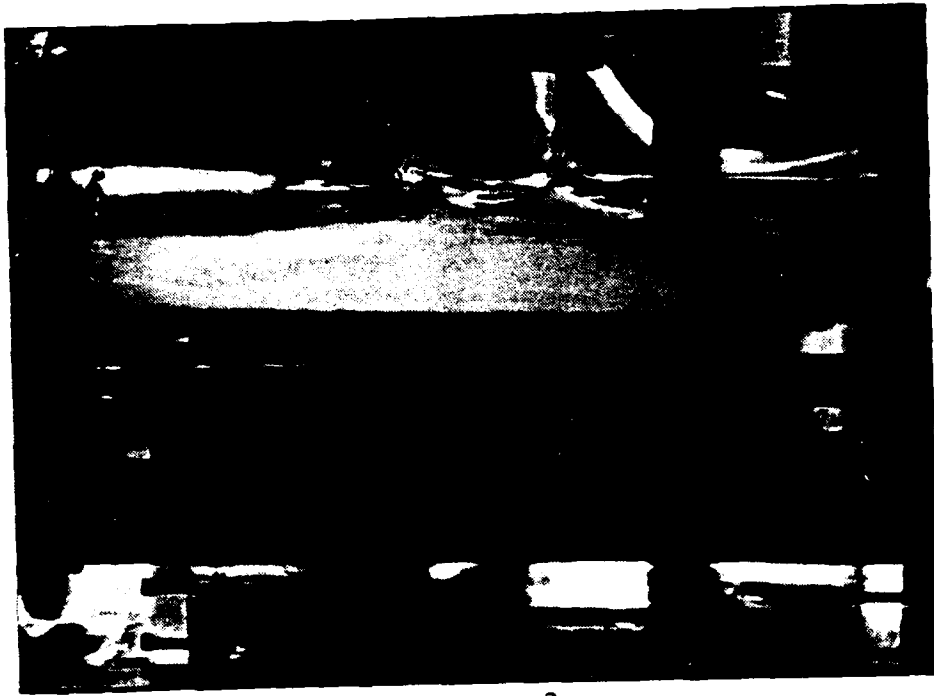


37 kW/m²



91 kW/m²

Figure 3.1 Foaming Action for Pure R-114

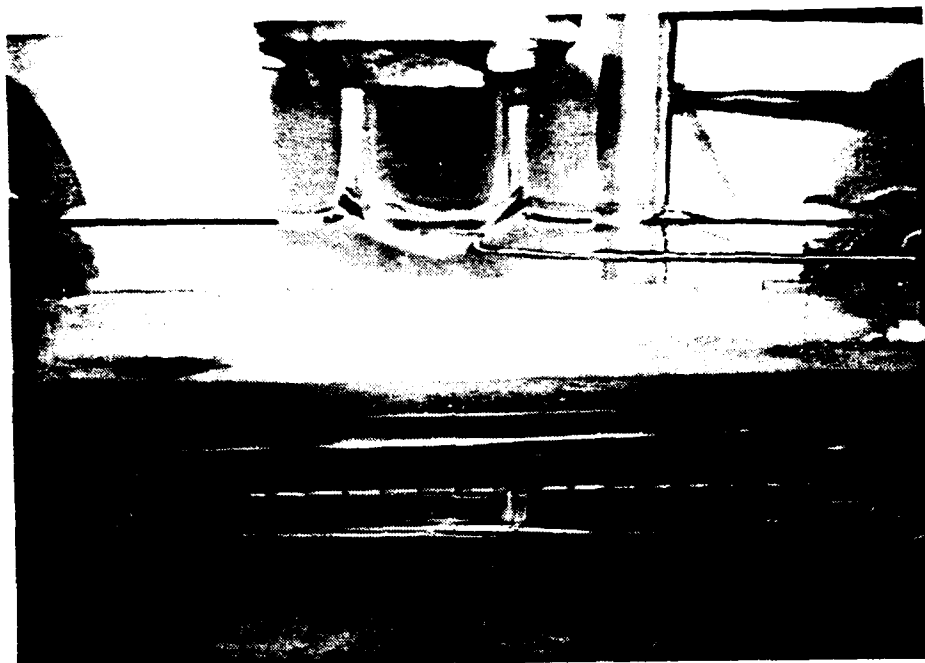


37 kW/m²



91 kW/m²

Figure 3.2 Foaming Action for R-114 with
6 Percent Oil



37 kW/m^2



91 kW/m^2

Figure 3.3 Foaming Action for R-114 with
10 Percent Oil

IV. RESULTS AND DISCUSSION

A. EFFECT OF CONVECTION SHIELD

Two sets of data runs were taken on the smooth copper tube; one set without the convection shield to validate the performance in comparison with the data obtained by Reilly (at a saturation temperature of -2.2°C) [Ref. 5]; and a second data run using the convection shield and the auxiliary cartridge heaters. These data runs allowed for an accurate comparison of the data taken over a period of time and provided justification for the use of the convection shield. As can be seen from Figures 4.1, 4.2 and 4.3, for 0, 3 and 10 percent oil concentration, respectively, the present data with and without the shield in place are essentially the same. However, as discussed in section II.C, the use of the shield provided consistent steady-state conditions over the entire range of heat fluxes and oil concentrations, thereby minimizing the efforts required by the operator.

Figure 4.1, which contains the data run for pure refrigerant for the smooth copper tube at a saturation temperature of 2.2°C , with and without the shield, demonstrates the repeatability of the data. Also plotted on this figure are Reilly's smooth-tube data for pure refrigerant at a saturation temperature of

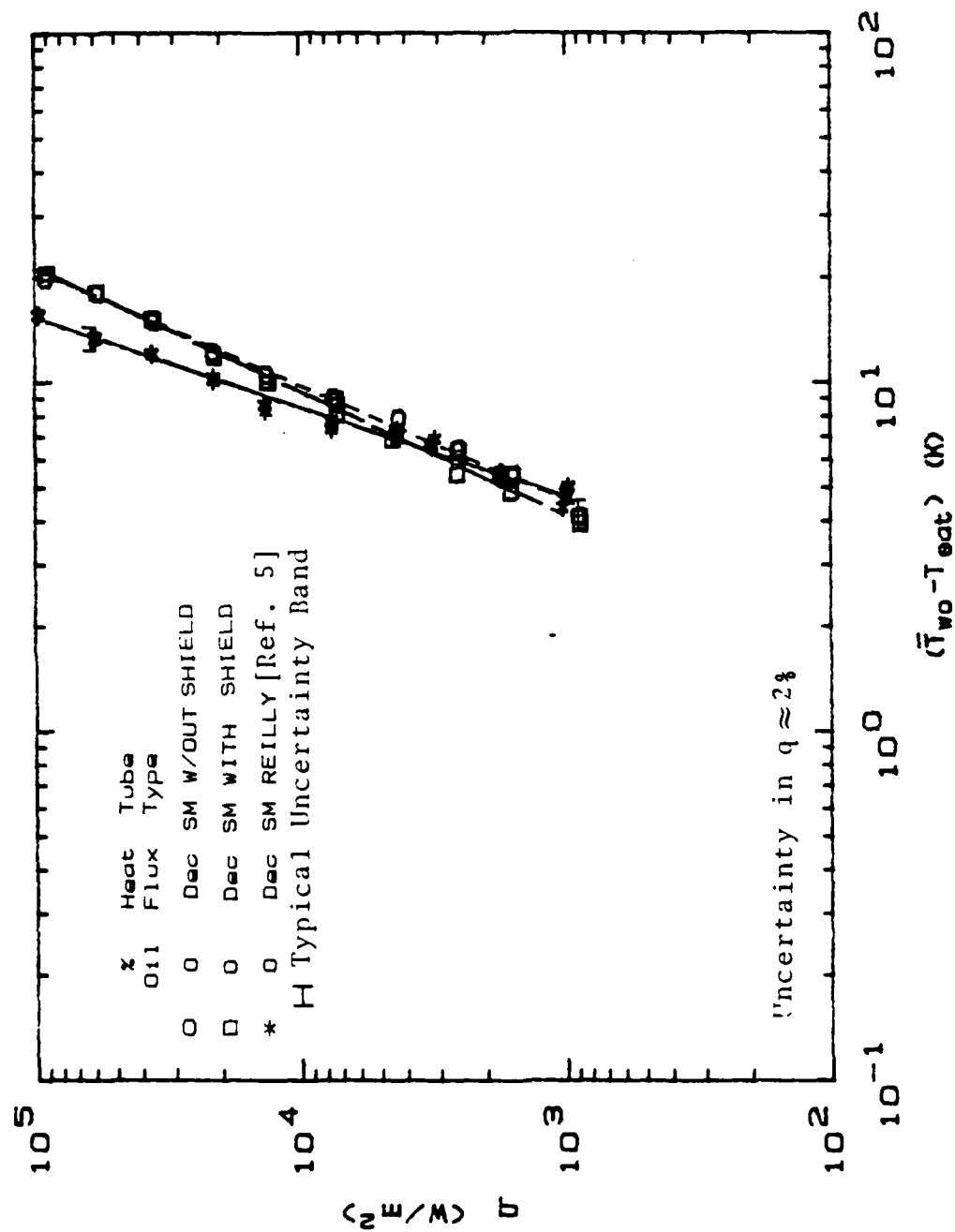


Figure 4.1 Performance Comparison for Pure R-114 Boiling from a Smooth Tube.

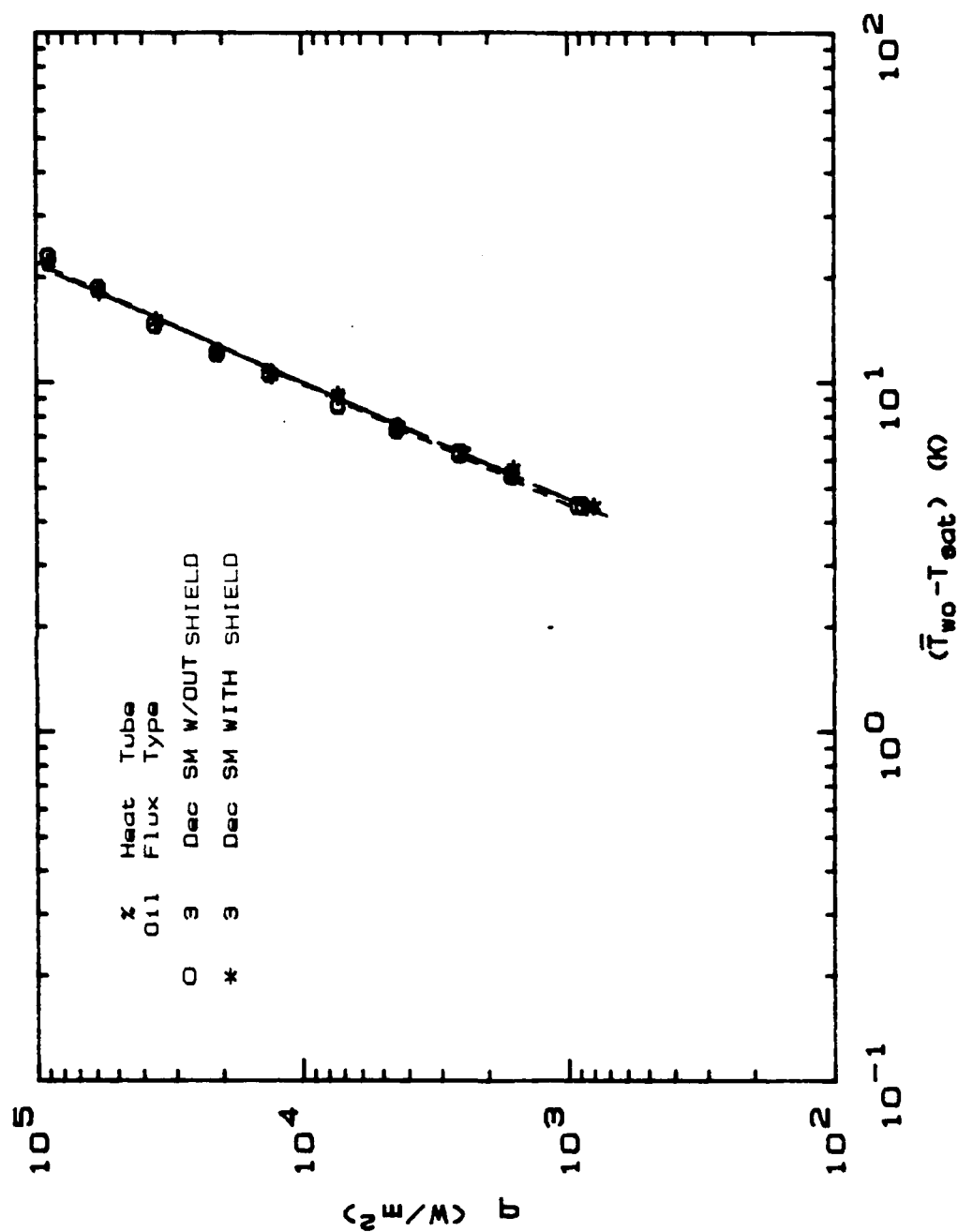


Figure 4.2 Performance Comparison for R-114 with 3 Percent Oil Boiling from a Smooth Tube.

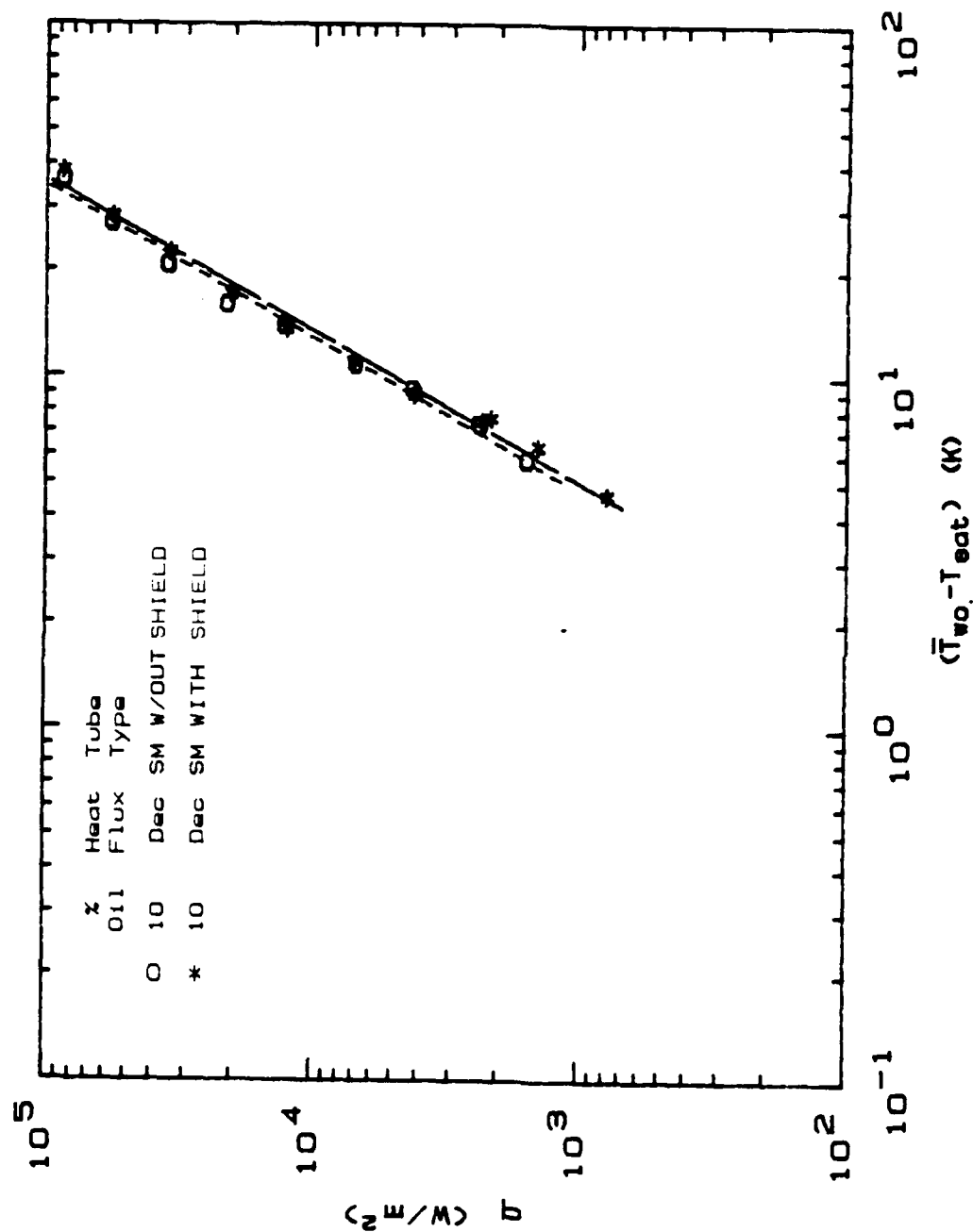


Figure 4.3 Performance Comparison for R-114 with 10 Percent Oil Boiling from a Smooth Tube.

-2.2°C. This data set represents a series of data runs, starting with a heat flux of 100 kW/m² and decreasing the heat flux to a minimum of 1 kW/m². The three sets of curves are nearly identical with the deviation between the Reilly data and the most recent data being attributed to the pressure effect and the possible aging of the tinned interface between the thermocouple sleeve and the inner surface of the smooth copper tube. The maximum discrepancy of the computed wall superheat between Reilly's data and the present data is about twenty percent at the maximum heat-flux setting. This figure also shows the typical uncertainty of about 10 percent computed for the wall superheat values during this investigation.

B. BOILING PERFORMANCE OF THE SMOOTH TUBE

Figure 4.4 shows the performance of the smooth copper tube in pure R-114 and refrigerant-oil mixtures of 3 and 10 mass percent oil. The behavior of the smooth copper tube in pure R-114 liquid demonstrates typical nucleate pool-boiling performance. As can be seen in Figure 4.4, the line between points A and B represents a region of constant slope (on a log-log scale) for the variation of heat flux with the tube wall superheat ($\bar{T}_{wo} - T_{sat}$). This section of the curve represents natural convection (i.e., no bubbles were generated).

Upon reaching point B (see Figure 4.4), the boiling tube wall superheat begins to decrease even though the heat flux is continually increased. At this point, the tube begins to demonstrate the characteristics of incipient nucleate boiling. This region is known as the mixed boiling region, where the transition from natural convection to nucleate boiling occurs. This event is characterized by the increasing number of active nucleation sites with increasing heat flux. It should be noted that during all data runs, the unheated ends of the tubes did not show any nucleation sites. Reilly [Ref. 5] also stated that the unenhanced ends of the boiling tube, at all observed heat fluxes, underwent only natural convection despite a small amount of heat axially conducted along the tube walls. It was observed that this transition from natural convection to nucleate boiling occurs very quickly, usually within a few seconds after the activation of the first nucleation site.

At the heat flux represented by point C in Figure 4.4, all the available activation sites of the boiling tube appear to be active and the wall superheat begins to increase with increasing heat flux. From point C to point D, where the heat flux is increased to a maximum of 91 kW/m², new activation sites are generated (maximum heat flux was limited by cartridge heater rated output).

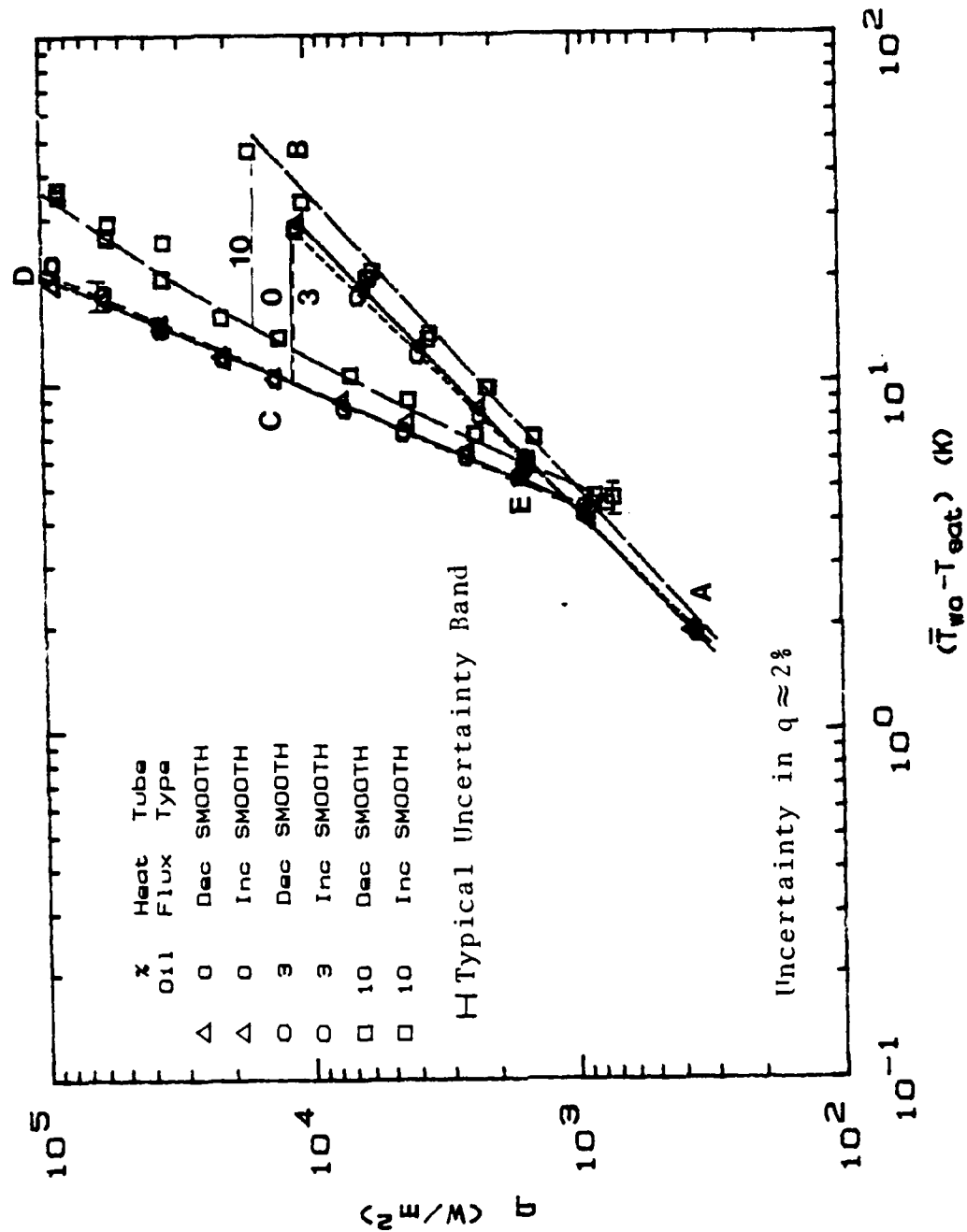


Figure 4.4 Heat-Transfer Performance for Smooth Tube in 0, 3 and 10 Percent Oil .

As the oil concentration was increased, there was a significant increase in the amount of foam generated.

After obtaining a maximum heat flux at point D, the heat flux was decreased and is represented as the region between points D and E on Figure 4.4. This region of the curve represents decreasing wall superheat; however, more activation sites that were created at the higher heat-flux settings remain active to lower heat fluxes. This increased range over which the boiling tube continues to nucleate results in an increase in the heat-transfer performance since the wall superheat temperature for the nucleate boiling at any particular heat flux is less than the tube wall superheat for the natural convection heating at the same heat flux.

Stephan [Ref. 9] reported that the effects of adding oil introduces a mass-diffusion resistance to the liquid and therefore lowers the heat-transfer coefficient. Reilly [Ref. 5], in his discussion of his smooth-tube data at a saturation temperature of -2.2°C (Figure 4.5), stated that the 3 mass percent oil and 10 mass percent oil concentrations demonstrated higher wall superheat temperature than that observed in the pure R-114 liquid. However, Reilly observed that the wall superheat for the 3 percent oil concentration was higher than that for the 10 percent oil concentration. He attributed this to the

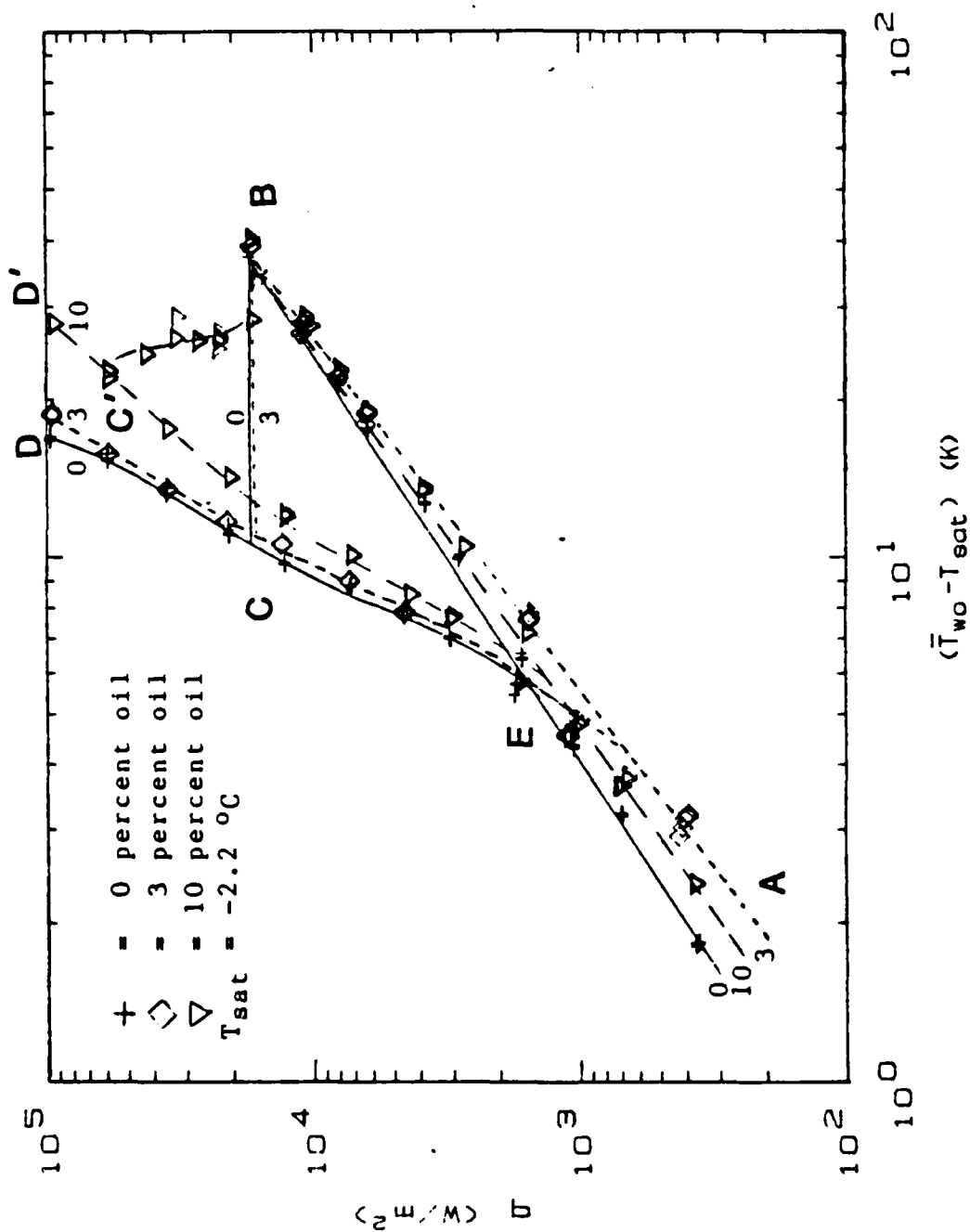


Figure 4.5 Reilly's [Ref. 5] Smooth Tube Data for 0, 3 and 10 Percent Oil.

non-linear physical property characteristics of the refrigerant-oil mixtures. As can be seen in Figure 4.4, the general trend of the data is the same with the exception of the 3 percent oil concentration wall superheat, which nearly overlays the data for pure R-114 liquid. This deviation from the Reilly data may be due in part to the difference in the saturation temperatures. The addition of oil to the pure R-114 liquid, up to a maximum of 10 percent, should delay the transition from natural convection to nucleate pool boiling on the tube. With a refrigerant-oil mixture of 10 mass percent oil, it was observed that the surface nucleation sites did appear to spread more slowly as the heat flux was increased. This condition continued until the tube was fully engulfed in the nucleate boiling mode. This observation was also noted by Reilly [Ref. 5] and it agrees with the contention of Chongrungreong and Sauer [Ref. 8] and Thome [Ref. 6] that, with the exception of the surface tension, the non-linear variations in the physical properties of the refrigerant-oil mixtures explain the variation in the boiling heat transfer of the tube.

Figure 4.6 shows the heat-transfer coefficient of the smooth tube in refrigerant-oil mixtures, plotted as a function of heat flux. Figure 4.7 shows the same plot for Reilly's data for a saturation temperature of -2.2°C

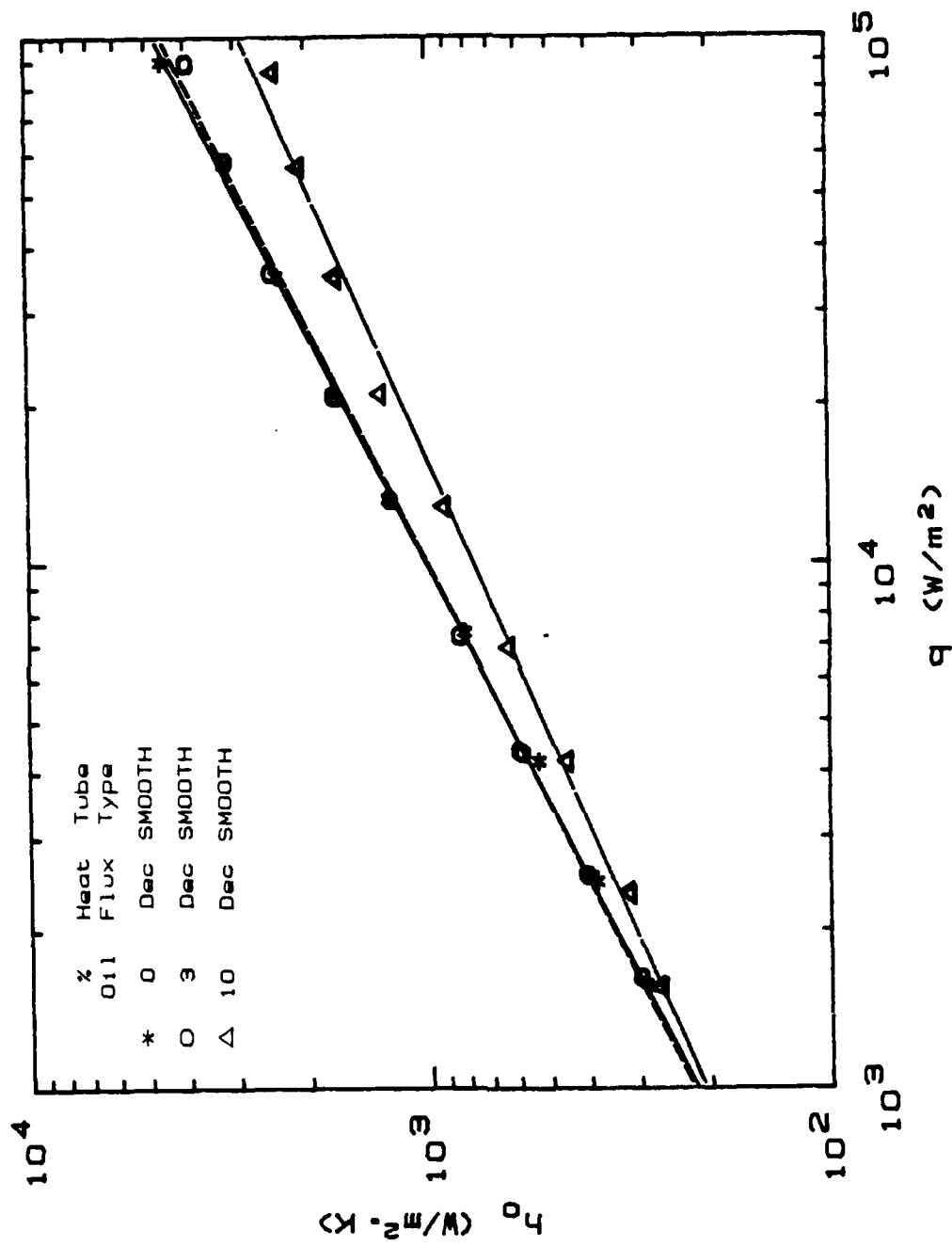


Figure 4.6 Boiling Heat-Transfer Coefficient for Smooth Tube.

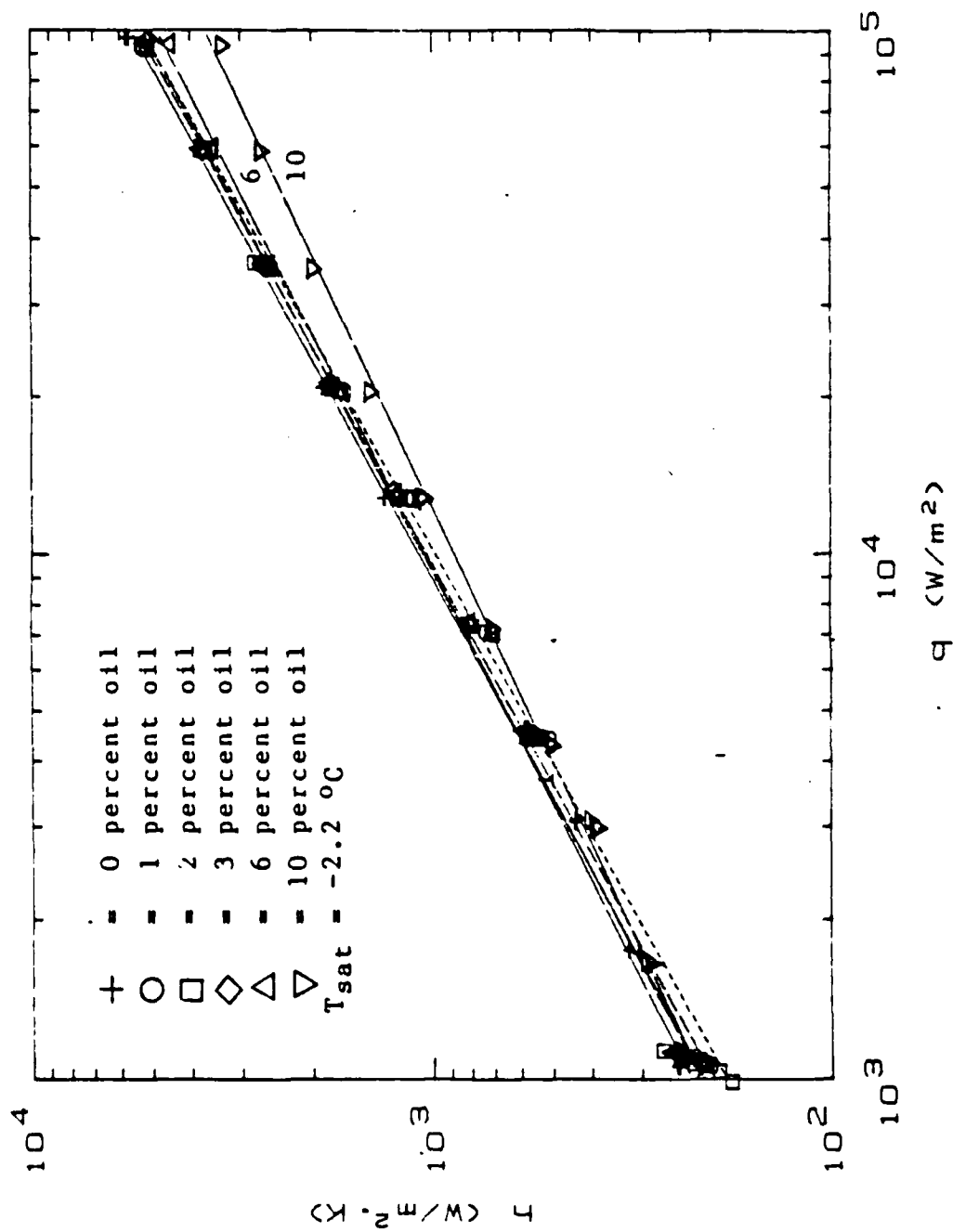


Figure 4.7 Boiling Heat-Transfer Coefficient for
 Reilly's Smooth Tube Data [Ref. 5]

[Ref. 5]. As can be seen, the two graphs are nearly identical, representing good repeatability of the data. Also, the effect of the addition of up to 6 percent oil (Figure 4.7) consistently represents an approximate decrease of 10 percent in the heat-transfer coefficient. As the oil concentration was increased from 6 to 10 percent, the decrease in the heat-transfer coefficient was a maximum of about 35 percent. These decreases in the heat-transfer coefficients were dependent on the comparison of the pure R-114 and the 10 percent oil concentration at equal heat-flux settings.

C. BOILING PERFORMANCE OF THE GEWA-T TUBE

Figure 4.8 shows the nucleate pool-boiling performance of the GEWA-T (1.02 fins/mm) tube in R-114-oil mixtures. The magnitude of the tube-wall superheat was considerably less than the values obtained for the smooth tube discussed in Section IV.B. This lower wall superheat can be attributed to the specially formed fins of the GEWA-T tube. The performance of the GEWA-T tube is similar to that of the smooth tube with the curves of the increasing heat flux to the point of incipient nucleate boiling (point B), paralleling the performance of the smooth copper tube (Figure 4.4). The same condition exists throughout the entire range of decreasing heat fluxes.

The region bounded by points A and B shows the characteristic natural-convection heating behavior. The onset of incipient nucleate boiling at point B is clearly defined for the pure R-114 liquid. However, as the oil concentration was increased, the point of incipient nucleate boiling becomes less clearly defined and the region of mixed boiling (point B to C) increased with increased heat flux. It was also observed that in the region from A to B, the 3 percent oil mixture showed the smallest wall superheat and the pure refrigerant showed the highest wall superheat. The reason for this behavior is not fully known at present, but may be due to convection effects within the channels of the GEWA-T tube which are enhanced by the foaming action in the presence of oil.

The region bounded by the points C and D for the increasing heat-flux condition is indicative of fully developed nucleate pool boiling. The region between points D and E represents nucleate pool boiling for decreasing heat flux. Figure 4.8 shows that, as the oil concentration was increased, the wall superheat increased at a given heat flux. This is contrary to the results for the condition of increasing heat flux in the region of natural-convection heating.

When comparing the performance of the smooth tube (Figure 4.4) to that of the GEWA-Tube (Figure 4.8), the

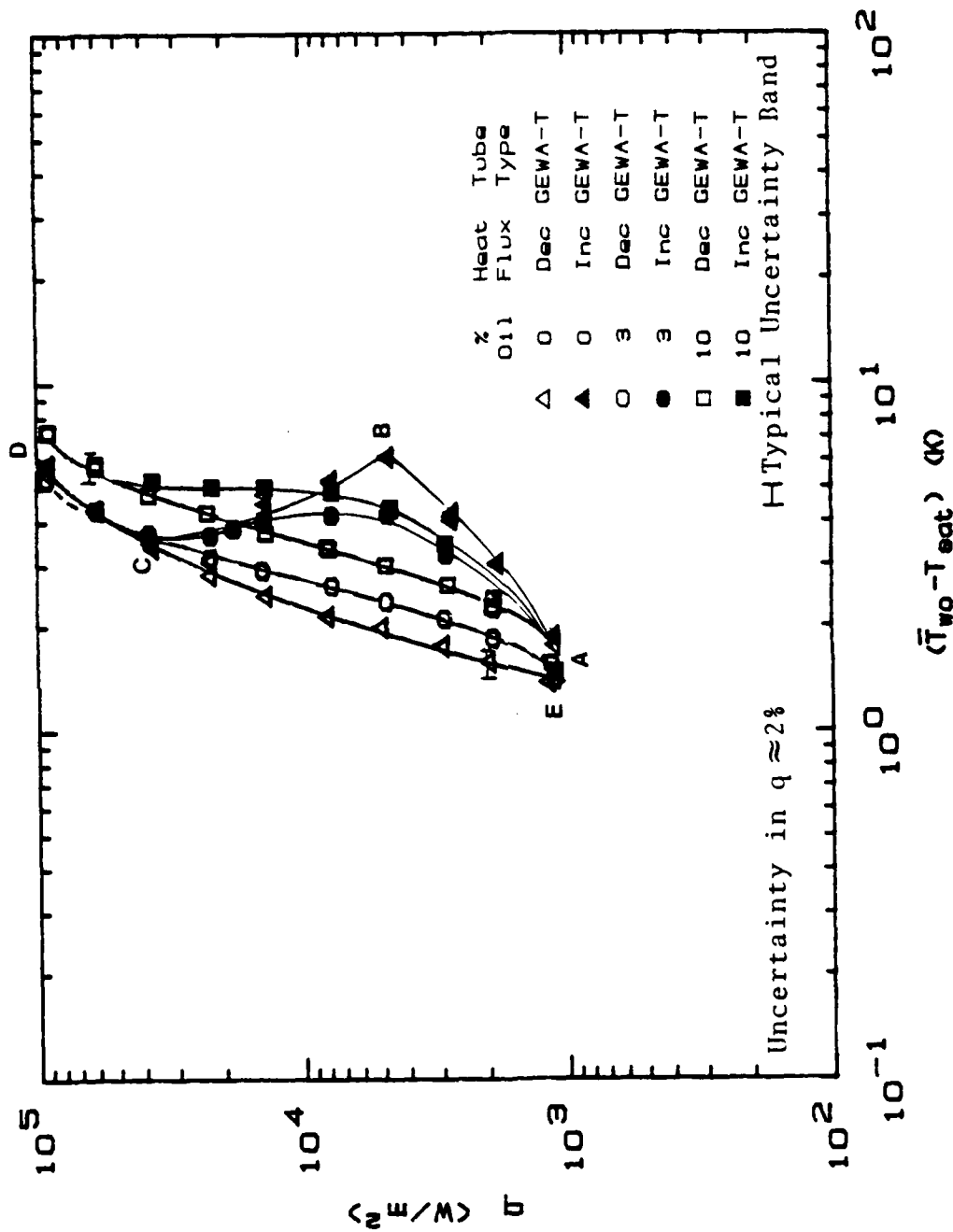


Figure 4.8 Heat-Transfer Performance for GEWA-T Surface.

maximum adverse effect of the increased oil content for the smooth tube, occurs at the higher heat-flux settings. For the GEWA-T tube, the maximum decrease in the tube performance for increased oil content, occurs in the lower and intermediate heat-flux range.

Figure 4.9 shows the heat-transfer coefficient as a function of heat flux over the range of R-114-oil mixtures (0, 1, 2, 3, 6 and 10 percent oil). Data observed over the range of R-114-oil mixtures of 1, 2, 3 and 6 percent oil are nearly coincident. The 10 percent oil concentration data represent an approximate 30 percent reduction of the heat-transfer coefficient when compared to the heat-transfer coefficient obtained during the data for pure R-114. Figure 4.10 shows the direct comparison of the GEWA-T tube with the smooth tube for R-114-oil mixtures of 0, 3 and 10 percent oil. The GEWA-T tube represents an overall enhancement of 4.2 over the baseline smooth copper tube at a heat flux of 40 kW/m^2 with pure R-114 and an overall enhancement of 3.8 with 10 percent oil. These results compare favorably with the results of Yilmaz, Hwalek and Westwater [Ref. 18] for a 12.3-mm OD GEWA-T tube in p-xylene, in which they obtained an enhancement of 5.3 in the pool-boiling heat-transfer coefficient over their baseline smooth copper tube. Additionally, Yilmaz and Westwater [Ref. 12] tested a similar surface in isopropyl

alcohol in which an enhancement of 2.0 was observed. Marto and Lepere [Ref. 13] tested a 17.9-mm OD GEWA-T surface in both R-113 and FC-72 and reported enhancements of 2.8 and 2.5, respectively.

Figure 4.11 shows more clearly the degradation that oil causes in the boiling heat-transfer performance for the GEWA-T tube. This figure plots the heat-transfer coefficient of the GEWA-T tube in the oil mixture relative to the heat-transfer coefficient in pure R-114 as a function of oil concentration. From the shape of the curves, the oil-caused degradation does not show a clear trend with the oil concentration at all practical heat fluxes. Over the range of oil concentrations, except at a heat flux setting of 37 kW/m², there is only a small degradation (up to a maximum of 35%) in the boiling performance. This is probably due to the large channels and reentrant cavities in the tube, allowing the "pumping" action of the bubbles to continue to remove the oil-rich liquid throughout the entire heat-flux range without a significant reduction in performance. The only significant decrease in performance occurred at heat fluxes greater than 5 kW/m² with 10 percent oil.

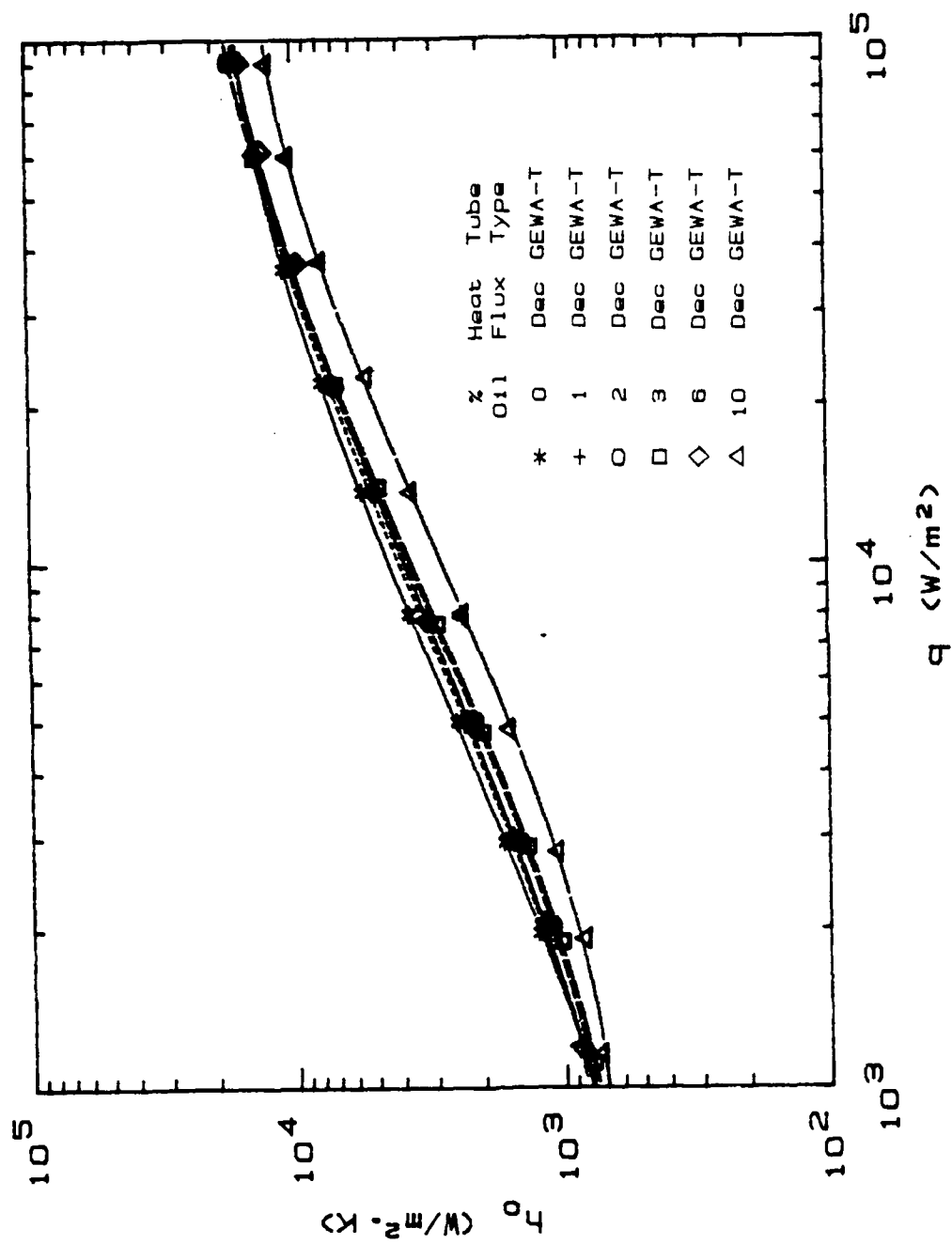


Figure 4.9 Boiling Heat-Transfer Coefficient for GEWA-T Surface.

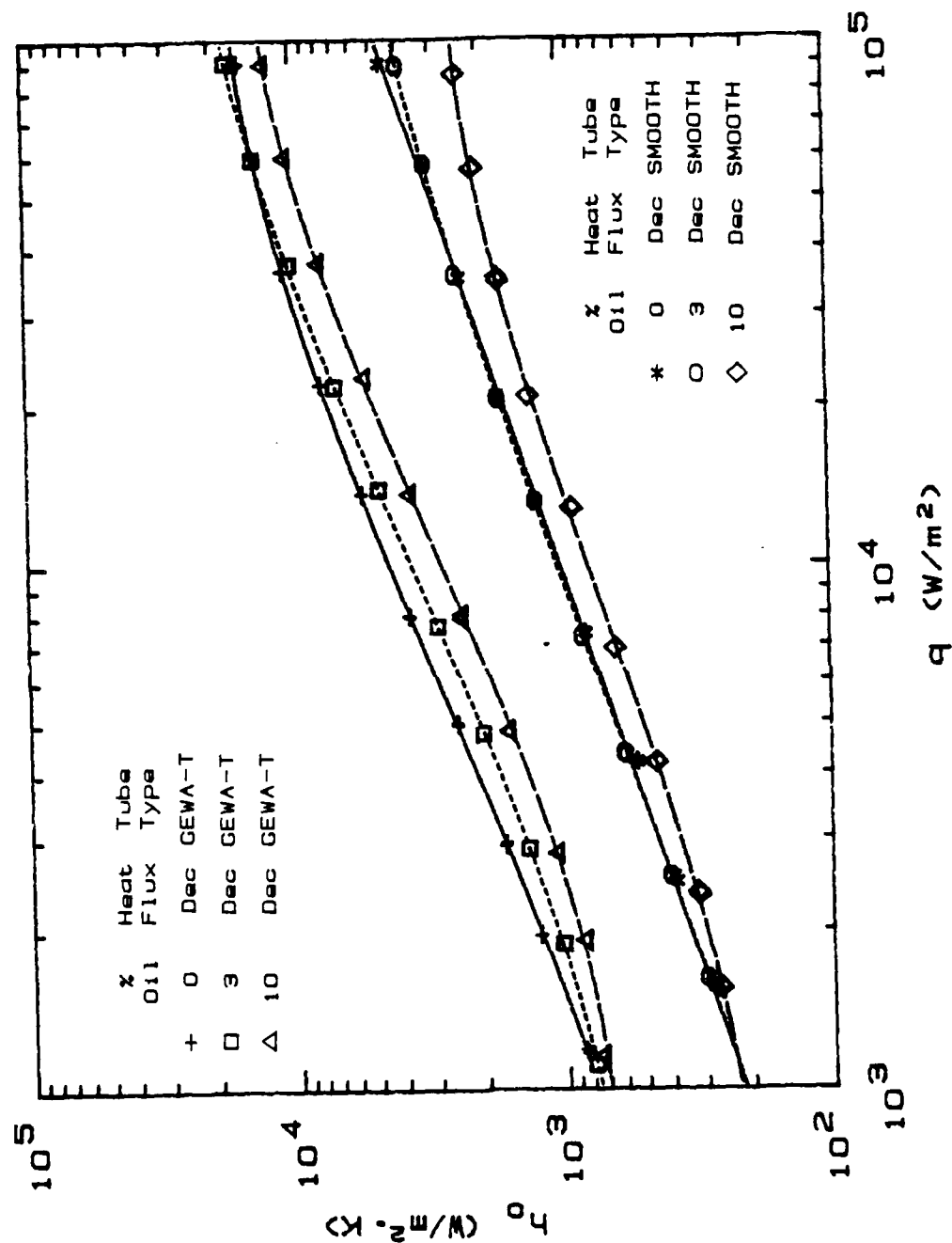


Figure 4.10 Boiling Heat Transfer Coefficient Comparison for GEWA-T Surface and Smooth Surface .

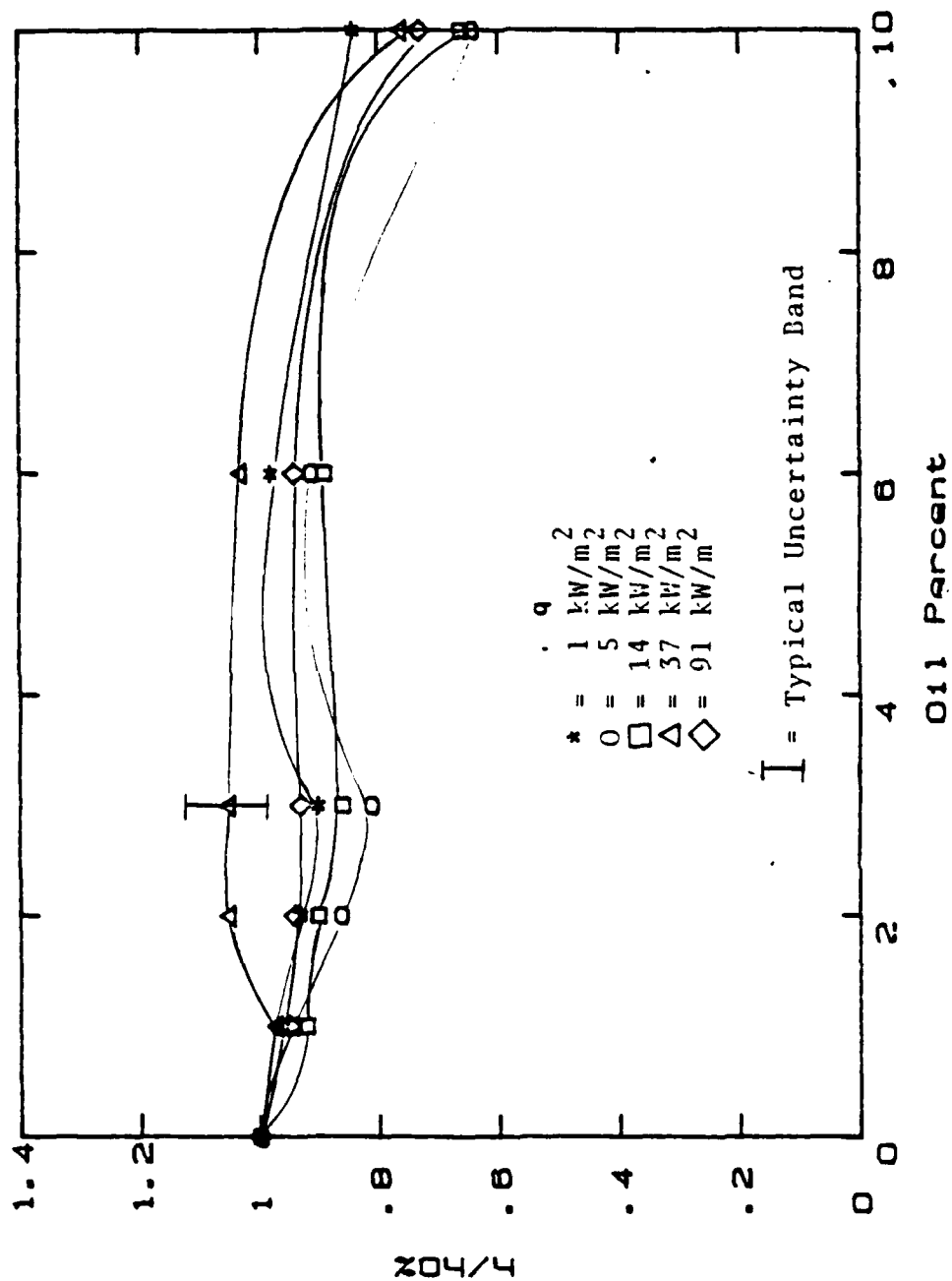


Figure 4.11 Relative Effect of Oil on GEWA-T Boiling Heat-Transfer Performance.

D. BOILING PERFORMANCE OF THE THERMOEXCEL-E TUBE

Figure 4.12 shows the nucleate pool-boiling performance of the Thermoexcel-E tube in R-114-oil mixtures. As can be seen in the figure, the region of natural-convection heating for the condition of increasing heat flux, points A to B, for the pure R-114 is very small, with the point of incipient nucleate boiling occurring at a reasonably low heat flux (1.5 kW/m^2). At this point of incipient nucleate boiling, the tube performs in the mixed boiling region as a limited number of nucleation sites become active. From point C to C', the tube appears to operate in more of a natural-convection heating mode as no new nucleation sites are activated, although previously activated sites continue to nucleate. This phenomenon is probably due to the inability of the cartridge heaters to produce uniform heat flux at these lower settings. At point C' with a heat-flux setting of 5 kW/m^2 , more nucleation sites are generated and as the heat flux is increased to 60 kW/m^2 , the tube becomes fully nucleated.

For the 3 percent oil concentration, the point of incipient nucleate boiling, point B', decreases as the non-linear physical properties of the R-114-oil mixture allow the onset of the mixed boiling region to occur. Also, the region of the mixed boiling, point B' to D', is

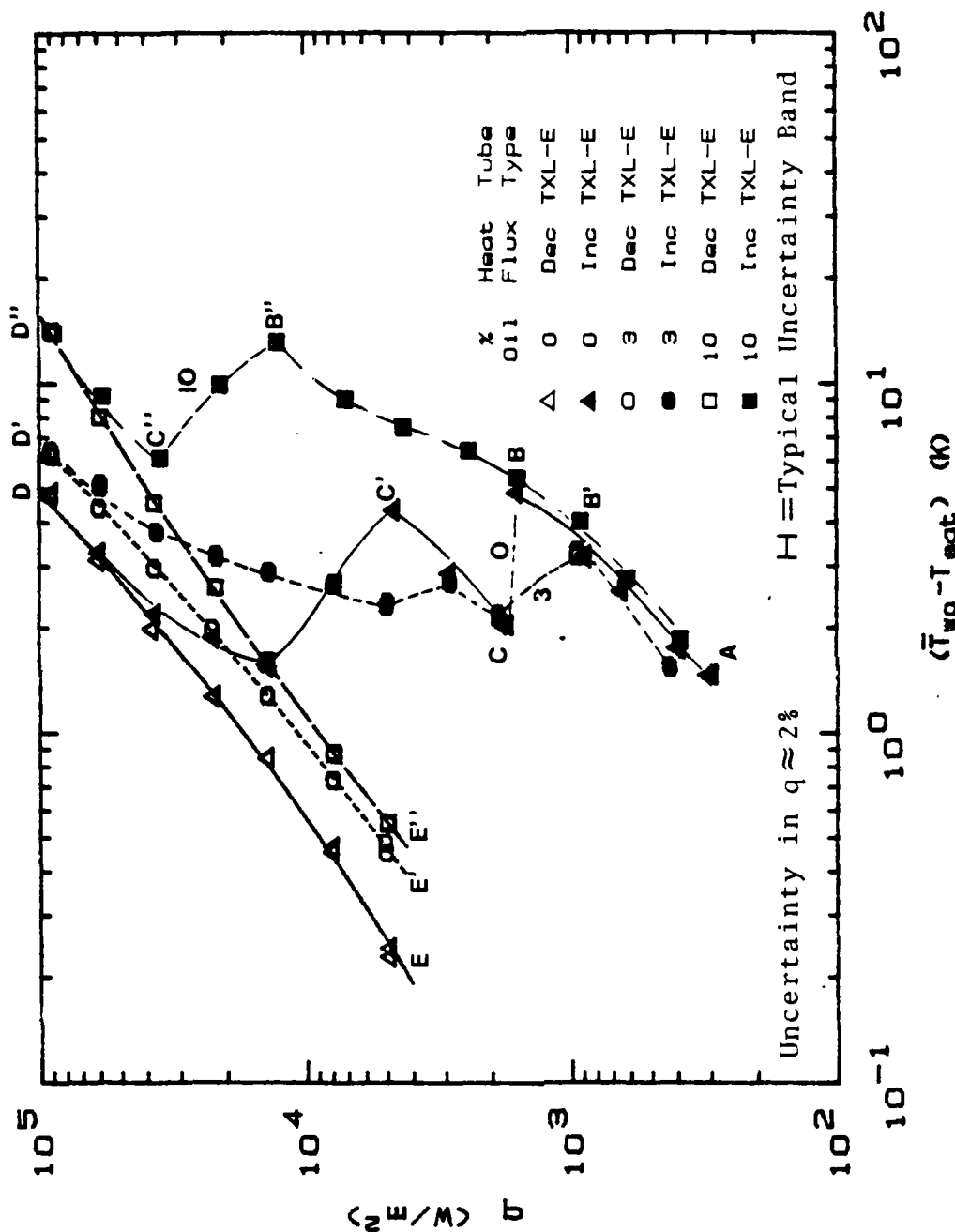


Figure 4.1.2 Heat-Transfer Performance for Thermoexcel-E Surface.

far larger than that for pure R-114, as the generation of new nucleation sites is retarded by the increased oil content.

For the 10 percent oil concentration, on the other hand, the point of incipient nucleate boiling, point B'', is delayed considerably. At approximately 14 kW/m², the transition from natural-convective heating to nucleate boiling occurs. The exact reason for the difference between the 3 percent and 10 percent behavior is not known, however it is possibly due to the change in the physical properties of the R-114-oil mixture.

The region of nucleate pool boiling for the condition of decreasing heat flux represented by points D to E, D' to E' and D'' to E'' for 0, 3 and 10 percent oil concentrations, respectively, for the Thermoexcel-E tube, represent classic nucleate pool-boiling characteristics. As the oil concentration increases, the wall superheat also increases throughout the range of heat-flux settings. At the lower heat fluxes, the largest increase in the wall superheat occurred at 3 percent oil concentration when compared to the pure R-114, while the 10 percent oil concentration was observed to undergo continual degradation in tube performance over the entire range of heat-flux settings, although a more noticeable reduction occurred at the higher heat fluxes. At a heat-flux setting of 91

kW/m^2 , the R-114-oil mixture of 10 percent oil was observed to undergo a reduction in tube performance by a factor of 3. For the practical heat-flux range of 30 to 40 kW/m^2 , there is an increase in wall superheat by factors of 1.4 and 2.6 for R-114-oil mixtures of 3 and 10 percent, respectively.

Figure 4.13 shows the heat-transfer coefficient of the Thermoexcel-E tube in refrigerant-oil mixtures, plotted as a function of heat flux. As can be seen in the figure, the heat-transfer coefficient remains nearly constant throughout the range of heat-flux settings for pure R-114, while there are slight reductions for the 1, 2 and 3 percent oil concentrations. Additionally, it can be seen that at these lower oil concentrations, the heat-transfer coefficients are nearly coincident. As the R-114-oil mixture oil concentration is increased to 6 percent, the tube performance increases with increasing heat flux until reaching a heat-flux setting of 60 kW/m^2 , at which time tube performance begins to deteriorate. This is contrary to the tube performance for 0, 2, and 3 percent oil concentrations in which the heat-transfer coefficient was observed to increase slightly over the range of heat fluxes. For the 10 percent oil concentration, the heat-transfer coefficient decreased as the heat flux was increased.

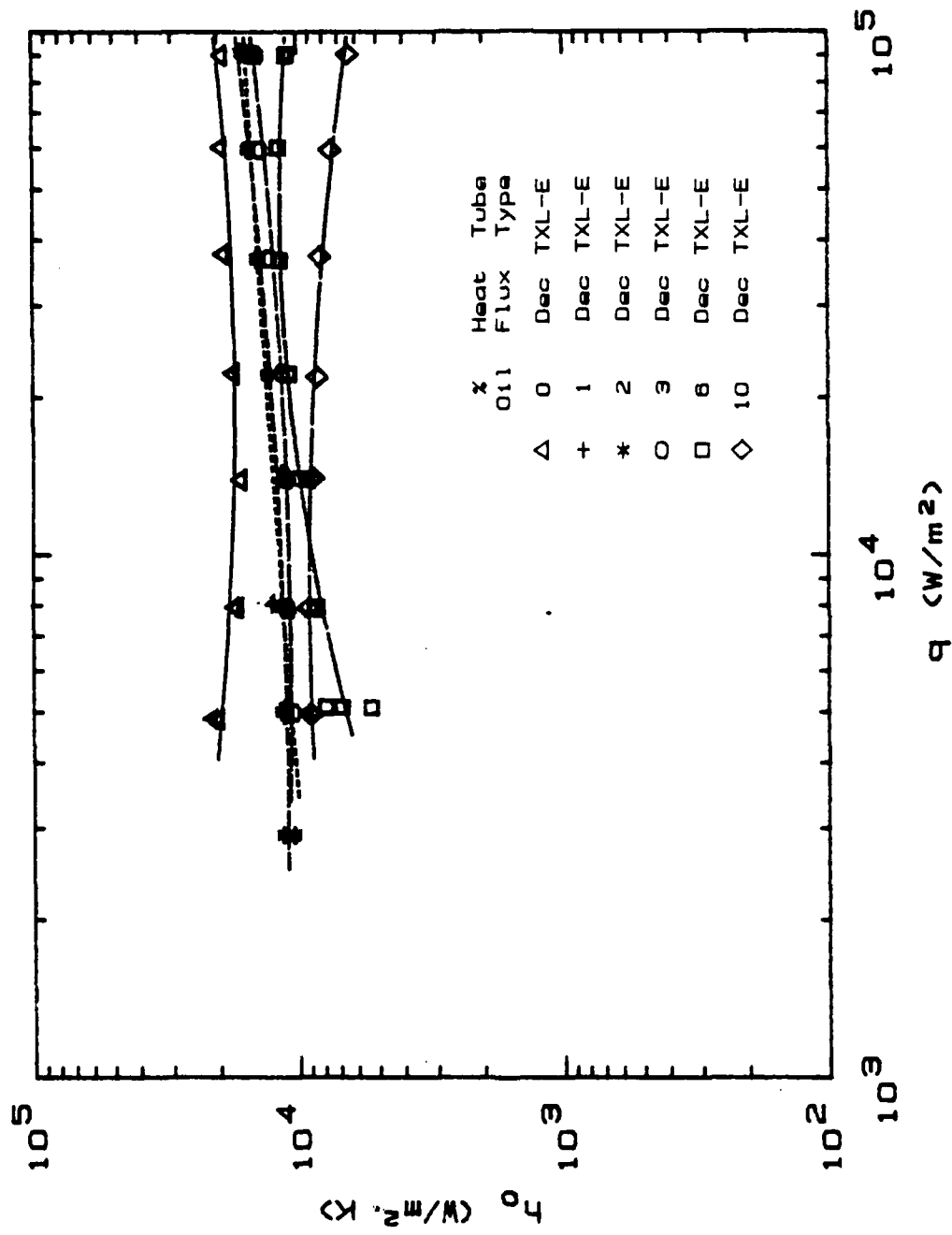


Figure 4.13 Boiling Heat-Transfer Coefficient for Thermoexcel-E Surface .

Figure 4.14 shows a direct comparison of the Thermoexcel-E tube to the smooth copper tube for R-114-oil mixtures of 0, 3 and 10 percent. The Thermoexcel-E tube presents enhancements of 6.6 and 4.1 over the performance of the smooth copper tube in pure R-114 and an R-114-oil mixture of 10 percent oil, respectively, at a heat-flux setting of 40 kW/m^2 . The results for the pure R-114 compare favorably with the results obtained by Yilmaz, Palen and Taborek [Ref. 19] for the Thermoexcel-E in p-xylene.

Figure 4.15 shows the degradation that oil causes in the boiling heat-transfer performance for the Thermoexcel-E tube. This figure plots the ratio of the heat-transfer coefficient of the Thermoexcel-E tube with oil to the value without oil as a function of oil concentration. The shapes of the curves continue to demonstrate the non-linear variation of the physical properties of refrigerant-oil mixtures. However, the significant degradation of the tube performance is probably due to the inability of the generated bubbles to scavenge the interior tunnels of the Thermoexcel-E tube. This is in contrast to the GEWA-T tube, where more scavenging is possible due to its larger channel size.

E. BOILING PERFORMANCE OF THE THERMOEXCEL-HE TUBE

Figure 4.16 shows the nucleate pool-boiling performance of the Thermoexcel-HE tube in R-114-oil

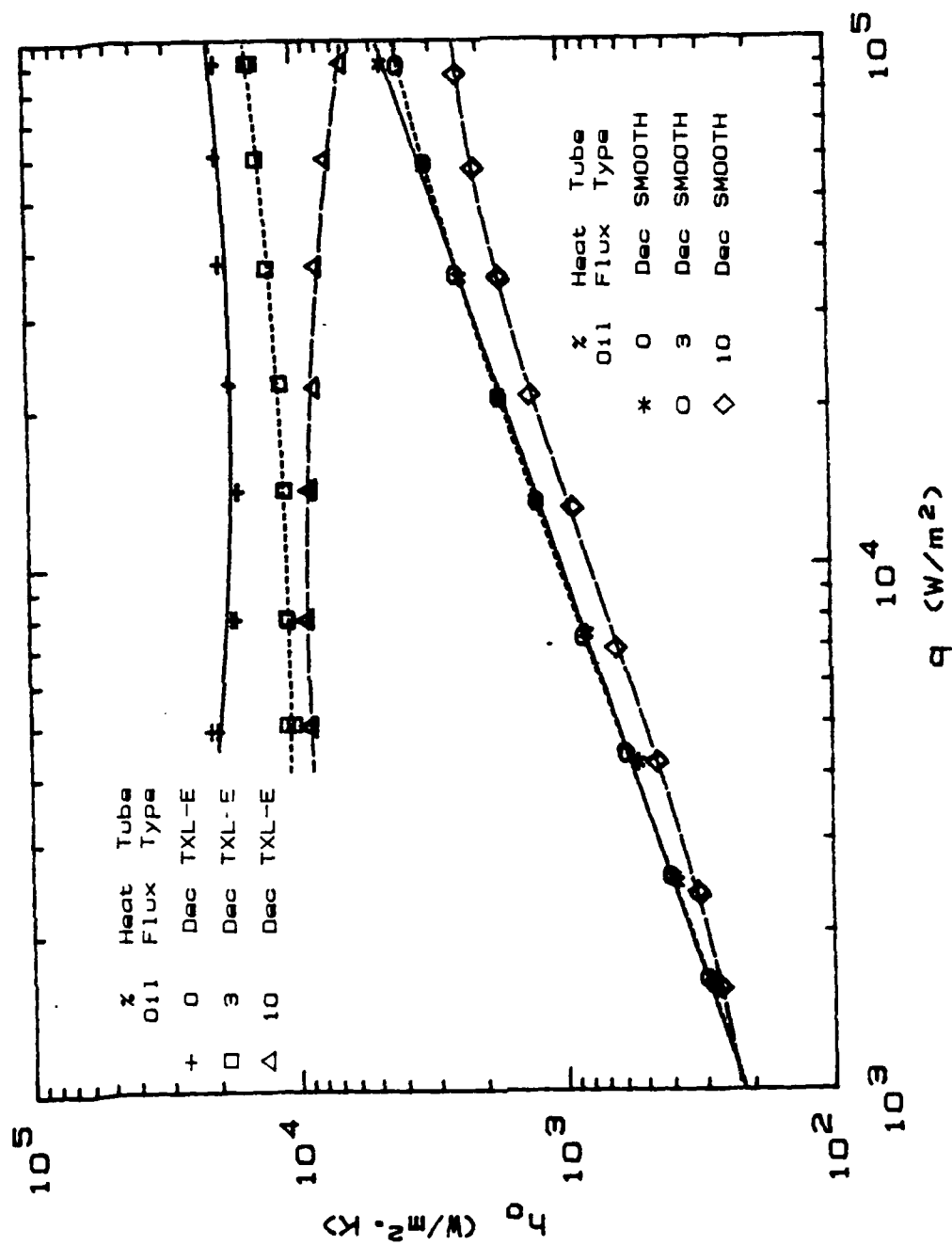


Figure 4.14 Boiling Heat-Transfer Coefficient for Thermoexcel-E vs. Smooth Surface.

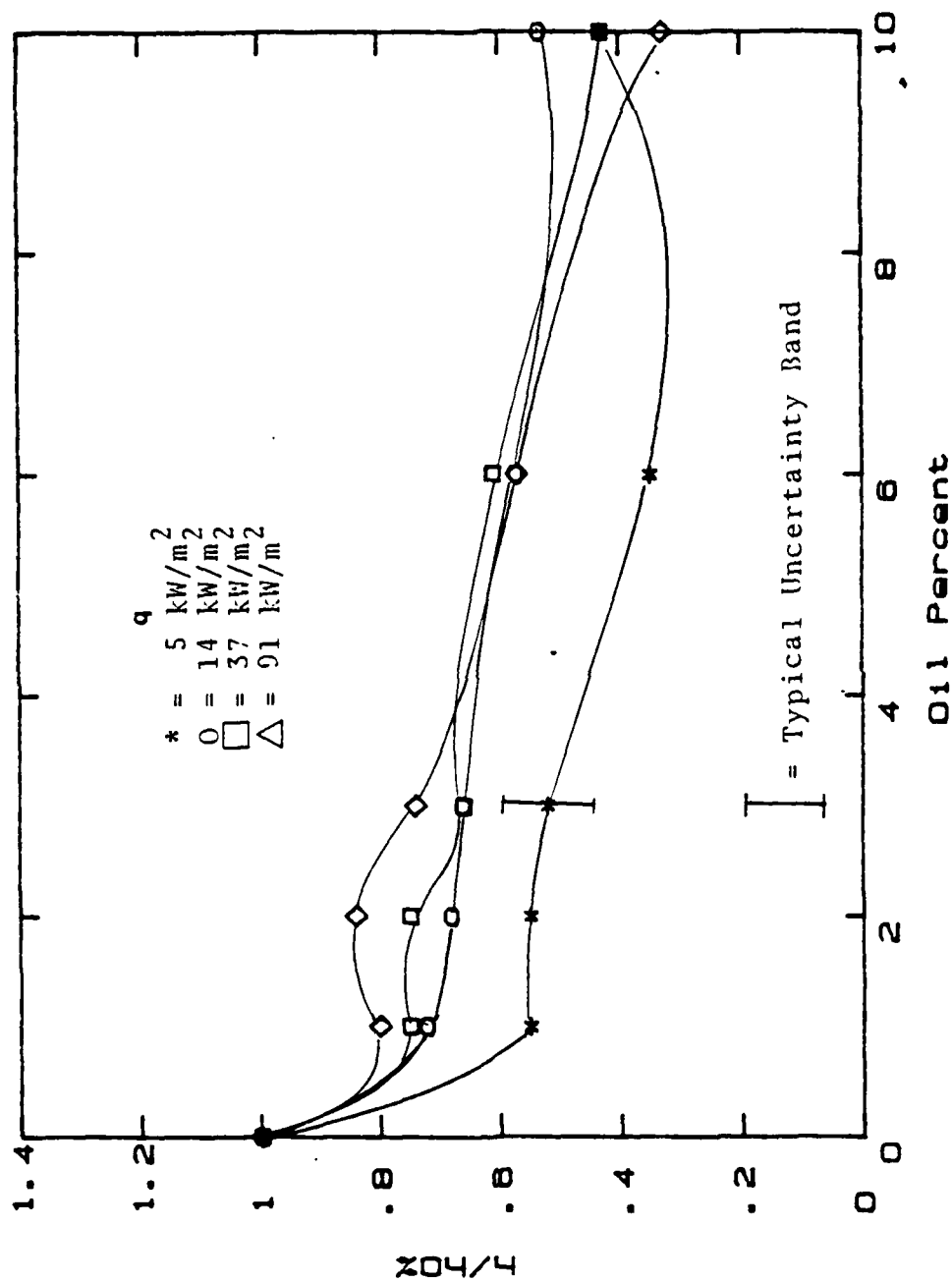


Figure 4.1.5 Relative Effect of Oil On Thermoexcel-E Boiling Heat-Transfer Performance.

mixtures. In the region between points A and B/B', natural-convection heating occurs for increasing heat flux. Although similar in performance to the Thermoexcel-E tube, the Thermoexcel-HE tube presented a more linear characteristic than that of the Thermoexcel-E tube, representing a more uniform heat distribution. At point B on the figure, the point of incipient nucleate boiling for pure R-114 liquid occurs at approximately 2 kW/m². For R-114-oil mixture of 3 and 10 percent oil concentrations, the point of incipient nucleate boiling, point B', occurs at approximately 8 kW/m². Also in this region, the pure R-114 and the R-114-oil mixture of 3 percent oil concentration are nearly coincident in the range of heat flux from 500 W/m² to 2 kW/m².

From points B to C, the Thermoexcel-HE tube in the pure R-114 liquid achieved full nucleate boiling at approximately 37 kW/m², with intermediate data points in the region of mixed boiling. These intermediate data points indicate that the Thermoexcel-HE tube was not able to activate all nucleation sites simultaneously for increasing heat-flux conditions. The R-114-oil mixture of 10 percent oil was able to achieve activation of all nucleation sites upon reaching 22 kW/m², without any data points contained in the mixed boiling region. With 3 percent oil, the Thermoexcel-HE tube was able to achieve

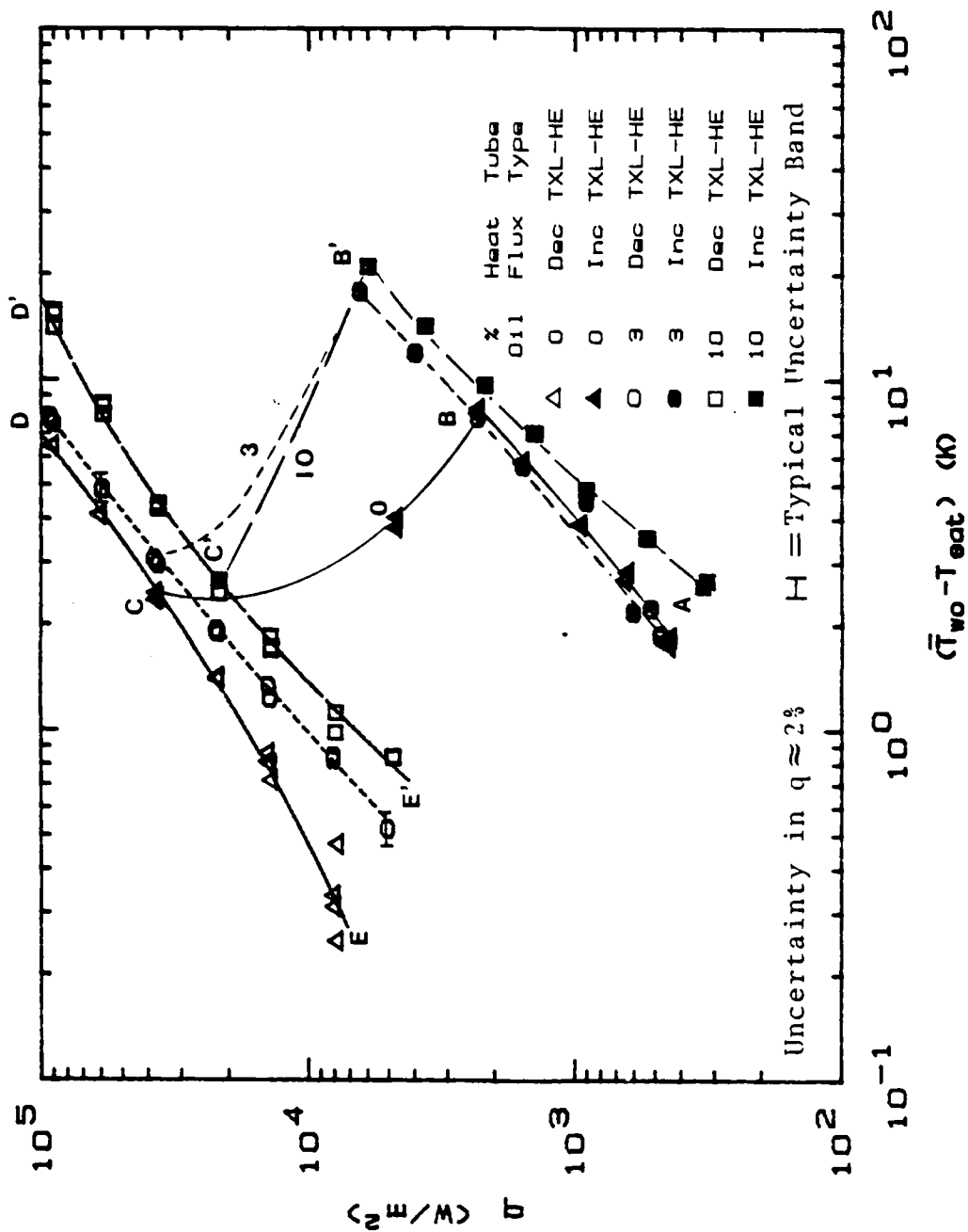


Figure 4.16 Heat-Transfer Performance for Thermoexcel-HE Surface .

full nucleate boiling at 37 kW/m^2 . The Thermoexcel-HE tube in the R-114-oil mixtures appeared to activate all nucleation sites simultaneously.

The region from points C to D and from C' to D' represent the nucleate pool boiling for increasing heat flux. The performance of the Thermoexcel-HE tube in this region appears to decrease as the oil content was increased. The 10 percent oil concentration increased the wall superheat by a factor of approximately 2 above the wall superheat for the pure R-114 liquid for heat-flux settings of 40 kW/m^2 .

The regions between the points D and E and D' and E' represent nucleate pool-boiling for decreasing heat-flux conditions. As can be seen from the figure, the greatest reduction in performance occurs in the lower heat-flux settings between the pure R-114 and the 3 percent oil concentration. This is similar to the results for the Thermoexcel-E tube, where the tube performance decreased as oil content increased. There is a significant decrease in the Thermoexcel-HE tube performance over the range of heat-flux settings as the oil concentration is increased to 10 percent.

Figure 4.17 shows the heat-transfer coefficient of the Thermoexcel-HE tube in refrigerant-oil mixtures, plotted as a function of heat flux. As can be seen, the performance is very similar to that of the Thermoexcel-E

tube (Figure 4.13). As was observed for the Thermoexcel-E tube, the Thermoexcel-HE tube undergoes a slight reduction in the heat-transfer coefficient as the oil concentration was increased from 1 to 3 percent. As the oil concentration is increased to 6 and 10 percent oil, the performance reduction is quite noticeable. With the 10 percent oil concentration, tube performance decreases at both the lower and higher heat-flux settings. This is contrary to the findings for the Thermoexcel-E tube where the performance decreased over the entire range of heat-flux settings, from low heat flux to high heat-flux settings.

Figure 4.18 shows a comparison of the Thermoexcel-HE tube to the smooth copper tube at R-114-oil mixtures of 0, 3 and 10 percent oil concentrations. The Thermoexcel-HE tube displayed an enhancement of 6.1, 4.6 and 4.1 at a heat flux setting of 40 kW/m^2 and R-114-oil mixtures of 0, 3 and 10 percent oil, respectively, over the same parameters for the smooth copper tube. These results are nearly identical to those found for the Thermoexcel-E tube.

Figure 4.19 shows the degradation that the oil has on the boiling heat-transfer performance of the Thermoexcel-HE tube. At the lower heat fluxes, the effect of the oil concentration is slightly more pronounced than that observed for the Thermoexcel-E tube throughout the range of

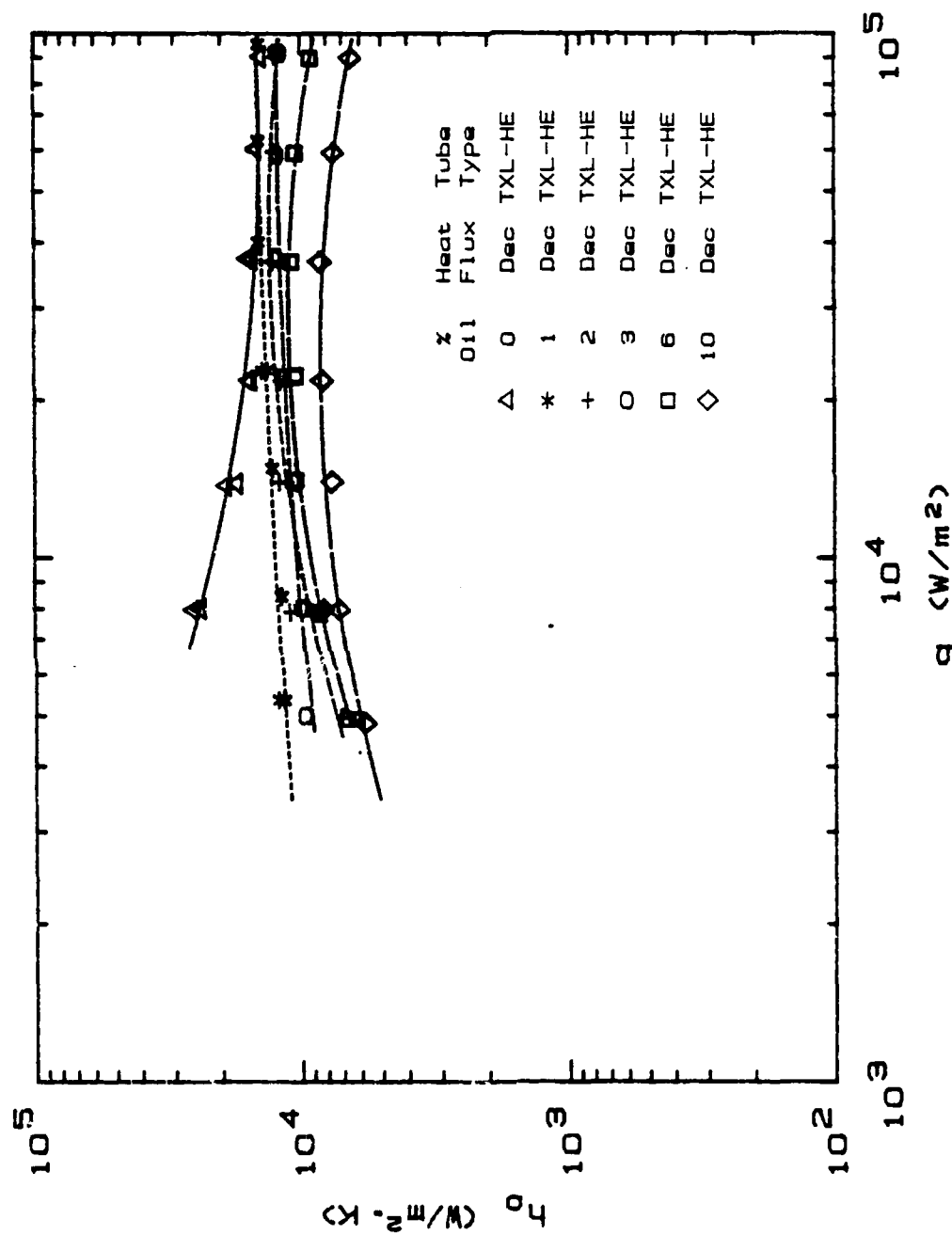


Figure 4.17 Boiling Heat-Transfer Coefficient for Thermoexcel-HE.

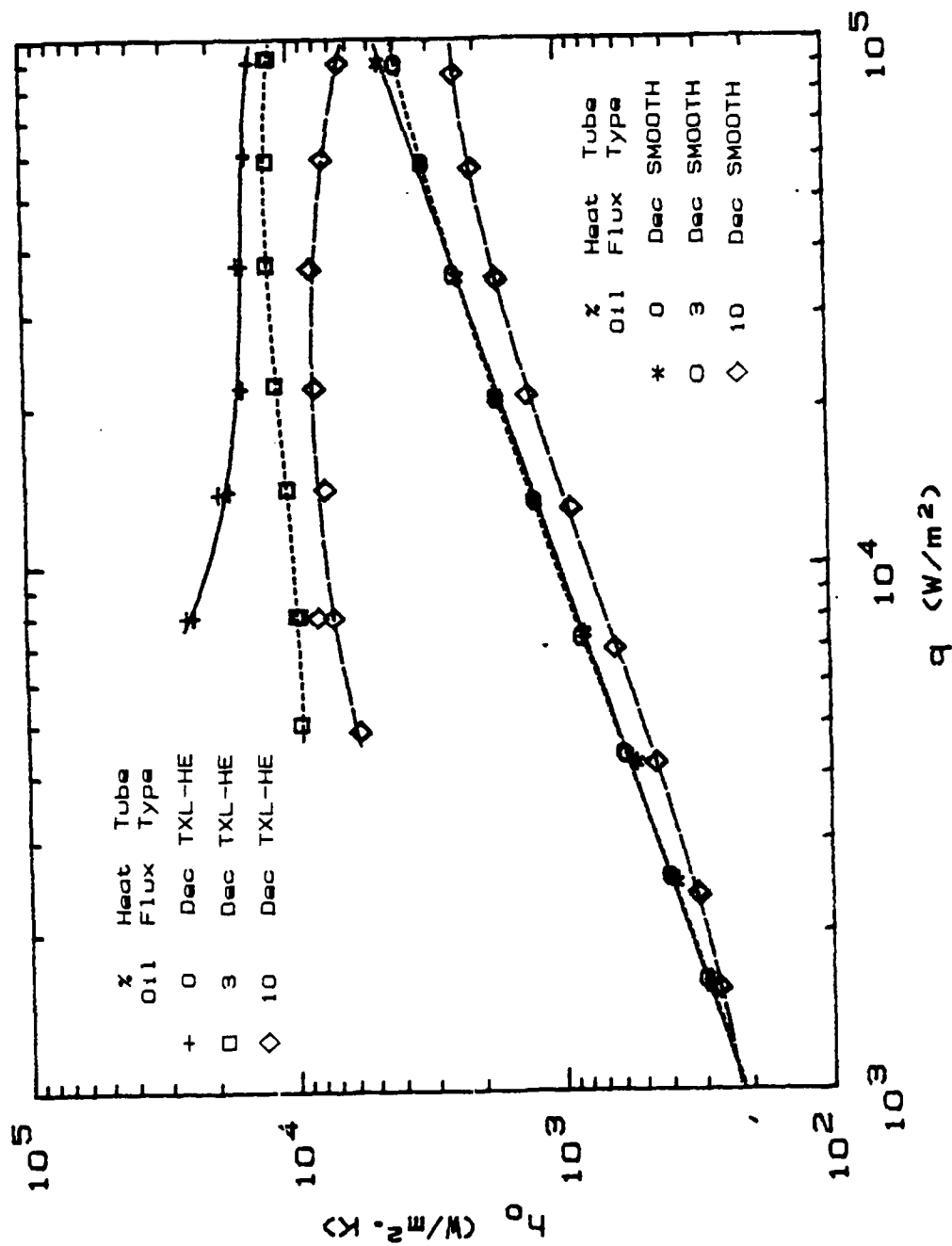


Figure 4.18 Boiling Heat-Transfer Coefficient Comparison for Thermoexcel-HE Surface vs. Smooth Surface .

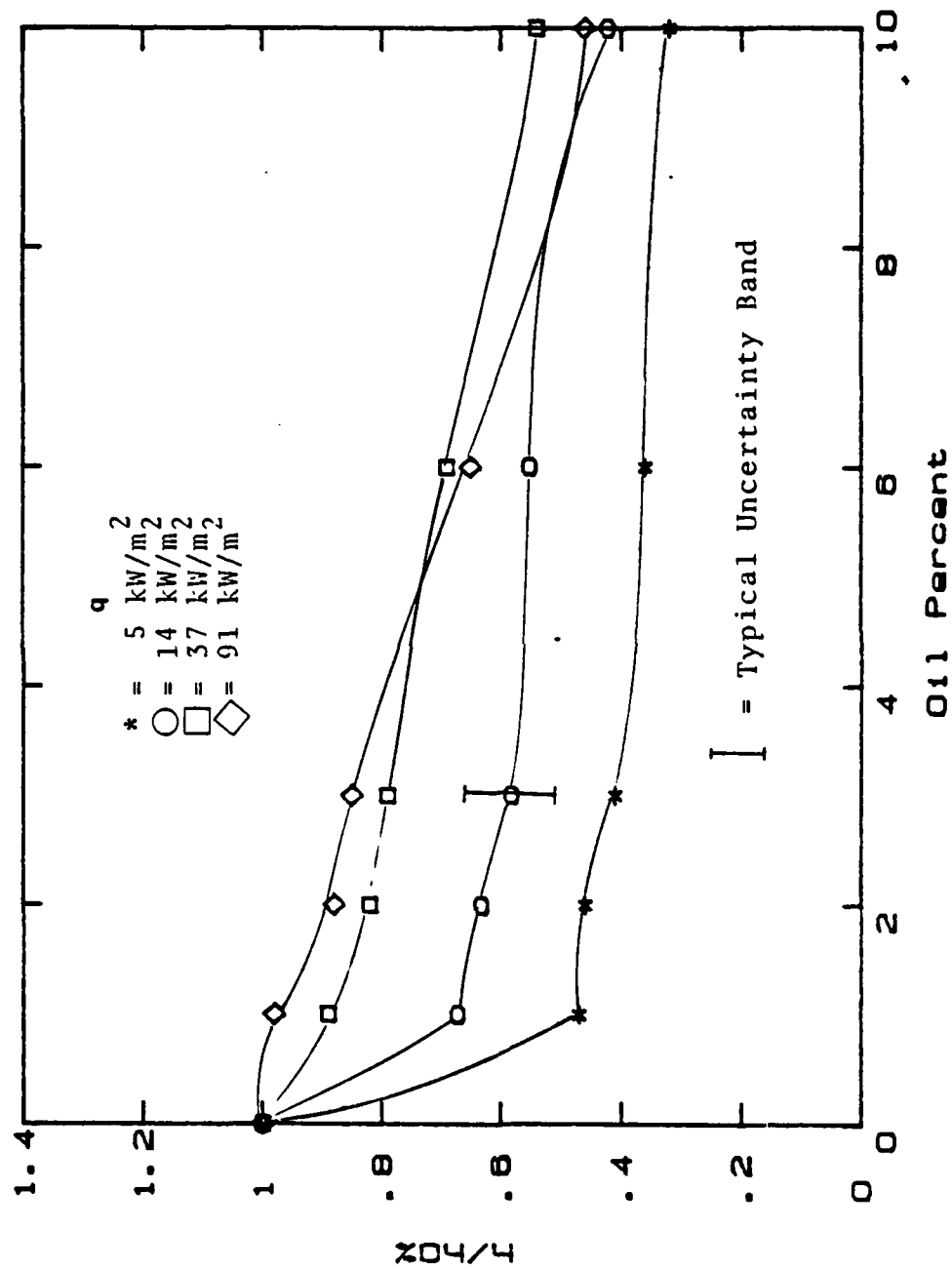


Figure 4.19 Relative Effect of Oil on Thermoexcel-HE Boiling Heat-Transfer Performance.

oil concentrations, although more severe at the lower oil concentrations. At the higher heat fluxes, the trend appears to reverse.

F. COMPARISON TO REILLY'S DATA FOR THE HIGH FLUX TUBE

Figures 4.20, 4.21 and 4.22 provide a comparison of the smooth, High Flux, GEWA-T, Thermoexcel-E and Thermoexcel-HE tubes for 0, 3 and 10 percent oil concentrations, respectively. For pure R-114 liquid, the High Flux, Thermoexcel-E and Thermoexcel-HE tubes operating at a heat flux of approximately 20 kW/m^2 , show nearly identical performance. As the heat flux was increased, the performance of the High Flux tube continued to increase while the performance of Thermoexcel-E and Thermoexcel-HE tubes remained nearly constant. At heat-flux settings lower than 20 kW/m^2 , the Thermoexcel-E and Thermoexcel-HE tubes showed higher heat-transfer coefficients than that for the High Flux tube. As the oil concentration was increased to 3 percent, the performance of all five tubes decreased, as can be seen in Figure 4.21. Additionally, the GEWA-T tube's performance appeared to decrease the least since, as discussed earlier in section IV.C, the finned surface of the GEWA-T tube is not adversely effected by the small increase in the oil content due to its large reentrant cavities. From this observation, it can be stated that the performance of the

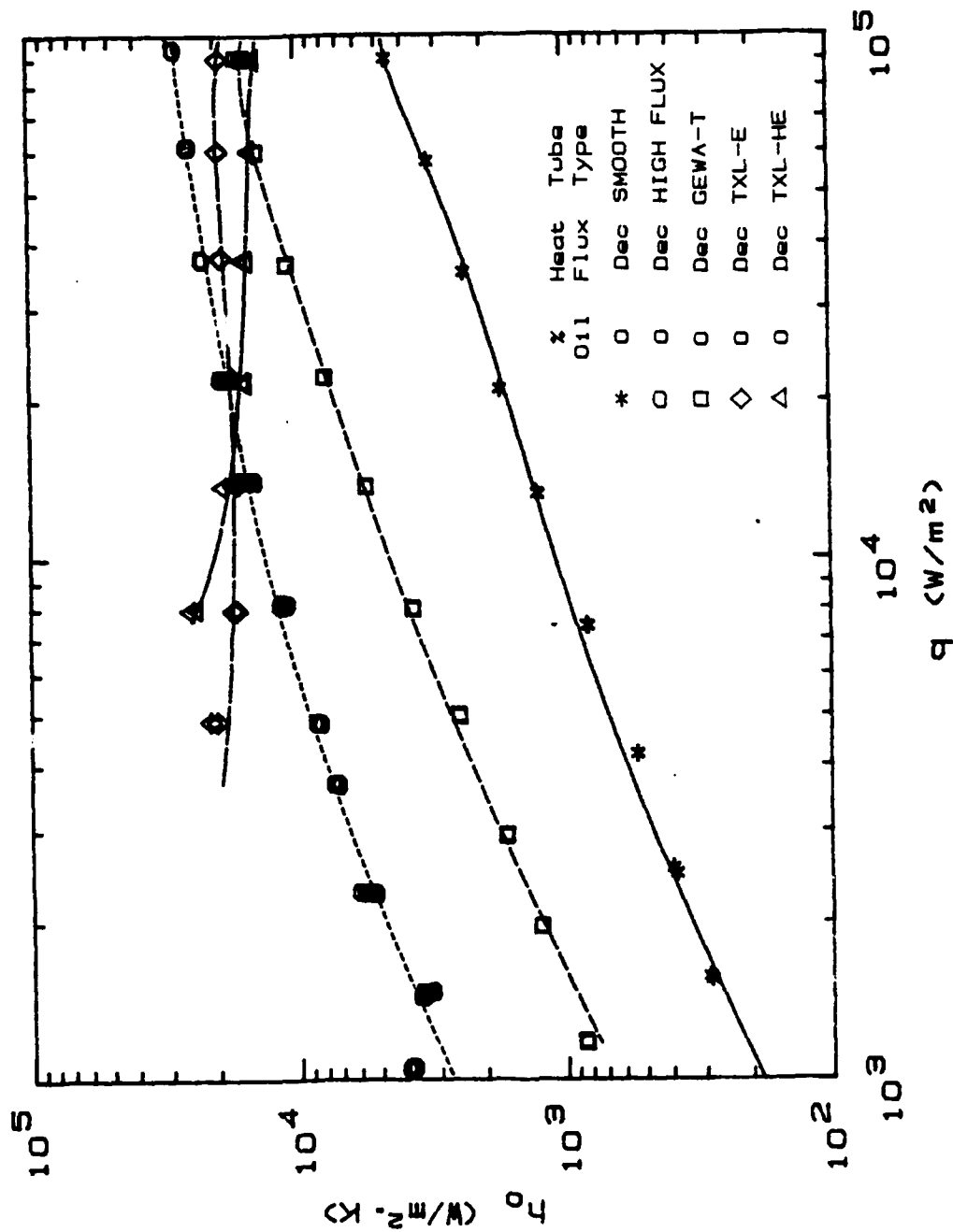


Figure 4.20 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5] GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces in Pure R-114.

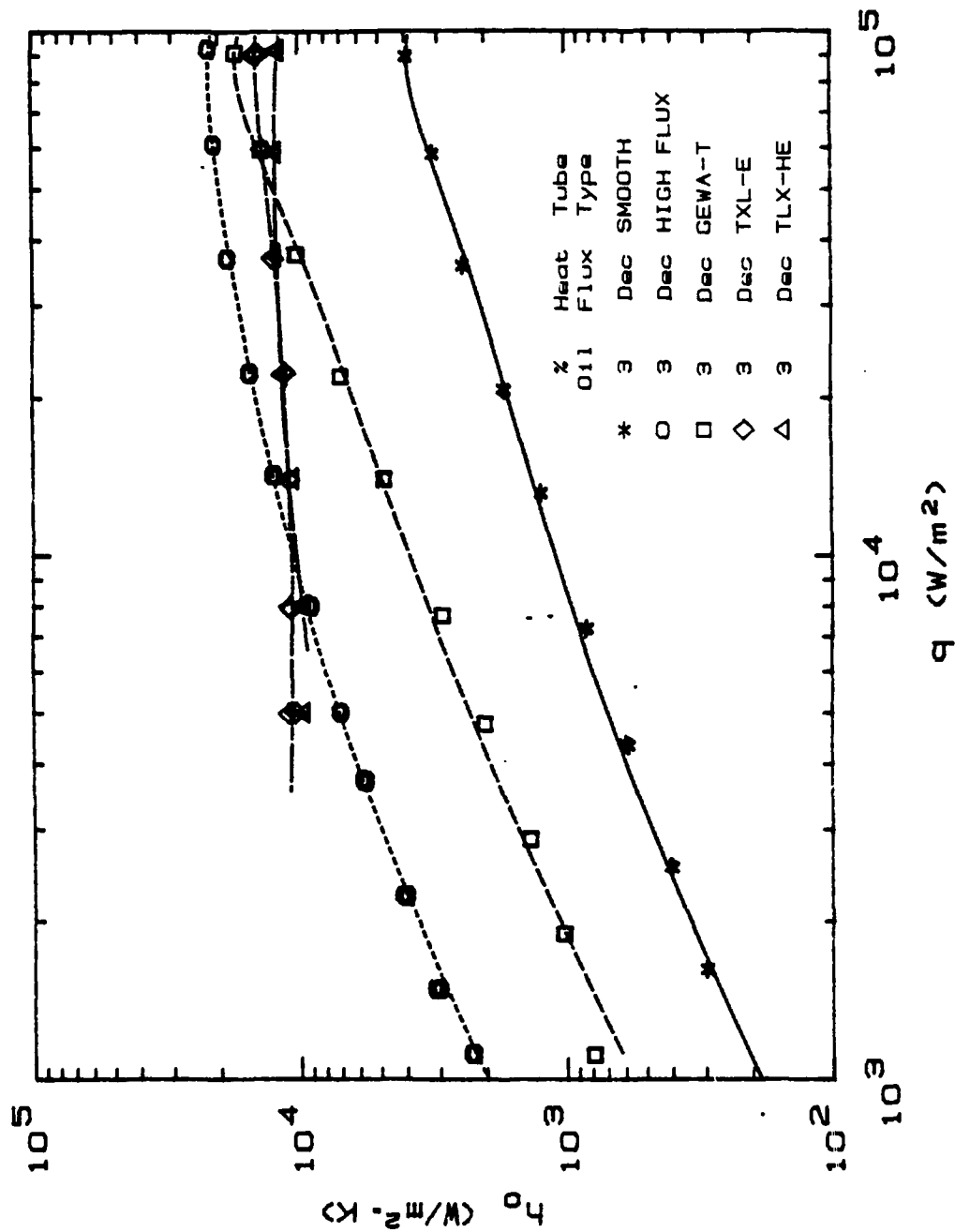


Figure 4.21 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5], GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 3 Percent Oil Content.

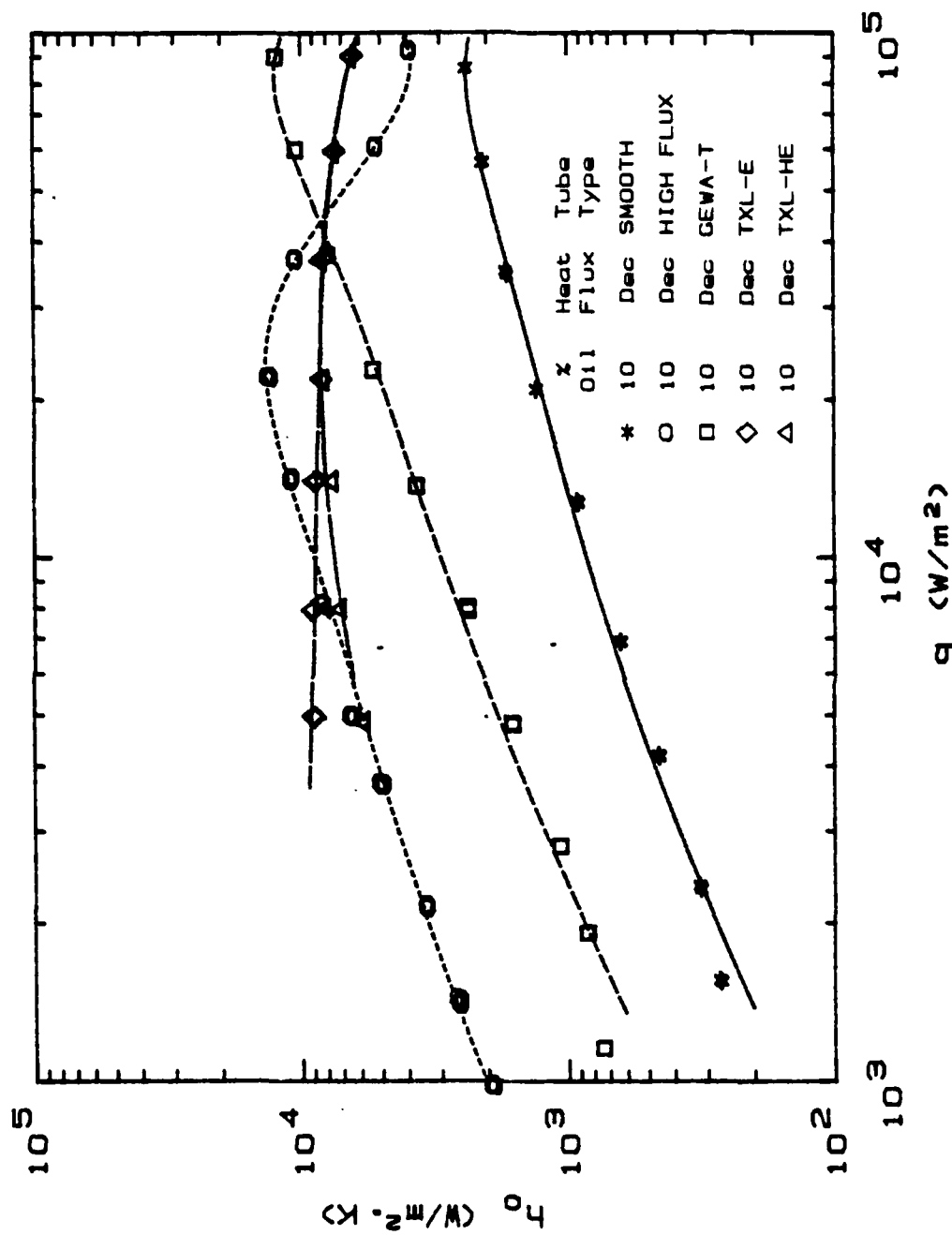


Figure 4.22 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5], GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 10 Percent Oil Content.

tubes with porous coatings or small reentrant cavities is adversely affected by the increase in oil content due to the generation of an oil-rich film in the nucleation sites impeding the tube's performance. This is further evidenced by Figure 4.22, which depicts the performance of all five tubes in R-114-oil mixtures of 10 percent oil. The performance of all the tubes is reduced significantly, while the performance of the High Flux tube is severely decreased in the range of heat-flux settings from 22 kW/m² to the maximum setting of 91 kW/m². At approximately 45 kW/m², the performance of the High Flux tube, the GEWA-T, the Thermoexcel-E and the Thermoexcel-HE tubes are approximately equal, although the performance of the Thermoexcel-E and the Thermoexcel-HE tubes remain nearly constant over the range of heat-flux settings of 14 kW/m² to 50 kW/m². Although the performance of the High Flux tube exceeds that of the GEWA-T, the Thermoexcel-E and the Thermoexcel-HE tubes over this range, its performance begins to severely degrade at the midpoint of the heat-flux range indicated. In the heat-flux range above 45 kW/m², the GEWA-T tube outperformed all the other tubes. This is attributed to the ability of bubbles generated in its larger channels to continually scavenge the oil-rich layer from the tube, and therefore remove the insulating oil from the tube's channels and exterior surface.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. In pure R-114, at a heat flux of 30 kW/m^2 the pool-boiling heat-transfer coefficient of the Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes were approximately 6.6, 6.1 and 4.2 times, respectively, larger than the baseline smooth tube.
2. In R-114-oil mixtures of 3 percent oil, at a heat flux of 30 kW/m^2 , the pool-boiling heat-transfer coefficient of the Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes were approximately 4.8, 4.6 and 4.0 times, respectively, larger than the smooth tube under the same conditions.
3. In R-114-oil mixtures of 10 percent oil, at a heat flux of 30 kW/m^2 , the performance of the Thermoexcel-E and Thermoexcel-HE tubes were nearly identical, with an enhancement of 4.1 over the pool-boiling heat-transfer coefficient of the smooth tube. The GEWA-T tube, under the same conditions, produced an enhancement of 3.8 over the smooth tube.
4. As oil content in the refrigerant-oil mixture increased, the performance of enhanced surfaces decreased; however, the amount of this decrease was directly related to the size of the subsurface channels (i.e., the larger the reentrant cavity or channel, the less adverse effect of the increased oil content).
5. As the oil content increases in the channels, the greater the adverse effect of the oil-rich layer has on the surface, insulating the surface from the refrigerant and therefore decreasing the performance of the surface.
6. The GEWA-T surface in refrigerant-oil mixtures, with its larger subsurface channels, was able to scavenge the oil-rich layer from its cavities by the bubbling action generated within the channels.
7. The performance of the Thermoexcel-E and Thermoexcel-HE tubes, with their smaller pore size and smaller tunnels, showed significant performance decreases as oil content was increased. The smaller pore and tunnel size under these conditions, were unable to

effectively disperse the oil-rich film from the sub-surface cavities and therefore allowing the oil-rich film to insulate the tube's surface.

B. RECOMMENDATIONS

1. The single-tube testing should be expanded to include multi-tube bundles. This would provide more realistic data with regard to the effects of tubes operating in close proximity to each other.
2. A uniform heat flux is necessary within the boiling tube and within the boiling section itself. Therefore, the present cartridge heaters need to be replaced with more precise heaters, capable of producing a uniform heat flux in the axial direction.
3. The testing of surfaces should be expanded to study the effects of various refrigerant oils.
4. Conduct experiments to establish the physical properties of refrigerant-oil mixtures to enable further understanding into the boiling mechanisms involved.
5. There needs to be additional studies undertaken on the effects of additional boiling temperatures on the mixture properties of the refrigerant-oil mixtures.

APPENDIX A

THERMOCOUPLE CALIBRATION [Ref. 5]

Karasabun [Ref. 17] described the thermocouple calibration procedure in great detail. Reilly [Ref. 5] stated that the data-reduction program utilized differences in thermocouple readings in all computations, such as the amount of the tube wall superheat ($T_{\text{wo}} - T_{\text{sat}}$). Reilly stated that the calibration of the thermocouples would be necessary if the thermocouples were measuring quantities such as absolute temperature to determine actual fluid properties. The procedure utilized by Karasabun and Reilly for the initial instrumentation for the experimental apparatus is as contained in Appendix A of Reference 5.

To determine the calibration for the thermocouples, two thermocouples were made, one from the beginning of the wire roll and the second from the end. The seventh-order polynomial equation provided by the wire manufacturer was corrected by adding to it a second-order curve fit of the variation of the manufacturer's computed temperature for a given emf from a known set of reference temperatures as measured by a Hewlett-Packard 2804A quartz thermometer. The thermometer had a temperature resolution of ± 0.0001 K and an accuracy of ± 0.03 K.

The manufacturer's emf to temperature conversion equation is:

$$T = a_0 + a_1 E + a_2 E^2 + a_3 E^3 + a_4 E^4 + a_5 E^5 + a_6 E^6 + a_7 E^7 \quad (A.1)$$

where

E = thermocouple reading in volts

T = temperature

$a_0 = 0.100860910$

$a_1 = 25727.94369$

$a_2 = -767345.8295$

$a_3 = 78025595.81$

$a_4 = -9247486589$

$a_5 = 6.97688 \times 10^{11}$

$a_6 = -2.66192 \times 10^{13}$

$a_7 = 3.94078 \times 10^{14}$

Figure A.1 [Ref. 5] shows the difference in the quartz thermocouple readings and the actual thermocouple readings (discrepancy) plotted as a function of temperature. As can be seen from the figure, the two thermocouples agreed to within 0.05 K of each other. The manufacturer's calibration equation needed an increase of approximately 0.1 K to more accurately convert the emf's to the true temperature. The second-order polynomial correction was as follows:

$$DCP = b_0 + b_1 T + b_2 T^2 \quad (A.2)$$

where

DCP = discrepancy (K)

$b_0 = 8.6268968 \times 10^{-2}$

$b_1 = 3.7619902 \times 10^{-3}$

$b_2 = -5.0689259 \times 10^{-5}$

T^2 = thermocouple readings from
equation A.1 in C

Therefore, the temperatures computed by the data-reduction program (DRP5) were emf's converted directly to temperatures by equation A.1 and corrected by equation A.2. This calibration was, thus estimated to result in temperature readings within ± 0.05 K of the true temperature.

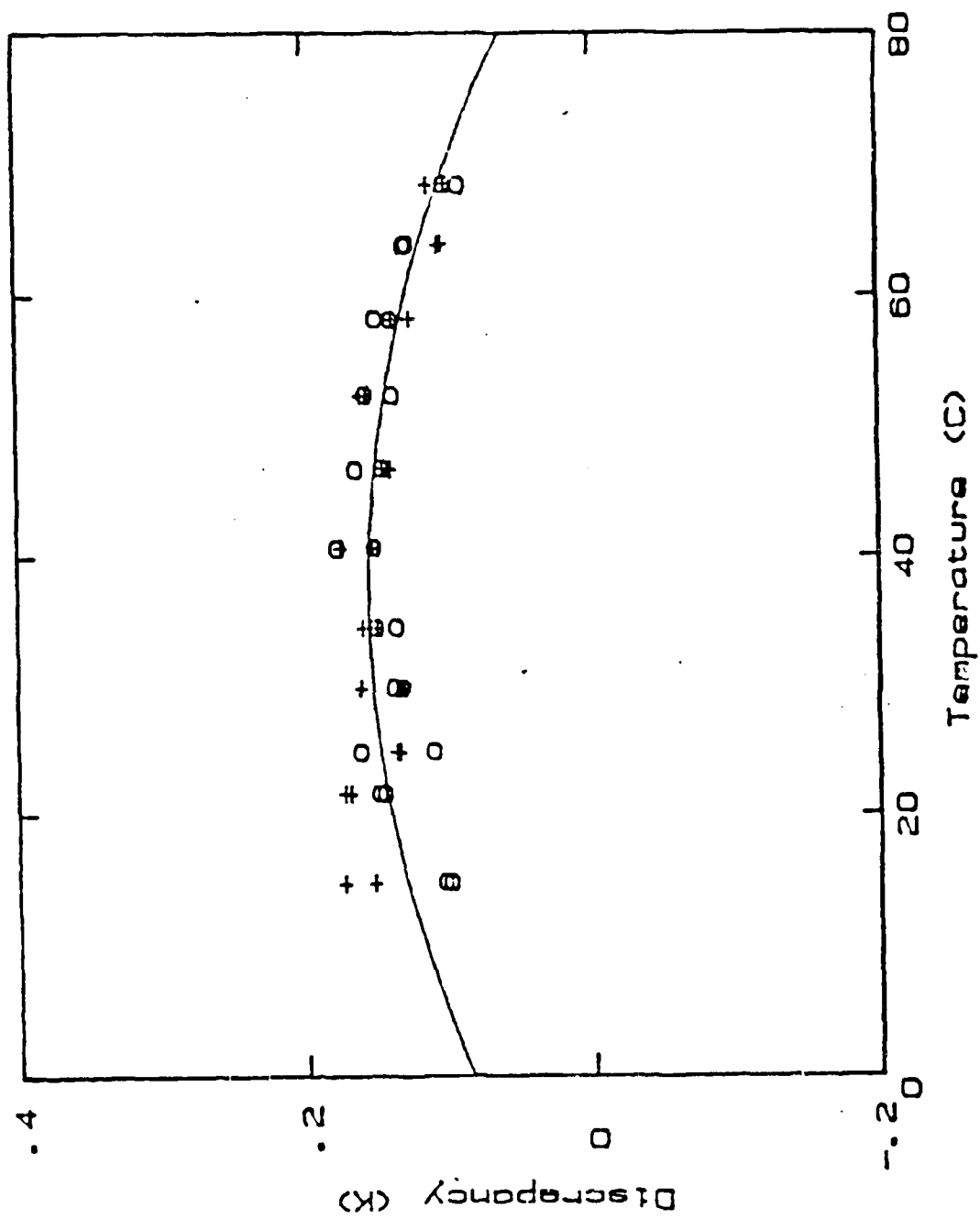


Figure A.1 Thermocouple Discrepancy Correction.

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THE EFFECTS OF OIL CONTAMINATION ON THE NUCLEATE
POOL-BOILING BEHAVIOR OF R-114 FROM ENHANCED SURFACES
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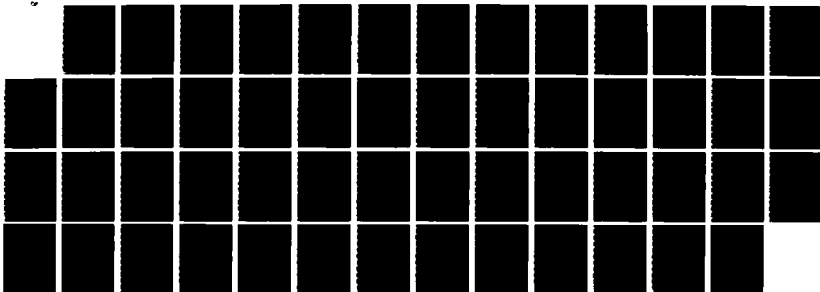
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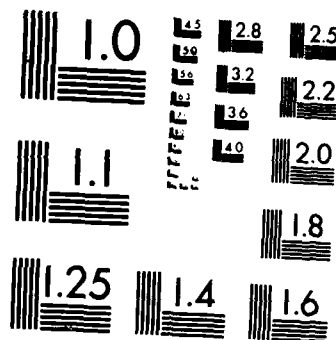
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APPENDIX B

DATA-REDUCTION PROGRAM [REF. 5]

The data-reduction program below consists of the following sections:

Main Program	- Menu of subprogram options
Sub Main	- Takes or reprocesses data
Sub plot	- Plots data on log-log scale
Sub Poly	- Computes least squares curve fit
Sub Plin	- Plots data on linear-linear scale
Sub Stats	- Computes average and standard deviation of data

Subprogram Main consists of the following steps:

1. Creates data file for data and plotting file.
2. Annotates tube type.
3. Monitors heat flux or saturation temperature to establish steady-state conditions.
4. Scans HP3497 channels and stores in data file.
5. Converts raw emf's to temperatures, current and voltages.
6. Computes the heat-transfer rate for the tube's internal cartridge heater.
7. Computes the average wall temperature of the tube, the average wall superheat and the film temperature.

8. Computes the physical properties of the R-114 using the given correlation temperature.
9. Computes the natural-convection heat-transfer coefficient of R-114 for the non-boiling tube ends.
10. Computes the heat loss from the non-boiling tube ends.
11. Calculates the corrected heat fluxes from the testing tube to the R-114.
12. Calculates the boiling heat-transfer coefficient of the R-114 from the tube being tested.
13. Prints the data and stores the heat flux and tube wall superheat values in the plot file.

The following is the listing of the complete data-reduction program (DRP5) written in Basic 3.0 for the Hewlett-Packard 9826 computer.

```

1000! FILE NAME: DRPS
1003! DATE: October 19, 1984
1006! REVISED: April 25, 1986
1009!
1012 COM /Idp/ Idp
1015 PRINTER IS 1
1018 CALL Select
1021 INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
1024 IF Isel=1 THEN GOTO 1018
1027 BEEP
1030 BEEP
1033 PRINTER IS 1
1036 PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
1039 END
1042 SUB Main
1045 COM /Idp/ Idp
1048 COM /Cc/ C(7).Ical
1051 COM /W1/ D2.D1.Do.L.Lu.Kcu
1054 DIM Emf(12),T(12),D1a(11),D2a(11),Dia(11),Doa(11),La(11),Lua(11),Kcua(11),
Et(19),Tn$(4){15}
1057 DATA 0,10086091,25727.94369,-767345.8295,78025595.81
1060 DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
1063 READ C(*)
1066! DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
1069 DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
1072 READ Tn$(*)
1075 PRINTER IS 701
1078 BEEP
1081 IF Idp=4 THEN PRINTER IS 1
1084 IF Idp=4 THEN GOTO 1774
1087 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Dates$
1090 OUTPUT 709:"TD":Dates$
1093 OUTPUT 709:"TD"
1096 ENTER 709:Dates$
1099 PRINT
1102 PRINT " Month, date and time :";Dates$
1105 PRINT
1108 PRINT USING "10X,"NOTE: Program name : DRP4""
1111 BEEP
1114 INPUT "ENTER DISK NUMBER",Dn
1117 PRINT USING "16X,"Disk number = "",ZZ";Dn
1120 BEEP
1123 INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1126 BEEP
1129 INPUT "SELECT HEATING MODE (0=ELEC: 1=WATER)",Ihm
1132 BEEP
1135 INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
1138 IF Im=0 THEN
1141 BEEP
1144 INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_files$
1147 PRINT USING "16X,"New file name: "",14A":D2_files$
1150 Size1=20
1153 CREATE BDAT D2_files$.Size1
1156 ASSIGN @file2 TO D2_files$
1159!
1162! DUMMY FILE UNTIL Nrun KNOWN
1165 D1_files$="DUMMY"
1168 CREATE BDAT D1_files$.Size1
1171 ASSIGN @file1 TO D1_files$
1174 OUTPUT @file1;Dates$

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```

1177 IF Ihm=0 THEN
1180 BEEP
1183 INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)".Idtc
1186 IF Idtc=0 THEN
1189 Ldtc1=0
1192 Ldtc2=0
1195 PRINT USING "16X,""No defective TCs exist""
1198 END IF
1201 IF Idtc=1 THEN
1204 BEEP
1207 INPUT "ENTER DEFECTIVE TC LOCATION",Ldtc1
1210 PRINT USING "16X,""TC is defective at location "",D";Ldtc1
1213 Ldtc2=0
1216 END IF
1219 IF Idtc=2 THEN
1222 BEEP
1225 INPUT "ENTER DEFECTIVE TC LOCATIONS",Ldtc1,Ldtc2
1228 PRINT USING "16X,""TC are defective at locations "",D,4X,D";Ldtc1,Ldtc2
1231 END IF
1234 IF Idtc>2 THEN
1237 BEEP
1240 PRINTER IS 1
1243 BEEP
1246 PRINT "INVALID ENTRY"
1249 PRINTER IS 701
1252 GOTO 1180
1255 END IF
1258 END IF
1261 OUTPUT @File1;Ldtc1,Ldtc2
1264! Im=1 option
1267 ELSE
1270 JEEP
1273 INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_files
1276 PRINT USING "16X,""Old file name: "",14A";D2_files$
1279 ASSIGN @File2 TO D2_files
1282 ENTER @File2:Nrun
1285 ENTER @File2:Dold$
1288 PRINT USING "16X,""This data set taken on : "",14A";Dold$
1291 ENTER @File2:Ldtc1,Ldtc2
1294 IF Ldtc1>0 OR Ldtc2>0 THEN
1297 PRINT USING "16X,""Thermocouples were defective at locations:"",2(3D,4X)";
Ldtc1,Ldtc2
1300 END IF
1303 ENTER @File2:Itt
1306 END IF
1309! IF Im=0 AND Ihm=1 THEN 1595
1312 BEEP
1315 INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1318 IF Iplot=1 THEN
1321 BEEP
1324 INPUT "GIVE NAME FOR PLOT FILE",P_files
1327 CREATE BOAT P_files$.4
1330 ASSIGN @Plot TO P_files$
1333 END IF
1336 IF Ihm=1 THEN
1339 BEEP
1342 INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1345 IF Iuf=1 THEN
1348 BEEP
1351 INPUT "ENTER Uo FILE NAME".Ufiles$

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```

1354 CREATE BDAT Ufiles.4
1357 ASSIGN @Ufile TO Ufiles
1360 END IF
1363 BEEP
1366 INPUT "WANT TO CREATE Re FILE? (0-N,1=Y)".Ire
1369 IF Ire=1 THEN
1372 BEEP
1375 INPUT "ENTER Re FILE NAME",Refiles
1378 CREATE BDAT Refiles.10
1381 ASSIGN @Refile TO Refiles
1384 END IF
1387 END IF
1390 PRINTER IS 1
1393 IF Im=0 THEN
1396 BEEP
1399 PRINT USING "4X,""Select tube number""
1402 IF Ihm=0 THEN
1405 PRINT USING "6X,""0 Smooth 4 inch Ref""
1408 PRINT USING "6X,""1 Smooth 4 inch Cu (Press/Slide)""
1411 PRINT USING "6X,""2 Soft Solder 4 inch Cu""
1414 PRINT USING "6X,""3 Soft Solder 4 inch HIGH FLUX""
1417 PRINT USING "6X,""4 Wieland Hard 8 inch""
1420 PRINT USING "6X,""5 HIGH FLUX 8 inch""
1423 PRINT USING "6X,""6 GEWA-K 19 Fins/in""
1426 PRINT USING "6X,""7 GEWA-K 26 Fins/in""
1429 PRINT USING "6X,""8 GEWA-T 19 Fins/in""
1432 PRINT USING "6X,""9 GEWA-T 26 Fins/in""
1435 PRINT USING "6X,""10 THERMOEXCEL-E""
1438 PRINT USING "6X,""11 THERMOEXCEL-HE""
1441 ELSE
1444 PRINT USING "6X,""0 Smooth tube""
1447 PRINT USING "6X,""1 High Flux""
1450 PRINT USING "6X,""2 Turbo-B""
1453 PRINT USING "6X,""3 High Flux Mod""
1456 PRINT USING "6X,""4 Turbo-B Mod""
1459 END IF
1462 INPUT Itt
1465 OUTPUT @File1;Itt
1468 END IF
1471 PRINTER IS 701
1474 IF Itt<10 THEN PRINT USING "16X,""Tube Number:  ",D":Itt
1477 IF Itt>9 THEN PRINT USING "16X,""Tube Number:  ",DD":Itt
1480 IF Ihm=1 THEN PRINT USING "16X,""Tube Type:  ",ISA":Tn$(Itt)
1483 BEEP
1486 INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)".Iov
1489 BEEP
1492 INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)".Ilqv
1495!
1498! DIMENSIONS FO TESTED TUBES
1501! ELECTRIC HEATED MODE
1504! D1=Diameter at thermocouple positions
1507 DATA .0111125..0111125..0111125..0129540..012446..0129540..0100965
1510 DATA .0100965..01157..01157..01157..01157
1513 READ D1a(*)
1516 D1=D1a(Itt)
1519!
1522! D2=Diameter of test section to the base of fins
1525 DATA .015875..015875..015875..015824..015875..015824..01270
1528 DATA .0127..0138..0138..0138..0138
1531 READ D2a(*)

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1534!
1537! Di=Inside diameter of unenhanced ends
1540 DATA .0127,.0127,.0127,.0132,.0127,.0132,.011125,.011125,.0118,.0118,.01
18,.0118
1543 READ Dia(*)
1546!
1549! Do=Outside diameter of unenhanced ends
1552 DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270,.01331,
.01331,.01331,.01331
1555 READ Doa(*)
1558!
1561! L=Length of enhanced surface
1564 DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32
1567 READ La(*)
1570!
1573! Lu=Length of unenhanced surface at the ends
1576 DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62
1579 READ Lua(*)
1582!
1585! Kcu=Thermal Conductivity of tube
1588 DATA 398,344,344,45,344,45,344,944,398,398,398,398
1591 READ Kcua(*)
1594 IF Ihm=1 THEN
1597!
1600! Data statements for water heating mode
1603!
1606 DATA 0.015875,0.015875,0.0169,0.0138,0.0169,0.0,0.0,0
1609 READ D2a(*)
1612 DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0.0,0.0,0
1615 READ Dia(*)
1618 DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0.0,0.0,0
1621 READ Doa(*)
1624 DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0.0,0.0,0
1627 READ La(*)
1630 DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0.0,0.0,0
1633 READ Lua(*)
1636 DATA 398,45,398,45,398,0.0,0.0,0
1639 READ Kcua(*)
1642 END IF
1645 D2=D2a(Itt)
1648 Di=Dia(Itt)
1651 Do=Doa(Itt)
1654 L=La(Itt)
1657 Lu=Lua(Itt)
1660 Kcu=Kcua(Itt)
1663 Xn=.8
1666 Fr=.3
1669 IF Itt=0 THEN Cf=1.70E+9
1672 IF Itt>0 THEN Cf=3.7037E+10
1675 A=PI*(Do^2-Di^2)/4
1678 P=PI*Do
1681 IF Ihm=1 THEN
1684 BEEP
1687 INPUT "TUBE INITIATION MODE. (1-HOT WATER,2-STEAM,3-COLD WATER)".Itim
1690 IF Itim=1 THEN PRINT USING "16X." "Tube Initiate: Hot Water""
1693 IF Itim=2 THEN PRINT USING "16X." "Tube Initiate: Steam""
1696 IF Itim=3 THEN PRINT USING "16X." "Tube Initiate: Cold Water""
1699 INPUT "TEMP/VEL MODE: (0-T-CONST,V-DEC;1-T-DEC,V-CONST;2-T-INC,V-CONST)".
Itv

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1702 IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing""
1705 IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant""
1708 IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant""
1711 INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iwil
1714 IF Ihm=1 AND Iwil=0 THEN
1717 IF Itt=0 THEN Ci=.032
1720 IF Itt=1 OR Itt=3 THEN Ci=.059
1723 IF Itt=2 OR Itt=4 THEN Ci=.062
1726 BEEP
1729 INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
1732 PRINT USING "16X,""Sieder-Tate ""
1735 PRINT USING "16X,"" Constant = "",Z.40":Ci
1738 END IF
1741 END IF
1744 IF Ihm=1 AND Im=1 AND Iwil=1 THEN
1747 IF Itt=0 THEN Ci=.032
1750 IF Itt=1 OR Itt=3 THEN Ci=.059
1753 IF Itt=2 OR Itt=4 THEN Ci=.062
1756 ASSIGN @File2 TO *
1759 CALL Wilson(Cf,Ci)
1762 ASSIGN @File2 TO D2_files
1765 ENTER @File2:Nrun,Dold$.Ldte1,Ldte2,Itt
1768 END IF
1771 Nsub=0
1774 IF Idp=4 THEN Ihm=1
1777 IF Ihm=1 THEN Nsub=8
1780 Ntc=6
1783 IF Ihm=0 THEN Ntc=12
1786 J=1
1789 Sx=0
1792 Sy=0
1795 Sxs=0
1798 Sxy=0
1801 Repeat: !
1804 IF Im=0 THEN
1807 Dtl=2.22
1810 Ido=2
1813 ON KEY 0,15 RECOVER 1801
1816 PRINTER IS 1
1819 PRINT USING "4X,""SELECT OPTION""
1822 PRINT USING "6X,""0-TAKE DATA""
1825 IF Ihm=0 THEN PRINT USING "6X,""1-SET HEAT FLUX""
1828 IF Ihm=1 THEN PRINT USING "6X,""1-SET WATER FLOW RATE""
1831 PRINT USING "6X,""2-SET Tsat""
1834 PRINT USING "4X,""NOTE: KEY 0 = ESCAPE""
1837 BEEP
1840 INPUT Ido
1843 IF Ido>2 THEN Ido=2
1846 IF Ido=0 THEN 2296
1849!
1852! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
1855 IF Ido=1 THEN
1858 IF Ihm=0 THEN
1861 OUTPUT 709;"AR AF12 AL13 VRS"
1864 BEEP
1867 INPUT "ENTER DESIRED Qdp",Qdp
1870 PRINT USING "4X,""DESIRED Qdp ACTUAL Qdp""
1873 Err=1000
1876 FOR I=1 TO 2
1879 OUTPUT 709;"AS SA"

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```

1882 Sum=0
1885 FOR J1=1 TO 5
1888 ENTER 709:E
1891 Sum=Sum+E
1894 NEXT J1
1897 IF I=1 THEN Volt=Sum*5
1900 IF I=2 THEN Amp=E
1903 NEXT I
1906 Aqdp=Volt*Amp/(PI*02*L)
1909 IF ABS(Aqdp-Dqdp)>Err THEN
1912 IF Aqdp>Dqdp THEN
1915 BEEP 4000..2
1918 BEEP 4000..2
1921 BEEP 4000..2
1924 ELSE
1927 BEEP 250..2
1930 BEEP 250..2
1933 BEEP 250..2
1936 END IF
1939 PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
1942 WAIT 2
1945 GOTO 1876
1948 ELSE
1951 BEEP
1954 PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
1957 Err=500
1960 WAIT 2
1963 GOTO 1876
1966 END IF
1969 ELSE
1972 BEEP
1975 INPUT "ENTER FLOWMETER SETTING".Fms
1978 GOTO 1819
1981 END IF
1984 END IF
1987!
1990! LOOP TO SET Tsat
1993 IF Ido=2 THEN
1996 IF Ikdt=1 THEN 2011
1999 BEEP
2002 INPUT "ENTER DESIRED Tsat",Dtld
2005! PRINT USING "4X, " DTsat ATsat Rate Tv Rate""
2008 Ikdt=1
2011 Old1=0
2014 Old2=0
2017 Nn=1
2020 Nrs=Nn MOD 15
2023 Nn=Nn+1
2026 IF Nrs=1 THEN
2029 PRINT USING "4X, " Tsat Tld1 Tld2 Tv Tsump Tinlet Tpile
Tout""
2032 END IF
2035 IF Ihm=0 THEN OUTPUT 709:"AR AF8 AL11 VR5"
2038 IF Ihm=1 THEN OUTPUT 709:"AR AF0 ALS VR5"
2041 FOR I=1 TO 6
2044 IF Ihm=0 AND I>4 THEN 2125
2047 Sum=0
2050 OUTPUT 709:"AS SA"
2053 FOR J1=1 TO 20
2056 ENTER 709:E11q

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```

2059 Sum=Sum+Elia
2062 NEXT Ji
2065 Elia=Sum/20
2068 Tld=FNTvsv(Elia)
2071 IF I=1 THEN Tld1=Tld
2074 IF I=2 THEN Tld2=Tld
2077 IF I=3 THEN Tv=Tld
2080 IF I=4 THEN Tsump=Tld
2083 IF I=5 THEN Tinlet=Tld
2086 IF I=6 THEN Tout=Tld
2089 NEXT I
2092 IF Ihm=1 THEN
2095 OUTPUT 709:"AR AF20 AL20 VRS"
2098 OUTPUT 709:"AS SA"
2101 Sum=0
2104 FOR Kk=1 TO 20
2107 ENTER 709:E
2110 Sum=Sum+E
2113 NEXT Kk
2116 Emf(7)=ABS(Sum/20)
2119 Toile=Emf(7)/3.96E-4
2122 END IF
2125 Atld=(Tld1+Tld2)*.5
2128 IF ABS(Atld-Dtld)>.2 THEN
2131 IF Atld>Dtld THEN
2134 BEEP 4000..2
2137 BEEP 4000..2
2140 BEEP 4000..2
2143 ELSE
2146 BEEP 250..2
2149 BEEP 250..2
2152 BEEP 250..2
2155 END IF
2158 Err1=Atld-Old1
2161 Old1=Atld
2164 Err2=Tv-Old2
2167 Old2=Tv
2170 IF Ihm=0 THEN PRINT USING "4X.5(MDD.DD.2X)";Dtld,Tld1,Tld2,Tv,Tsump
2173 IF Ihm=1 AND Idp=0 THEN PRINT USING "4X.7(MDD.DD.2X)";Dtld,Tld1,Tld2,Tv,Ts
ump,Tinlet,Toile
2176* IF Ihm=1 AND Idp=4 THEN PRINT USING "4X.5(MDD.DD.2X),3(M3D.DD.2X)";Dtld,Tl
d1,Tld2,Tv,Tsump,Tin
2179 WAIT 2
2182 GOTO 2020
2185 ELSE
2188 IF ABS(Atld-Dtld)>.1 THEN
2191 IF Atld>Dtld THEN
2194 BEEP 3000..2
2197 BEEP 3000..2
2200 ELSE
2203 BEEP 800..2
2206 BEEP 800..2
2209 END IF
2212 Err1=Atld-Old1
2215 Old1=Atld
2218 Err2=Tv-Old2
2221 Old2=Tv
2224 IF Ihm=0 THEN PRINT USING "4X.5(MDD.DD.2X)";Dtld,Tld1,Tld2,Tv,Tsump
2227* IF Ihm=1 THEN PRINT USING "4X.5(MDD.DD.2X),3(M3D.DD.1X)";Dtld,Tld1,Tld2,Tv
,Tsump,Tinlet,Toile,

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```

2230 WAIT 2
2233 GOTO 2020
2236 ELSE
2239 BEEP
2242 Err1=Atld-Old1
2245 Old1=Atld
2248 Err2=Tv-Old2
2251 Old2=Tv
2254 IF Ihm=0 THEN PRINT USING "4X.5(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2257 IF Ihm=1 THEN PRINT USING "4X.8(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump,Tinlet
,Tpile,Tout
2260 WAIT 2
2263 GOTO 2020
2266 END IF
2269 END IF
2272 END IF
2275! ERROR TRAP FOR Ido OUT OF BOUNDS
2278 IF Ido>2 THEN
2281 BEEP
2284 GOTO 1819
2287 END IF
2290!
2293! TAKE DATA IF Im=0 LOOP
2296 IF Ikol=1 THEN 2308
2299 BEEP
2302 INPUT "ENTER BULK OIL %",Bop
2305 Ikol=1
2308 IF Ihm=0 THEN OUTPUT 709:"AR AFO AL11 VRS"
2311 IF Ihm=1 THEN OUTPUT 709:"AR AFO ALS VRS"
2314 IF Ihm=0 THEN Ntc=12
2317 FOR I=1 TO Ntc
2320 OUTPUT 709:"AS SA"
2323 Sum=0
2326 FOR Ji=1 TO 20
2329 ENTER 709:E
2332 Sum=Sum+E
2335 IF I=(9-Nsub) OR I=(10-Nsub) THEN Et(Ji-1)=E
2338 NEXT Ji
2341 Kdl=0
2344 IF I=(9-Nsub) OR I=(10-Nsub) THEN
2347 Eave=Sum/20
2350 Sum=0.
2353 FOR Jk=0 TO 19
2356 IF ABS(Et(Jk)-Eave)<5.0E-6 THEN
2359 Sum=Sum+Et(Jk)
2362 ELSE
2365 Kdl=Kdl+1
2368 END IF
2371 NEXT Jk
2374 IF I=(9-Nsub) OR I=(10-Nsub) THEN PRINT USING "4X.``Kdl = ``.DD";Kdl
2377 IF Kdl>10 THEN
2380 BEEP
2383 BEEP
2386 PRINT USING "4X.``Too much scattering in data - repeat data set""
2389 GOTO 1816
2392 END IF
2395 END IF
2398 Emr(I)=Sum/(20-Kdl)
2401 NEXT I
2404 IF Ihm=1 THEN
2407 OUTPUT 709:"AR AF20 AL20 VRS"

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```

2590 NEXT I
2593  $T_w = T_{wa} / (8 - Idtc)$ 
2596 END IF
2599  $T_{ld} = T(9 - Nsub)$ 
2602  $T_{ld2} = T(10 - Nsub)$ 
2605  $T_{lda} = (T_{ld} + T_{ld2}) * .5$ 
2608  $T_v = T(11 - Nsub)$ 
2611 IF  $Itt < 3$  AND  $Ihm = 0$  THEN
2614  $T_{ld2} = -99.99$ 
2617  $T_v = (T(10) + T(11)) / 2$ 
2620 END IF
2623  $T_{sump} = T(12 - Nsub)$ 
2626 IF  $Ihm = 0$  THEN 2635
2629  $T_{inlet} = T(13 - Nsub)$ 
2632  $T_{out} = T(14 - Nsub)$ 
2635 IF  $Ihm = 0$  THEN
2638  $Amp = ABS(I_r)$ 
2641  $Volt = ABS(V_r) * 25$ 
2644  $Q = Volt * Amp$ 
2647 END IF
2650 IF  $Itt = 0$  AND  $Ihm = 0$  THEN
2653  $K_{cu} = FNK_{cu}(T_w)$ 
2656 ELSE
2659  $K_{cu} = K_{cua}(Itt)$ 
2662 END IF
2665!
2668! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
2671 IF  $Ihm = 0$  THEN  $T_w = T_w - Q * LOG(D2/D1) / (2 * PI * K_{cu} * L)$ 
2674 IF  $Ilqv = 0$  THEN  $T_{sat} = T_{lda}$ 
2677 IF  $Ilqv = 1$  THEN  $T_{sat} = (T_{lda} + T_v) * .5$ 
2680 IF  $Ilqv = 2$  THEN  $T_{sat} = T_v$ 
2683 IF  $Ihm = 1$  THEN
2686  $T_{avg} = T_{inlet}$ 
2689  $Grad = 37.9853 + .104388 * T_{avg}$ 
2692  $T_{drop} = ABS(Emf(7)) * 1.E+6 / (10 * Grad)$ 
2695  $T_{avgc} = T_{inlet} - T_{drop} * .5$ 
2698 IF  $ABS(T_{avg} - T_{avgc}) > .01$  THEN
2701  $T_{avg} = (T_{avg} + T_{avgc}) * .5$ 
2704 GOTO 2689
2707 END IF
2710!
2713! COMPUTE WATER PROPERTIES
2716 IF  $Ihm = 1$  THEN
2719  $K_w = FNK_w(T_{avg})$ 
2722  $\mu_{wa} = FNM_{\mu w}(T_{avg})$ 
2725  $C_{pw} = FNC_{pw}(T_{avg})$ 
2728  $P_{rw} = FNP_{rw}(T_{avg})$ 
2731  $R_{\rho w} = FNR_{\rho w}(T_{avg})$ 
2734  $T_{w1} = T_{avg}$ 
2737!
2740! Compute MDOT
2743  $Mdot = 3.9657E-3 + Fms * (3.61955E-3 - Fms * (8.82006E-6 - Fms * (1.23688E-7 - Fms * 4.31897E-10)))$ 
2746!  $Mdot = Mdot * (1.0365 - T_{inlet} * (1.96644E-3 - T_{inlet} * 5.252E-6)) / 1.0037$ 
2749  $K_{dt} = 0$ 
2752  $Q = Mdot * C_{pw} * T_{drop}$ 
2755  $L_{mtd} = T_{drop} / LOG((T_{inlet} - T_{sat}) / (T_{inlet} - T_{drop} - T_{sat}))$ 
2758  $U_o = Q / (PI * D_o * L * L_{mtd})$ 
2761  $R_u = D_o * LOG(D_o/D_i) / (2 * K_{cu})$ 
2764  $T_w = T_{sat} + Fr * L_{mtd}$ 

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```

2410 OUTPUT 709:"AS SA"
2413 Sum=0
2416 FOR Kk=1 TO 20
2419 ENTER 709:E
2422 Sum=Sum+E
2425 NEXT Kk
2428 Emf(7)=ABS(Sum)/20
2431 END IF
2434 IF Ihm=0 THEN
2437 OUTPUT 709:"AR AF12 AL13 VR5"
2440 FOR I=1 TO 2
2443 OUTPUT 709:"AS SA"
2446 Sum=0
2449 FOR Ji=1 TO 2
2452 ENTER 709:E
2455 Sum=Sum+E
2458 NEXT Ji
2461 IF I=1 THEN Vr=Sum/2
2464 IF I=2 THEN Ir=Sum/2
2467 NEXT I
2470 END IF
2473 ELSE
2476 IF Ihm=0 THEN ENTER @File2:Bop.Told$.Emf(*),Vr,Ir
2479 IF Ihm=1 THEN ENTER @File2:Bop.Told$.Emf(*),Fms
2482 END IF
2485!
2488! CONVERT emf'S TO TEMP,VOLT,CURRENT
2491 Twa=0
2494 FOR I=1 TO Ntc
2497 IF Idtc>0 THEN
2500 IF I=Ldte1 OR I=Ldte2 THEN
2503 T(I)=-99.99
2506 GOTO 2536
2509 END IF
2512 END IF
2515 IF Itt<4 AND Ihm=0 THEN
2518 IF I>4 AND I<9 THEN
2521 T(I)=-99.99
2524 GOTO 2536
2527 END IF
2530 END IF
2533 T(I)=FNTvsv(Emf(I))
2536 NEXT I
2539 IF Itt<4 THEN
2542 FOR I=1 TO 4
2545 IF I=Ldte1 OR I=Ldte2 THEN
2548 Twa=Twa
2551 ELSE
2554 Twa=Twa+T(I)
2557 END IF
2560 NEXT I
2563 Twa=Twa/(4-Idtc)
2566 ELSE
2569 IF Ihm=1 THEN 2599
2572 FOR I=1 TO 8
2575 IF I=Ldte1 OR I=Ldte2 THEN
2578 Twa=Twa
2581 ELSE
2584 Twa=Twa+T(I)
2587 END IF

```

```

2767 Vu=Mdot/(Rhow*PI*D1^2/4)
2770 Rew=Rhow*Vu*D1/Muwa
2773 H1=C1*Kw/D1+Rew*.8*Prw^(1/3.)*(Muwa/FNMuw(Tw1))*.14
2776 Tw1c=Tavg-Q/(PI*Do*L*H1)
2779 IF ABS(Tw1-Tw1c)>.01 THEN
2782 Tw1=(Tw1+Tw1c)*.5
2785 GOTO 2773
2788 END IF
2791 Tw1=(Tw1+Tw1c)*.5
2794 Ho=1/(1/Uo-Do/(D1*H1)-Rw)
2797 END IF
2800 END IF
2803 IF Ih=1 THEN
2806 Thetab=Q/(Ho*PI*Do*L)
2809 Tw=Ts+Thetab
2812 ELSE
2815 Thetab=Tw-Ts
2818 END IF
2821 IF Thetab<0 THEN
2824 BEEP
2827 INPUT "WALL<TSAT (0=CONTINUE, 1=END)".Iev
2830 IF Iev=0 THEN GOTO 1804
2833 IF Iev=1 THEN 3130
2836 END IF
2839!
2842! COMPUTE VARIOUS PROPERTIES
2845 Tfilm=(Tw+Ts)*.5
2848 Rho=FNRho(Tfilm)
2851 Mu=FNMu(Tfilm)
2854 K=FNK(Tfilm)
2857 Cp=FNCP(Tfilm)
2860 Beta=FNBeta(Tfilm)
2863 Hfg=FNHfg(Ts)
2866 Ni=Mu/Rho
2869 Alpha=K/(Rho*Cp)
2872 Pr=Ni/Alpha
2875 Psat=FNPsat(Ts)
2878!
2881! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
2884! FOR UNENHANCED END(S)
2887 Hbar=190
2890 Fe=(Hbar*P/(Kcu*A))*.5*Lu
2893 Tanh=FNtanh(Fe)
2896 Theta=Thetab*Tanh/Fe
2899 Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))*.16667
2902 Yy=(1+ (.559/Pr)^(9/16))^(8/27)
2905 Hbarc=K/Do*(.6+.387*Xx/Yy)^2
2908 IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
2911 Hbar=(Hbar+Hbarc)*.5
2914 GOTO 2890
2917 END IF
2920!
2923! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
2926 Ql=(Hbar+P*Kcu*A)*.5*Thetab*Tanh
2929 Qc=Q-2*Ql
2932 As=PI*Do*L
2935!
2938! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
2941 Qdp=Qc/As
2944 Htube=Qdp/Thetab

```

```

2947 Csf=(Cp*Thetab/Hfg)/(Qdp/(Mu*Hfg)+(.014/(9.81*Rho)*.5)**(1/3.)*Pr**1.7)
2950!
2953! RECORD TIME OF DATA TAKING
2956 IF Im=0 THEN
2959 OUTPUT 709:"TD"
2962 ENTER 709:Told$
2965 END IF
2968!
2971! OUTPUT DATA TO PRINTER
2974 PRINTER IS 701
2977 IF Iov=0 THEN
2980 PRINT
2983 PRINT USING "10X, ""Data Set Number = "",DDD,2X, ""Bulk Oil % = "",DD,D,5X,1
4A":J,Bop,Told$
2986 IF Ihm=0 THEN
2989 PRINT USING "10X, ""TC No:      1      2      3      4      5      6      7
8""
2992 PRINT USING "10X, ""Temp : "",8(1X,MDD,DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
2995 PRINT USING "10X, "" Twa      Tliqd      Tliqd2      Tvaqr      Psat      Tsump""
2998 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
3001 PRINT USING "10X, "" Thetab      Htube      Qdp""
3004 PRINT USING "10X,MDD,3D,1X,MZ,3DE,1X,MZ,3DE";Thetab,Htube,Qdp
3007 ELSE
3010 PRINT USING "10X, "" Fms      Vu      Tsat      Tlnl      Tdrop      Thetab      q      Uo
Ho""
3013* PRINT USING "10X,4(2D,DD,1X),Z,3D,1X,DD,DD,1X,3(MZ,3DE,1X)";Fms,Vu,Tsat,Tl
nlet,Tdrop,Thetab,Qd
3016 END IF
3019 END IF
3022 IF Iov=1 THEN
3025 IF J=1 THEN
3028 PRINT
3031 IF Ihm=0 THEN
3034 PRINT USING "10X, "" RUN No      Oil%      Tsat      Htube      Qdp      Thetab""
3037 ELSE
3040 PRINT USING "10X, "" FMS      OIL%      TSAT      HTUBE      QDP      THETAB""
3043 END IF
3046 END IF
3049 IF Ihm=0 THEN
3052 PRINT USING "12X,3D,4X,DD,2X,MDD,DD,3(1X,MZ,3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
3055 ELSE
3058 PRINT USING "12X,3D,4X,DD,2X,MDD,DD,3(1X,MZ,3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
3061 END IF
3064 END IF
3067 IF Im=0 THEN
3070 BEEP
3073 INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
3076 END IF
3079 IF Ok=1 OR Im=1 THEN J=J+1
3082 IF Ok=1 AND Im=0 THEN
3085 IF Ihm=0 THEN OUTPUT @File1:Bop,Told$,Emf(*),Vr,Ir
3088 IF Ihm=1 THEN OUTPUT @File1:Bop,Told$,Emf(*),Fms
3091 END IF
3094 IF Iuf=1 THEN OUTPUT @Ufile:Vu,Uo
3097 IF Ire=1 THEN OUTPUT @Rfile:Fms,Rew
3100 IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot:Qdp,Thetab
3103 IF Im=0 THEN

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```

3106 BEEP
3109 INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
3112 Nrun=J
3115 IF Go_on=0 THEN 3130
3118 IF Go_on<>0 THEN Repeat
3121 ELSE
3124 IF J<Nrun+1 THEN Repeat
3127 END IF
3130 IF Im=0 THEN
3133 BEEP
3136 PRINT USING "10X,"NOTE: "",ZZ," data runs were stored in file "",10A";J-
1,D2_files
3139 ASSIGN @File1 TO *
3142 OUTPUT @File2;Nrun-1
3145 ASSIGN @File1 TO D1_files
3148 ENTER @File1;Date$,Ldte1,Ldte2,Itt
3151 OUTPUT @File2;Date$,Ldte1,Ldte2,Itt
3154 FOR I=1 TO Nrun-1
3157 IF Ih=0 THEN
3160 ENTER @File1;Bop,Told$,Enf(*),Vr,Ir
3163 OUTPUT @File2;Bop,Told$,Enf(*),Vr,Ir
3166 ELSE
3169 ENTER @File1;Bop,Told$,Enf(*),Fms
3172 OUTPUT @File2;Bop,Told$,Enf(*),Fms
3175 END IF
3178 NEXT I
3181 ASSIGN @File1 TO *
3184 PURGE "DUMMY"
3187 END IF
3190 BEEP
3193 PRINT
3196* IF Iplot=1 THEN PRINT USING "10X,"NOTE: "",ZZ," X-Y pairs were stored in
plot data file "",1
3199 ASSIGN @File2 TO *
3202 ASSIGN @Plot TO *
3205 IF Iuf=1 THEN ASSIGN @Ufile TO *
3208 IF Ire=1 THEN ASSIGN @Refile TO *
3211 CALL Stats
3214 BEEP
3217 INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
3220 IF Ok=1 THEN CALL Plot
3223 SUBEND
3226!
3229! CURVE FITS OF PROPERTY FUNCTIONS
3232 DEF FNKcu(T)
3235! OFHC COPPER 250 TO 300 K
3238 Tk=T+273.15 !C TO K
3241 K=434-.112*Tk
3244 RETURN K
3247 FNEND
3250 DEF FNMu(T)
3253! 170 TO 360 K CURVE FIT OF VISCOSITY
3256 Tk=T+273.15 !C TO K
3259 Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
3262 RETURN Mu
3265 FNEND
3268 DEF FNCp(T)
3271! 180 TO 400 K CURVE FIT OF Cp
3274 Tk=T+273.15 !C TO K
3277 Cp=.40188+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3

```

```

3280 - Cp=Cp*1000
3283 RETURN Cp
3286 FNEND
3289 DEF FNRho(T)
3292 Tk=T+273.15 !C TO K
3295 X=1-(1.8*Tk/753.95) !K TO R
3298 Ro=36.32+61.146414*X*(1/3)+16.418015*X+17.476838*X*.5+1.119828*X^2
3301 Ro=Ro/.062428
3304 RETURN Ro
3307 FNEND
3310 DEF FNPt(T)
3313 Pt=FNCp(T)*FNMu(T)/FNK(T)
3316 RETURN Pt
3319 FNEND
3322 DEF FNK(T)
3325! T<360 K WITH T IN C
3328 K=.071-.000261*T
3331 RETURN K
3334 FNEND
3337 DEF FNTanh(X)
3340 P=EXP(X)
3343 Q=1/P
3346 Tanh=(P-Q)/(P+Q)
3349 RETURN Tanh
3352 FNEND
3355 DEF FNTvsV(V)
3358 COM /Cc/ C(7),Ical
3361 T=C(0)
3364 FOR I=1 TO 7
3367 T=T+C(I)*V*I
3370 NEXT I
3373 IF Ical=1 THEN
3376 T=T-6.7422934E-2+T*(9.0277043E-3-T*(-9.3259917E-5))
3379 ELSE
3382 T=T+8.626897E-2+T*(3.76199E-3-T*5.0689259E-5)
3385 END IF
3388 RETURN T
3391 FNEND
3394 DEF FNBeta(T)
3397 Rop=FNRho(T+.1)
3400 Rom=FNRho(T-.1)
3403 Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
3406 RETURN Beta
3409 FNEND
3412 DEF FNHfg(T)
3415 Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
3418 RETURN Hfg
3421 FNEND
3424 DEF FNPsat(Tc)
3427! 0 TO 80 deg F CURVE FIT OF Psat
3430 Tf=1.8*Tc+32
3433 Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
3436 Pg=Pa-14.7
3439 IF Pg>0 THEN ! +=PSIG,--in Hg
3442 Psat=Pg
3445 ELSE
3448 Psat=Pg*29.92/14.7
3451 END IF
3454 RETURN Psat
3457 FNEND

```

```

3460 DEF FNHsmooth(X,Bop,Isat)
3463 DIM A(5),B(5),C(5),D(5)
3466 DATA .20526..25322..319048..55322..79909.1.00258
3469 DATA .74515..72992..73189..71225..68472..64197
3472 DATA .41092..17726..25142..54806..81916.1.0845
3475 DATA .71403..72913..72565..696691..665867..61889
3478 READ A(*),B(*),C(*),D(*)
3481 IF Bop<6 THEN I=Bop
3484 IF Bop=6 THEN I=4
3487 IF Bop=10 THEN I=5
3490 IF Isat=1 THEN
3493 Hs=EXP(A(I)+B(I)*LOG(X))
3496 ELSE
3499 Hs=EXP(C(I)+D(I)*LOG(X))
3502 END IF
3505 RETURN Hs
3508 FNEND
3511 DEF FNPoly(X)
3514 COM /Cpoly/ A(10,10),C(10),B(4),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3517 X1=X
3520 Poly=B(0)
3523 FOR I=1 TO Nop
3526 IF Ilog=1 THEN X1=LOG(X)
3529 Poly=Poly+B(I)*X1^I
3532 NEXT I
3535 IF Ilog=1 THEN Poly=EXP(Poly)
3538 RETURN Poly
3541 FNEND
3544 SUB Poly
3547 DIM R(10),S(10),Sy(12),Sx(12),Xx(100),Yy(100)
3550 COM /Cpoly/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3553 COM /Xxyy/ Xp(25),Yp(25)
3556 FOR I=0 TO 4
3559 B(I)=0
3562 NEXT I
3565 BEEP
3568 INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",Im
3571 Im=Im+1
3574 BEEP
3577 INPUT "ENTER NUMBER OF X-Y PAIRS",No
3580 IF Im=1 THEN
3583 BEEP
3586 INPUT "ENTER DATA FILE NAME",D_files$
3589 BEEP
3592 INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
3595 IF Ied=1 THEN
3598 BEEP
3601 INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
3604 END IF
3607 ASSIGN @File TO D_files$
3610 ELSE
3613 BEEP
3616 INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
3619 IF Yes=1 THEN
3622 BEEP
3625 INPUT "GIVE A NAME FOR DATA FILE",D_files$
3628 CREATE BDAT D_files$.S
3631 ASSIGN @File TO D_files$
3634 END IF
3637 END IF

```

```

3640 BEEP
3643 INPUT "ENTER THE ORDER OF POLYNOMIAL",N
3646 FOR I=0 TO N*2
3649 Sy(I)=0
3652 Sx(I)=0
3655 NEXT I
3658 IF Ied=1 AND Im=1 THEN
3661 FOR I=1 TO Ipex
3664 ENTER @File:X.Y
3667 NEXT I
3670 END IF
3673 FOR I=1 TO Np
3676 IF Im=1 THEN
3679 IF Opo=2 THEN ENTER @File:X.Y
3682 IF Opo<2 THEN ENTER @File:Y.X
3685 IF Opo=1 THEN Y=Y/X
3688 IF Ilog=1 THEN
3691 IF Opo=2 THEN Xt=X/Y
3694 X=LOG(X)
3697 IF Opo=2 THEN Y=LOG(Xt)
3700 IF Opo<2 THEN Y=LOG(Y)
3703 END IF
3706 END IF
3709 IF Im=2 THEN
3712 BEEP
3715 INPUT "ENTER NEXT X-Y PAIR",X.Y
3718 IF Yes=1 THEN OUTPUT @File:X.Y
3721 END IF
3724 IF Im<3 THEN
3727 Xx(I)=X
3730 Yy(I)=Y
3733 ELSE
3736 X=Xp(I-1)
3739 Y=Yp(I-1)
3742 END IF
3745 R(0)=Y
3748 Sy(0)=Sy(0)+Y
3751 S(1)=X
3754 Sx(1)=Sx(1)+X
3757 FOR J=1 TO N
3760 R(J)=R(J-1)*X
3763 Sy(J)=Sy(J)+R(J)
3766 NEXT J
3769 FOR J=2 TO N*2
3772 S(J)=S(J-1)*X
3775 Sx(J)=Sx(J)+S(J)
3778 NEXT J
3781 NEXT I
3784 IF Yes=1 AND Im=2 THEN
3787 BEEP
3790 PRINT USING "12X,DD.[]" X-Y pairs were stored in file ".10A";Np,D_files
3793 END IF
3796 Sx(0)=Np
3799 FOR I=0 TO N
3802 C(I)=Sy(I)
3805 FOR J=0 TO N
3808 A(I,J)=Sx(I+J)
3811 NEXT J
3814 NEXT I
3817 FOR I=0 TO N-1
3820 CALL Divide(I)

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3823 CALL Subtract(I+1)
3826 NEXT I
3829 B(N)=C(N)/A(N,N)
3832 FOR I=0 TO N-1
3835 B(N-1-I)=C(N-1-I)
3838 FOR J=0 TO I
3841 B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
3844 NEXT J
3847 B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
3850 NEXT I
3853 !PRINTER IS 701
3856 !PRINT B(*)
3859 !PRINTER IS 705
3862 IF Iprnt=0 THEN
3865 PRINT USING "12X,""EXPONENT    COEFFICIENT""
3868 FOR I=0 TO N
3871 PRINT USING "15X,DD.5X,MD.7DE";I,B(I)
3874 NEXT I
3877 PRINT " "
3880 PRINT USING "12X,""DATA POINT      X          Y          Y(CALCULATED) DISCR
EPANCY""
3883 FOR I=1 TO Np
3886 Yc=B(0)
3889 FOR J=1 TO N
3892 Yc=Yc+B(J)*Xx(I)*J
3895 NEXT J
3898 D=Yy(I)-Yc
3901 PRINT USING "15X,3D.4X.4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
3904 NEXT I
3907 END IF
3910 ASSIGN @File TO *
3913 SUBEND
3916 SUB Divide(M)
3919 COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,0po,Ilog,Ifn,Ijoin,Njoin
3922 FOR I=M TO N
3925 Ao=A(I,M)
3928 FOR J=M TO N
3931 A(I,J)=A(I,J)/Ao
3934 NEXT J
3937 C(I)=C(I)/Ao
3940 NEXT I
3943 SUBEND
3946 SUB Subtract(K)
3949 COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,0po,Ilog,Ifn,Ijoin,Njoin
3952 FOR I=K TO N
3955 FOR J=K-1 TO N
3958 A(I,J)=A(K-1,J)-A(I,J)
3961 NEXT J
3964 C(I)=C(K-1)-C(I)
3967 NEXT I
3970 SUBEND
3973 SUB Plin
3976 COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,0po,Ilog,Ifn,Ijoin,Njoin
3979 COM /Xxyy/ Xx(25),Yy(25)
3982 PRINTER IS 705
3985 BEEP
3988 INPUT "WANT TO PLOT Uo vs Vw? (1-Y,0-N)",Iuo
3991 IF Iuo=0 THEN
3994 BEEP
3997 INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt

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4000 BEEP
4003 INPUT "SELECT h/h RATIO (1=FILE.0-COMPUTED)".Ihrat
4006 IF Ihrat=0 THEN
4009 BEEP
4012 INPUT "WHICH Tsat (1=6.7,0=-2.2)".Isat
4015 END IF
4018 Xmin=0
4021 Xmax=10
4024 Xstep=2
4027 IF Irt=0 THEN
4030 Ymin=0
4033 Ymax=1.4
4036 Ystep=.2
4039 ELSE
4042 Ymin=0
4045 Ymax=15
4048 Ystep=5
4051 END IF
4054 ELSE
4057 Opo=2
4060 Ymin=0
4063 Ymax=12
4066 Ystep=3
4069 Xmin=0
4072 Xmax=4
4075 Xstep=1
4078 END IF
4081 IF Ihrat=1 THEN
4084 Ymin=0
4087 Ymax=18
4090 Ystep=3
4093 Xmin=0
4096 Xmax=9
4099 Xstep=2
4102 END IF
4105 BEEP
4108 PRINT "IN:SP1:IP 2300.2200.8300.6800;"
4111 PRINT "SC 0.100.0.100:TL 2.0;"
4114 Sfx=100/(Xmax-Xmin)
4117 Sfy=100/(Ymax-Ymin)
4120 PRINT "PU 0.0 PD"
4123 FOR Xa=Xmin TO Xmax STEP Xstep
4126 X=(Xa-Xmin)*Sfx
4129 PRINT "PA":X,".0: XT;"
4132 NEXT Xa
4135 PRINT "PA 100.0:PU:"
4138 PRINT "PU PA 0.0 PD"
4141 FOR Ya=Ymin TO Ymax STEP Ystep
4144 Y=(Ya-Ymin)*Sfy
4147 PRINT "PA 0.";Y,"YT"
4150 NEXT Ya
4153 PRINT "PA 0.100 TL 0 2"
4156 FOR Xa=Xmin TO Xmax STEP Xstep
4159 X=(Xa-Xmin)*Sfx
4162 PRINT "PA":X,".100: XT"
4165 NEXT Xa
4168 PRINT "PA 100.100 PU PA 100.0 PD"
4171 FOR Ya=Ymin TO Ymax STEP Ystep
4174 Y=(Ya-Ymin)*Sfy
4177 PRINT "PD PA 100.";Y,"YT"
4180 NEXT Ya

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4183 PRINT "PA 100,100 PU"
4186 PRINT "PA 0,-2 SR 1.5,2"
4189 FOR Xa=Xmin TO Xmax STEP Xstep
4192 X=(Xa-Xmin)*Sfx
4195 PRINT "PA";X,".0:"
4198 IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;"
4201 IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;"
4204 NEXT Xa
4207 PRINT "PU PA 0.0"
4210 FOR Ya=Ymin TO Ymax STEP Ystep
4213 IF ABS(Ya)<1.E-5 THEN Ya=0
4216 Y=(Ya-Ymin)*Sfy
4219 PRINT "PA 0,";Y,"
4222 IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;"
4225 IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;"
4228 NEXT Ya
4231 Xlabels="Oil Percent"
4234 IF Iuo=0 THEN
4237 IF Irt=0 THEN
4240 Ylabels="h/h0z"
4243 ELSE
4246 Ylabels="h/hsmooth"
4249 END IF
4252 PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabels)/2;"0;LB";Xlabels;"
4255 PRINT "PA -11,50 CP 0,";-LEN(Ylabels)/2*5/6;"DI 0,1;LB";Ylabels;"
4258 PRINT "CP 0,0"
4261 ELSE
4264 PRINT "SP0;SP2"
4267 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

4270 PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
4273 PRINT "PA 42,-10;DI 1,0;LBV;PR .4,-1;LBw;PR 1,.5;LB(m/s)"
4276 PRINT "SP0;SP1"
4279 END IF
4282 Ipn=0
4285 BEEP
4288 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Okp
4291 Icn=0
4294 IF Okp=1 THEN
4297 BEEP
4300 INPUT "ENTER THE NAME OF THE DATA FILE",D_files
4303! IF Iuo=0 THEN
4306 BEEP
4309 INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)).Ilog
4312! END IF
4315 ASSIGN %File TO D_files
4318 BEEP
4321 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
4324 BEEP
4327 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
4330 IF Iuo=0 AND Ihrat=0 THEN
4333 BEEP
4336 INPUT "ENTER DESIRED HEAT FLUX",Q
4339 END IF
4342 BEEP
4345 PRINTER IS 1
4348 PRINT USING "4X,";"Select a symbol:"
4351 PRINT USING "4X,";"1 Star 2 Plus sign"
4354 PRINT USING "4X,";"3 Circle 4 Square"
4357 PRINT USING "4X,";"5 Rombus"

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4360 PRINT USING "4X."*6 Right-side-up triangle""
4363 PRINT USING "4X."*7 Up-side-down triangle""
4366 INPUT Sym
4369 PRINTER IS 705
4372 PRINT "PU DI"
4375 IF Sym=1 THEN PRINT "SM*"
4378 IF Sym=2 THEN PRINT "SM+"
4381 IF Sym=3 THEN PRINT "SMo"
4384 Nn=4
4387 IF Ilog=1 THEN Nn=1
4390 IF Md>1 THEN
4393 FOR I=1 TO (Md-1)
4396 ENTER @File:Xa,Ya
4399 NEXT I
4402 END IF
4405 IF Ihrat=0 THEN
4408 Q1=Q
4411 IF Ilog=1 THEN Q=LOG(Q)
4414 END IF
4417 FOR I=1 TO Npairs
4420 IF Iuo=0 AND Ihrat=0 THEN
4423 ENTER @File:Xa,B(*)
4426 Ya=B(0)
4429 FOR K=1 TO Nn
4432 Ya=Ya+B(K)*Q*K
4435 NEXT K
4438 END IF
4441 IF Iuo=1 OR Ihrat=1 THEN
4444 ENTER @File:Xa,Ya
4447 IF Iuo=1 THEN Ya=Ya/1000
4450 END IF
4453 IF Iuo=0 AND Ihrat=0 THEN
4456 IF Ilog=1 THEN Ya=EXP(Ya)
4459 IF Ilog=0 THEN Ya=Q1/Ya
4462 IF Irt=0 THEN
4465 IF Xa=0 THEN
4468 Yo=Ya
4471 Ya=1
4474 ELSE
4477 Ya=Ya/Yo
4480 END IF
4483 ELSE
4486 Hsm=FNHsmooth(Q,Xa,Isat)
4489 Ya=Ya/Hsm
4492 END IF
4495 END IF
4498 Xx(I-1)=Xa
4501 Yy(I-1)=Ya
4504 X=(Xa-Xmin)*Sfx
4507 Y=(Ya-Ymin)*Sfy
4510 IF Sym>3 THEN PRINT "SM"
4513 IF Sym<4 THEN PRINT "SR 1.4,2.4"
4516 PRINT "PA",X,Y,""
4519 IF Sym>3 THEN PRINT "SR 1.2,1.6"
4522 IF Sym=4 THEN PRINT "UC2,4.99,0,-8,-4,0,0,8,4,0,;"
4525 IF Sym=5 THEN PRINT "UC3,0.99,-3,-6,-3,6,3,6,3,-6,;"
4528 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8,;"
4531 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8,;"
4534 NEXT I
4537 BEEP
4540 ASSIGN @File TO *

```

```

4543 END IF
4546 PRINT "PU SM"
4549 BEEP
4552 INPUT "WANT TO PLOT A POLYNOMIAL (1-Y,0-N)?",Okp
4555 IF Okp=1 THEN
4558 BEEP
4561 PRINTER IS 1
4564 PRINT USING "4X.";"Select line type:***
4567 PRINT USING "6X.";"0      Solid line***
4570 PRINT USING "6X.";"1      Dashed***
4573 PRINT USING "6X.";"2...5 Longer line - dash***
4576 INPUT Ipn
4579 PRINTER IS 705
4582 BEEP
4585 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
4588 Iprnt=1
4591 CALL Poly
4594 IF Iuo=1 THEN
4597 BEEP
4600 INPUT "DESIRE TO SET X Lower and Upper Limit (1-Y,0-N)?",Ixlim
4603 IF Ixlim=0 THEN
4606 Xll=0
4609 Xul=7
4612 END IF
4615 IF Ixlim=1 THEN
4618 BEEP
4621 INPUT "ENTER X Lower Limit",Xll
4624 BEEP
4627 INPUT "ENTER X Upper Limit",Xul
4630 END IF
4633 END IF
4636 FOR Xa=Xll TO Xul STEP Xstep/25
4639 Icn=Icn+1
4642 Ya=FNPoly(Xa)
4645 IF Iuo=1 THEN Ya=Ya/1000
4648 Y=(Ya-Ymin)*Sfy
4651 X=(Xa-Xmin)*Sfx
4654 IF Y<0 THEN Y=0
4657 IF Y>100 THEN GOTO 4637
4660 Pu=0
4663 IF Ipn=1 THEN Idf=Icn MOD 2
4666 IF Ipn=2 THEN Idf=Icn MOD 4
4669 IF Ipn=3 THEN Idf=Icn MOD 8
4672 IF Ipn=4 THEN Idf=Icn MOD 16
4675 IF Ipn=5 THEN Idf=Icn MOD 32
4678 IF Idf=1 THEN Pu=1
4681 IF Pu=0 THEN PRINT "PA".X.Y,"PD"
4684 IF Pu=1 THEN PRINT "PA".X.Y,"PU"
4687 NEXT Xa
4690 PRINT "PU"
4693 GOTO 4285
4696 END IF
4699 BEEP
4702 INPUT "WANT TO QUIT (1-Y,0-N)?",Iquit
4705 IF Iquit=1 THEN 4711
4708 GOTO 4285
4711 PRINT "PU SP0"
4714 SUBEND
4717 SUB Stats
4720 PRINTER IS 701

```

```

4723 J=0
4726 K=0
4729 BEEP
4732 IF Iplot=1 THEN ASSIGN @File TO P_file$
4735 BEEP
4738 INPUT "LAST RUN No?(0=QUIT)",Nn
4741 IF Nn=0 THEN 4849
4744 Nn=Nn-J
4747 Sx=0
4750 Sy=0
4753 Sz=0
4756 Sxs=0
4759 Sys=0
4762 Szs=0
4765 FOR I=1 TO Nn
4768 J=J+1
4771 ENTER @File:Q,T
4774 H=Q/T
4777 Sx=Sx+Q
4780 Sxs=Sxs+Q^2
4783 Sy=Sy+T
4786 Sys=Sys+T^2
4789 Sz=Sz+H
4792 Szs=Szs+H^2
4795 NEXT I
4798 Qave=Sx/Nn
4801 Tave=Sy/Nn
4804 Have=Sz/Nn
4807 Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
4810 Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
4813 Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
4816 Sh=100*Sdevh/Have
4819 Sq=100*Sdevq/Qave
4822 St=100*Sdevt/Tave
4825 IF K=1 THEN 4843
4828 PRINT
4831 PRINT USING "11X,""DATA FILE:"",14A":File$
4834 PRINT
4837 PRINT USING "11X,""RUN Htube      SdevH      Qdp      SdevQ      Thetab SdevT""
-
4840 K=1
4843 PRINT USING "11X,DD,2(2X,D.3DE.1X.3D.2D),2X,DD.3D.1X.3D.2D":J,Have,Sh,Qave,
,Sq,Tave,St
4846 GOTO 4735
4849 ASSIGN @File1 TO *
4852 PRINTER IS 1
4855 SUBEND
4858 SUB Coef
4861 COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4864 BEEP
4867 INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
4870 CREATE BDAT Cpf$.2
4873 ASSIGN @File TO Cpf$
4876 BEEP
4879 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
4882 BEEP
4885 INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
4888 IF Bop<0 THEN 4900
4891 CALL Poly
4894 OUTPUT @File:Bop.B(*)
4897 GOTO 4882

```

```

4900 ASSIGN %File TO *
4903 SUBEND
4906 SUB Wilson(Cf,Ci)
4909 COM /Wil/ 02.Di,Do,L,Lu,Kcu
4912 DIM Emf(12)
4915! WILSON PLOT SUBROUTINE DETERMINE CF AND CI
4918 BEEP
4921 INPUT "ENTER DATA FILE NAME",File$
4924 BEEP
4927 PRINTER IS 1
4930 PRINT USING "4X.""Select option:""
4933 PRINT USING "4X."" 0 Vary Cf and Ci""
4936 PRINT USING "4X."" 1 Fix Cf Vary Ci""
4939 PRINT USING "4X."" 2 Vary Cf Fix Ci""
4942 INPUT "ENTER OPTION",Icfix
4945 PRINTER IS 701
4948 IF Icfix=0 THEN 4960
4951 IF Icfix>0 THEN BEEP
4954 IF Icfix=1 THEN INPUT "ENTER Cf",Csf
4957 IF Icfix=2 THEN INPUT "ENTER CI",Ci
4960 PRINTER IS 1
4963 INPUT "Want To Vary Coeff?(1-Y,0-N)",Iccoeff
4966 IF Iccoeff=1 THEN INPUT "ENTER COEFF",R
4969 PRINTER IS 701
4972 IF Icfix=0 OR Icfix=2 THEN Cfa=.004
4975 IF Icfix=1 THEN Cfa=Csf
4978 Cia=Ci
4981 Xn=.3
4984 Fr=.3
4987 Jj=0
4990 Rr=3.
4993 IF Iccoeff=1 THEN Rr=R
4996 PRINTER IS 1
4999 PRINT Do,Di,Kcu
5002 ASSIGN %File TO Files
5005 ENTER %File:Nrun,Date$,Ldte1,Ldte2,Itt
5008 Rn=Do*LOG(Do/Di)/(2*Kcu)
5011 Sx=0
5014 Sy=0
5017 Sxy=0
5020 Sx2=0
5023 Sy2=0
5026 FOR I=1 TO Nrun
5029 ENTER %File:Bop,Told$,Emf(*).Fms
5032! CONVERT EMF'S TO TEMPERATURE
5035 FOR J=1 TO 5
5038 T(J)=FNTvsv(Emf(J))
5041 NEXT J
5044 Tsat=(T(1)+T(2))*5
5047 Tavg=T(5)
5050 Grad=37.3853+.104388*Tavg
5053 Tdrop=Emf(7)*1.E+6/(10.*Grad)
5056 Tavgc=T(5)-Tdrop*.5
5059 IF ABS(Tavg-Tavgc)>.01 THEN
5062 Tavg=(Tavg+Tavgc)*.5
5065 GOTO 5050
5068 END IF
5071!
5074! Compute properties of water
5077 Kw=FNKw(Tavg)

```

```

5080 Muwa=FNMuw(Tavg)
5083 Cpw=FNCPw(Tavg)
5086 Prw=FNPrw(Tavg)
5089 Rhow=FNRRhow(Tavg)
5092!
5095! Compute properties of Freon-114
5098 Lmtd=Tdrop/LOG((T(S)-Tsat)/(T(S)-Tdrop-Tsat))
5101 IF Jj=0 THEN
5104 Tw=Tsat+Fr*Lmtd
5107 Thetab=Tw-Tsat
5110 Jj=1
5113 END IF
5116 Tf=(Tw+Tsat)*.5
5119 Rho=FNRRho(Tf)
5122 Mu=FNMu(Tf)
5125 K=FNK(Tf)
5128 Cp=FNCP(Tf)
5131 Beta=FNBeta(Tf)
5134 Hfg=FNHfg(Tsat)
5137 Ni=Mu/Rho
5140 Alpha=K/(Rho*Cp)
5143 Pr=Ni/Alpha
5146!
5149! Analysis
5152! COMPUTE MDOT
5155 A=PI*(Do^2-Di^2)/4
5158 P=PI*Do
5161 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
5164 Q=Mdot*Cpw*Tdrop
5167! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
5170! FOR UNENHANCED END(S)
5173 Hbar=190
5176 Fe=(Hbar*P/(Kcu*A))*.5*Lu
5179 Tanh=FNtanh(Fe)
5182 Theta=Thetab*Tanh/Fe
5185 Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni+Alpha))*.166667
5188 Yy=(1+ (.559/Pr)^(9/16))^(8/27)
5191 Hbarc=K/Do*(.6+.387*Xx/Yy)^.2
5194 IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
5197 Hbar=(Hbar+Hbarc)*.5
5200 GOTO 5176
5203 END IF
5206!
5209! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
5212 Q1=(Hbar*P*Kcu*A)*.5*Theta*Tanh
5215 Qc=Q-2*Q1
5218 As=PI*O2*L
5221! COMPUTE ACTUAL HEAT FLUX
5224 Qdp=Qc/As
5227 IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf*(1./Rr)
5230 Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))*.5)^(1/Rr)*Pr^1.7
5233 Ho=Qdp/Thetab
5236 Omega=Ho/Cf
5239 Uo=Q/(PI*Do*L+Lmtd)
5242 Vw=Mdot/(Rhow*PI*Di^2/4)
5245 Rew=Rhow*Vw*Di/Muwa
5248 Tw=Tw+Q*Rw/(PI*Do*L)
5251 Gama=Kw/Di+Rew*.3*Prw^(1/3.)*(Muwa/FNMuw(Tw))*.14
5254! PRINTER IS 1
5257 Yw=(1./Uo-Rw)*Omega

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```

5260 Xu=Omega*Do/(Gama*D1)
5263 Sx=Sx+Xu
5266 Sy=Sy+Yu
5269 Sxy=Sxy+Yu*Xu
5272 Sx2=Sx2+Xu*Xu
5275 Sy2=Sy2+Yu*Yu
5278 NEXT I
5281 ASSIGN @File TO *
5284 M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
5287 C=(Sy-Sx*M)/Nrun
5290 IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
5293 Cic=1/M
5296 Cfc=1/C
5299 END IF
5302 IF Icfix=1 THEN
5305 Cic=1/M
5308 Cfc=Cf
5311 END IF
5314 IF Icfix=2 THEN
5317 Cic=Ci
5320 Cfc=1/C
5323 END IF
5326 IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
5329 Ci=(Ci+Cic)*.5
5332 Cf=(Cf+Cfc)*.5
5335 PRINTER IS 1
5338 PRINT USING "2X.`` Csf = ``.MZ.3DE.2X.`` Ci = ``.MZ.3DE``:Csf,Ci
5341 PRINTER IS 701
5344 GOTO 5002
5347 END IF
5350 PRINT
5353 PRINTER IS 701
5356 PRINT USING "23X.`` Cf          Ci``"
5359 PRINT USING "8X.``ASSUMED      ``.MZ:3DE.3X.MZ.3DE``:Cfa,Cia
5362 PRINT USING "8X.``CALCULATED   ``.MZ.3DE.3X.MZ.3DE``:Csf,Ci
5365 PRINT
5368 Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
5371 PRINT USING "10X.``Sum of Squares = ``.Z.3DE``:Sum2
5374 PRINT USING "10X.``Coefficient = ``.D.000``:Rr
5377 SUBEND
5380 DEF FNMuu(T)
5383 A=247.8/(T+133.15)
5386 Mu=2.4E-5+10*A
5389 RETURN Mu
5392 FNEEND
5395 DEF FNCpu(T)
5398 Cpu=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
5401 RETURN Cpu*1000
5404 FNEEND
5407 DEF FNRhow(T)
5410 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
5413 RETURN Ro
5416 FNEEND
5419 DEF FNPtu(T)
5422 Ptu=FNCpu(T)*FNMuu(T)/FNKu(T)
5425 RETURN Ptu
5428 FNEEND
5431 DEF FNKu(T)
5434 X=(T+273.15)/273.15
5437 Ku=-.92247+X*(2.9395-X*(1.9007-X*(.52577-.07344*X)))

```

```

5440 RETURN Kw
5443 FNEND
5446 SUB Plot
5449 COM /Cply/ A(10,10),C(10),B(4),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
5452 DIM Bs(3)
5455 INTEGER I1
5458 PRINTER IS 1
5461 BEEP
5464 INPUT "SELECT HEATING MODE (0-ELECTRIC, 1-WATER)",Ihm
5467 Idv=0
5470 BEEP
5473 INPUT "LIKE DEFAULT VALUES FOR PLOT (1-Y,0-N)?",Idv
5476 Opo=0
5479 BEEP
5482 PRINT USING "4X,""Select Option: ""
5485 PRINT USING "6X,""0 q versus delta-T""
5488 PRINT USING "6X,""1 h versus delta-T""
5491 PRINT USING "6X,""2 h versus q""
5494 INPUT Opo
5497 BEEP
5500 INPUT "SELECT UNITS (0-SI,1-ENGLISH)",Iun
5503 PRINTER IS 705
5506 IF Idv<>1 THEN
5509 BEEP
5512 INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
5515 BEEP
5518 INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
5521 BEEP
5524 INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
5527 BEEP
5530 INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
5533 ELSE
5536 IF Opo=0 THEN
5539 IF Ihm=1 THEN
5542 Cy=1
5545 Cx=2
5548 Xmin=1
5551 Ymin=10000
5554 ELSE
5557 Cy=3
5560 Cx=3
5563 Xmin=.1
5566 Ymin=100
5569 END IF
5572 END IF
5575 IF Opo=1 THEN
5578 IF Ihm=1 THEN
5581 Cy=2
5584 Cx=2
5587 Xmin=.1
5590 Ymin=100
5593 ELSE
5596 Cy=3
5599 Cx=2
5602 Xmin=1000
5605 Ymin=100
5608 END IF
5611 END IF
5614 IF Opo=2 THEN
5617 IF Ihm=1 THEN
5620 Cy=2

```

```

5623 Cx=1
5626 Xmin=10000
5629 Ymin=100
5632 ELSE
5635 Cy=3
5638 Cx=3
5641 Xmin=.1
5644 Ymin=100
5647 END IF
5650 END IF
5653 END IF
5656 BEEP
5659 PRINT "IN:SP1:IP 2300.2200.8300.6800;"
5662 PRINT "SC 0.100.0.100:TL 2.0;"
5665 Sfx=100/Cx
5668 Sfy=100/Cy
5671 BEEP
5674 INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
5677 IF Ibyp=1 THEN 6049
5680 PRINT "PU 0.0 PD"
5683 Nn=9
5686 FOR I=1 TO Cx+1
5689 Xat=Xmin*10*(I-1)
5692 IF I=Cx+1 THEN Nn=1
5695 FOR J=1 TO Nn
5698 IF J=1 THEN PRINT "TL 2 0"
5701 IF J=2 THEN PRINT "TL 1 0"
5704 Xa=Xat*J
5707 X=LGT(Xa/Xmin)*Sfx
5710 PRINT "PA";X;".0: XT:"
5713 NEXT J
5716 NEXT I
5719 PRINT "PA 100.0:PU:"
5722 PRINT "PU PA 0.0 PD"
5725 Nn=9
5728 FOR I=1 TO Cy+1
5731 Yat=Ymin*10*(I-1)
5734 IF I=Cy+1 THEN Nn=1
5737 FOR J=1 TO Nn
5740 IF J=1 THEN PRINT "TL 2 0"
5743 IF J=2 THEN PRINT "TL 1 0"
5746 Ya=Yat*J
5749 Y=LGT(Ya/Ymin)*Sfy
5752 PRINT "PA 0.";Y;"YT"
5755 NEXT J
5758 NEXT I
5761 PRINT "PA 0.100 TL 0 2"
5764 Nn=9
5767 FOR I=1 TO Cx+1
5770 Xat=Xmin*10*(I-1)
5773 IF I=Cx+1 THEN Nn=1
5776 FOR J=1 TO Nn
5779 IF J=1 THEN PRINT "TL 0 2"
5782 IF J>1 THEN PRINT "TL 0 1"
5785 Xa=Xat*J
5788 X=LGT(Xa/Xmin)*Sfx
5791 PRINT "PA";X;".100: XT"
5794 NEXT J
5797 NEXT I
5800 PRINT "PA 100.100 PU PA 100.0 PD"

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```

5803 Nn=9
5806 FOR I=1 TO Cy+1
5809 Yat=Ymin*10*(I-1)
5812 IF I=Cy+1 THEN Nn=1
5815 FOR J=1 TO Nn
5818 IF J=1 THEN PRINT "TL 0 2"
5821 IF J>1 THEN PRINT "TL 0 1"
5824 Ya=Yat+J
5827 Y=LGT(Ya/Ymin)*Sfy
5830 PRINT "PD PA 100.",Y,"YT"
5833 NEXT J
5836 NEXT I
5839 PRINT "PA 100.100 PU"
5842 PRINT "PA 0.-2 SR 1.5,2"
5845 Ii=LGT(Xmin)
5848 FOR I=1 TO Cx+1
5851 Xa=Xmin*10*(I-1)
5854 X=LGT(Xa/Xmin)*Sfx
5857 PRINT "PA":X,".0:"
5860 IF Ii>0 THEN PRINT "CP -2,-2;LB10;PR -2.2;LB":Ii:""
5863 IF Ii<0 THEN PRINT "CP -2,-2;LB10;PR 0.2;LB":Ii:""
5866 Ii=Ii+1
5869 NEXT I
5872 PRINT "PU PA 0.0"
5875 Ii=LGT(Ymin)
5878 Y10=10
5881 FOR I=1 TO Cy+1
5884 Ya=Ymin*10*(I-1)
5887 Y=LGT(Ya/Ymin)*Sfy
5890 PRINT "PA 0.",Y,""
5893 PRINT "CP -4,-.25;LB10;PR -2.2;LB":Ii:""
5896 Ii=Ii+1
5899 NEXT I
5902 BEEP
5905 INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?".Id1
5908 IF Id1<>1 THEN
5911 BEEP
5914 INPUT "ENTER X-LABEL",Xlabels
5917 BEEP
5920 INPUT "ENTER Y-LABEL",Ylabels
5923 END IF
5926 IF Opo<2 THEN
5929 PRINT "SR 1.2;PU PA 40,-14:"
5932 PRINT "LB(T;PR -1.6,3 PD PR 1.2,0 PU;PR .5,-4;LBwo;PR .5,1:"
5935 PRINT "LB-T;PR .5,-1;LBsat;PR .5,1:"
5938 IF Iun=0 THEN
5941 PRINT "LB) (K)"
5944 ELSE
5947 PRINT "LB) (F)"
5950 END IF
5953 END IF
5956 IF Opo=2 THEN
5959 IF Iun=0 THEN
5962 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)"
5965 ELSE
5968 PRINT "SR 1.5,2;PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.;PR .5,-.5:"
5971 PRINT "LBft;PR .5,1;SR 1.1,5;LB2;SR 1.5,2;PR .5,-1;LB);"
5974 END IF
5977 END IF
5980 IF Opo=0 THEN

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5983 IF Iun=0 THEN
5986 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 1.5.5:LB)"
5989 ELSE
5992 PRINT "SR 1.5.2:PU PA -12.32:DI 0.1:LBq (Btu/hr:PR -.5.5:LB.:PR .5.5:"
5995 PRINT "LBft:SR 1.1.5:PR -1.5:LB2:PR 1.5.5:SR 1.5.2:LB)"
5998 END IF
6001 END IF
6004 IF Opo>0 THEN
6007 IF Iun=0 THEN
6010! 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:"
6013 PRINT "SR 1.2.2.4:PU PA -12.37:DI 0.1:LBh:PR 1.0.5:LB0:PR -1.0.5:LB (W/m
6016 PRINT "PR -1.5:SR 1.1.5:LB2:SR 1.5.2:PR .5.5:LB.:PR .5.0:LBK)"
6019 ELSE
6022 PRINT "SR 1.5.2:PU PA -12.28:DI 0.1:LBh (Btu/hr:PR -.5.5:LB.:PR .5.5:"
6025 PRINT "LBft:PR -1.5:SR 1.1.5:LB2:SR 1.5.2:PR .5.5:LB.:PR .5.5:LBF)"
6028 END IF
6031 END IF
6034 IF Idl=0 THEN
6037 PRINT "SR 1.5.2:PU PA 50.-16 CP":;-LEN(Xlabels)/2:"0:LB":Xlabels:;;
6040 PRINT "PA -14.50 CP 0.":;-LEN(Ylabels)/2*5/6:"DI 0.1:LB":Ylabels:;;
6043 PRINT "CP 0.0 DI"
6046 END IF
6049 Ipn=0
6052 Xll=1.E+6
6055 Xul=-1.E+6
6058 Icn=0
6061 Ifn=0
6064 Ijoin=1
6067 BEEP
6070 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?".Ok
6073 IF Ok=1 THEN
6076 BEEP
6079 INPUT "ENTER THE NAME OF THE DATA FILE".D_files
6082 ASSIGN @File TO D_files
6085 BEEP
6088 BEEP
6091 INPUT "ENTER THE BEGINNING RUN NUMBER".Md
6094 BEEP
6097 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED".Npairs
6100! BEEP
6103! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?".Icl
6106 BEEP
6109 PRINTER IS 1
6112 PRINT USING "4X.***Select a symbol:***
6115 PRINT USING "6X.***1 Star 2 Plus sign***
6118 PRINT USING "6X.***3 Circle 4 Square***
6121 PRINT USING "6X.***5 Rombus***
6124 PRINT USING "6X.***6 Right-side-up triangle***
6127 PRINT USING "6X.***7 Up-side-down triangle***
6130 INPUT Sym
6133 PRINTER IS 705
6136 PRINT "PU DI"
6139 IF Sym=1 THEN PRINT "SM*"
6142 IF Sym=2 THEN PRINT "SM+"
6145 IF Sym=3 THEN PRINT "SMo"
6148 IF Md>1 THEN
6151 FOR I=1 TO (Md-1)

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6154 ENTER #File:Ya.Xa
6157 NEXT I
6160 END IF
6163 FOR I=1 TO Npairs
6166 ENTER #File:Ya.Xa
6169 IF I=1 THEN Q1=Ya
6172 IF I=Npairs THEN Q2=Ya
6175 IF Opo=1 THEN Ya=Ya/Xa
6178 IF Opo=2 THEN
6181 Q=Ya
6184 Ya=Ya/Xa
6187 Xa=Q
6190 END IF
6193 IF Xa<X11 THEN X11=Xa
6196 IF Xa>Xul THEN Xul=Xa
6199 IF Iun=1 THEN
6202 IF Opo<2 THEN Xa=Xa*1.8
6205 IF Opo>0 THEN Ya=Ya*.1761
6208 IF Opo=0 THEN Ya=Ya*.317
6211 IF Opo=2 THEN Xa=Xa*.317
6214 END IF
6217 X=LGT(Xa/Xmin)*Sfx
6220 Y=LGT(Ya/Ymin)*Sfy
6223 Kj=0
6226 CALL Symb(X,Y,Sym,Icl,Kj)
6229 GOTO 6268
6232 IF Sym>3 THEN PRINT "SM"
6235 IF Sym<4 THEN PRINT "SR 1.4.2.4"
6238 IF Icl=0 THEN
6241 PRINT "PA",X,Y,""
6244 ELSE
6247 PRINT "PA",X,Y,"PD"
6250 END IF
6253 IF Sym>3 THEN PRINT "SR 1.2.1.6"
6256 IF Sym=4 THEN PRINT "UC2.4.99.0,-8,-4,0,0.8,4,0;"
6259 IF Sym=5 THEN PRINT "UC3.0.99,-3,-6,-3,6,3,6,3,-6;"
6262 IF Sym=6 THEN PRINT "UC0.5.3.99,3,-8,-6,0,3,8;"
6265 IF Sym=7 THEN PRINT "UC0.-5.3.99,-3,8,6,0,-3,-8;"
6268 NEXT I
6271 PRINT "PIJ"
6274 BEEP
6277 INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
6280 IF Ilab=1 THEN
6283 PRINT "SP0:SP2"
6286 BEEP
6289 IF Klab=0 THEN
6292 Xlab=5
6295 Ylab=85
6298 INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
6301 Xtt=Xlab-5
6304 Ytt=Ylab+8
6307 PRINT "SR 1,1.5"
6310 BEEP
6313 INPUT "SELECT LABEL TYPE (0=FILE NAME, 1=TUBE TYPE)",Ifntt
6316 IF Ifntt=0 THEN
6319 PRINT "SM:PA",Xtt,Ytt,"LB" % Heat File"
6322 Ytt=Ytt-3
6325 PRINT "SM:PA",Xtt,Ytt,"LB" % Heat File"
6328 ELSE
6331 PRINT "SM:PA",Xtt,Ytt,"LB" % Heat Tube"

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6334 Ytt=Ytt-3
6337 PRINT "PA",Xtt,Ytt,"LB      Oil Flux Type"
6340 END IF
6343 IF Sym=1 THEN PRINT "SM*"
6346 IF Sym=2 THEN PRINT "SM+"
6349 IF Sym=3 THEN PRINT "SMo"
6352 Klab=1
6355 END IF
6358 Kj=1
6361 CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
6364 PRINT "SR 1.1.5:SM"
6367 IF Sym<4 THEN PRINT "PR 2.0"
6370 BEEP
6373 INPUT "ENTER BOP",Bop
6376 IF Ifntt=1 THEN
6379 BEEP
6382 INPUT "ENTER TUBE TYPE",Ttypes
6385 END IF
6388 IF Bop<10 THEN PRINT "PR 2.0:LB":Bop;"
6391 IF Bop>9 THEN PRINT "PR .5.0:LB":Bop;"
6394 Ihf=0
6397 IF Q1>Q2 THEN Ihf=1
6400 IF Ihf=0 THEN PRINT "PR 4.0:LBInc"
6403 IF Ihf=1 THEN PRINT "PR 4.0:LBDec"
6406 IF Ifntt=0 THEN
6409 PRINT "PR 2.0:LB":D_files;"
6412 ELSE
6415 PRINT "PR 2.0:LB":Ttypes;"
6418 END IF
6421 PRINT "SP0:SP1:SR 1.5.2"
6424 Ylab=Ylab-5
6427 END IF
6430 BEEP
6433 ASSIGN #file TO *
6436 X11=X11/1.2
6439 Xul=Xul*1.2
6442! GOTO 8040
6445 END IF
6448 PRINT "PU SM"
6451 BEEP
6454 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
6457 IF Go_on=1 THEN
6460 BEEP
6463 PRINTER IS 1
6466 PRINT USING "4X,""Select line type:"""
6469 PRINT USING "6X,""0      Solid line""
6472 PRINT USING "6X,""1      Dashed""
6475 PRINT USING "6X,""2,,,5 Longer line - dash""
6478 INPUT Ipn
6481 PRINTER IS 705
6484 BEEP
6487 INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
6490 Iprnt=1
6493 CALL Poly
6496 IF Ifn=0 THEN
6499 Njoin=1
6502 BEEP
6505 INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
6508 END IF
6511 Ijoin=0
6514 IF Ifn<Njoin THEN Ijoin=1

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```

6517 IF Ifn=0 OR Ijoin=1 THEN
6520 FOR Ij=0 TO 3
6523 Bs(Ij)=Bs(Ij)+B(Ij)
6526 NEXT Ij
6529 Ifn=Ifn+1
6532 END IF
6535 IF Njoin=Ifn THEN
6538 FOR Ij=0 TO 3
6541 B(Ij)=Bs(Ij)/Njoin
6544 Bs(Ij)=0
6547 NEXT Ij
6550 Ifn=0
6553 ELSE
6556 GOTO 6067
6559 END IF
6562 BEEP
6565 INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
6568 FOR Xx=0 TO Cx STEP Cx/200
6571 Xa=Xmin+10*Xx
6574 IF Xa<Xll OR Xa>Xul THEN 6655
6577 Icn=Icn+1
6580 Pu=0
6583 IF Ipn=1 THEN Idf=Icn MOD 2
6586 IF Ipn=2 THEN Idf=Icn MOD 4
6589 IF Ipn=3 THEN Idf=Icn MOD 8
6592 IF Ipn=4 THEN Idf=Icn MOD 16
6595 IF Ipn=5 THEN Idf=Icn MOD 28
6598 IF Idf=1 THEN Pu=1
6601 IF Opo=0 THEN Ya=FNPoly(Xa)
6604 IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
6607 IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
6610 IF Opo=1 THEN Ya=FNPoly(Xa)
6613 IF Ya<Ymin THEN 6655
6616 IF Ya<Yll OR Ya>Yul THEN 6655
6619 IF Iun=1 THEN
6622 IF Opo<2 THEN Xa=Xa*1.8
6625 IF Opo>0 THEN Ya=Ya*.1761
6628 IF Opo=0 THEN Ya=Ya*.317
6631 IF Opo=2 THEN Xa=Xa*.317
6634 END IF
6637 Y=LGT(Ya/Ymin)*Sfy
6640 X=LGT(Xa/Xmin)*Sfx
6643 IF Y<0 THEN Y=0
6646 IF Y>100 THEN GOTO 6655
6649 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
6652 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
6655 NEXT Xx
6658 PRINT "PJ"
6661 GOTO 6067
6664 END IF
6667 BEEP
6670 INPUT "WANT TO PLOT REILLY'S SMOOTH-TUBE DATA? (1=Y,0=N)",Irly
6673 IF Opo=0 OR Opo=1 THEN
6676 Xll=3
6679 Xul=20
6682 END IF
6685 IF Opo=2 THEN
6688 Xll=10000
6691 Xul=100000
6694 END IF

```

```

6697 IF Irly=1 THEN
6700 Yll=20
6703 Yul=70
6706 BEEP
6709 INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
6712 FOR Xx=0 TO Cx STEP Cx/200
6715 Xa=Xmin+10*Xx
6718 IF Xa<Xll OR Xa>Xul THEN 6757
6721 Xl=LOG(Xa)
6724 IF Opo=0 THEN Yl=-2.5402837E-1+Xl*(4.9720151-Xl*2.5134787E-1)
6727 IF Opo=1 THEN Yl=-2.5402837E-1+Xl*(3.9720151-Xl*2.5134787E-1)
6730 IF Opo=2 THEN Yl=-3.7073801E-1+Xl*(8.7259190E-1-Xl*6.8826842E-3)
6733 Ya=EXP(Yl)
6736 Y=LGT(Ya/Ymin)*Sfy
6739 X=LGT(Xa/Xmin)*Sfx
6742 Ipu=0
6745 IF Y<Yll THEN Ipu=1
6748 IF Y>Yul THEN GOTO 6757
6751 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
6754 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
6757 NEXT Xx
6760 PRINT "PU"
6763 END IF
6766 BEEP
6769 INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
6772 IF Irohs=1 THEN
6775 Yll=15
6778 Yul=80
6781 BEEP
6784 INPUT "ENTER Tsat (Deg C)",Tsat
6787 Csf=.0040
6790 BEEP
6793 INPUT "ENTER Csf (DEF=0.004)",Csf
6796 Tf=Tsat+2
6799 FOR Xx=0 TO Cx STEP Cx/200
6802 Xa=Xmin+10*Xx
6805 IF Xa<Xll OR Xa>Xul THEN 6889
6808 Xl=LOG(Xa)
6811 IF Opo<2 THEN Tf=Tsat+Xa/2
6814 Rho=FNRho(Tf)
6817 K=FNK(Tf)
6820 Mu=FNMu(Tf)
6823 Cp=FNCP(Tf)
6826 Hfg=FNHfg(Tsat)
6829 Ni=Mu/Rho
6832 Pr=Cp*Mu/K
6835 Omega=Csf+Hfg/Cp*((.014/(9.81*Rho))*.5/(Mu+Hfg))^(1./3)*Pr^1.7
6838 IF Opo=0 THEN Ya=(Xa/Omega)^3
6841 IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
6844 IF Opo=2 THEN Ya=Xa^(2./3)/Omega
6847 IF Opo=2 THEN
6850 Tfc=Tsat+Xa/Ya*.5
6853 IF ABS(Tf-Tfc)>.01 THEN
6856 Tf=(Tf+Tfc)*.5
6859 GOTO 6814
6862 END IF
6865 END IF
6868 Y=LGT(Ya/Ymin)*Sfy
6871 X=LGT(Xa/Xmin)*Sfx
6874 Ipu=0

```

```

7060 PRINT
7063 PRINT USING "10X.," Fms Tin Tev Vu'2 Tdrop""
7066 IF K=0 THEN
7069 PRINTER IS 701
7072 PRINT
7075 PRINT " Month. date and time: ";Date$
7078 IF Itt=0 THEN PRINT USING "10X.,"Tube Type: Wiceland Smooth""
7081 IF Itt=1 THEN PRINT USING "10X.,"Tube Type: High Flux""
7084 IF Itt=2 THEN PRINT USING "10X.,"Tube Type: Turbo-B""
7087 PRINT
7090 PRINT USING "10X.," Fms Tin Tev Vu'2 Tdrop""
7093 PRINTER IS 1
7096 K=1
7099 END IF
7102 BEEP
7105 INPUT "ENTER FLOWMETER READING".Fms
7108 OUTPUT 709;"AR AF0 AL4 VR1"
7111 FOR L=0 TO 4
7114 OUTPUT 709;"AS SA"
7117 IF L>0 AND L<4 THEN 7141
7120 S=0
7123 FOR I=0 TO 9
7126 ENTER 709:E
7129 S=S+E
7132 NEXT I
7135 IF L=0 THEN Emf(0)=ABS(S/10)
7138 IF L=4 THEN Emf(1)=ABS(S/10)
7141 NEXT L
7144 OUTPUT 709;"AR AF20 AL20 VR1"
7147 OUTPUT 709;"AS SA"
7150 Etp=0
7153 FOR I=0 TO 9
7156 ENTER 709:E
7159 Etp=Etp+E
7162 NEXT I
7165 Etp=Etp/10
7168 Tin=FNTvsv(Emf(1))
7171 Tev=FNTvsv(Emf(0))
7174 Grad=37.9853+.104388*Tin
7177 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.92006E-6-Fms*(1.23688E-7-Fms*4.31897E-10)))
7180 Vu=Mdot/((1000*PI*D1^2)*4
7183 Tdrop=Etp*1.E+6/(10*Grad)
7186 PRINT USING "10X.3(DD.DD.4X).1X.Z.DD.4X.MZ.4D";Fms.Tin.Tev.Vu'2.Tdrop
7189 BEEP
7192 INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)".Ok
7195 J=J+1
7198 IF Ok=0 THEN
7201 J=J-1
7204 GOTO 7102
7207 ELSE
7210 OUTPUT 3File:Fms.Emf(*),Etp
7213 PRINTER IS 701
7216 PRINT USING "10X.3(DD.DD.4X).1X.Z.DD.4X.MZ.4D";Fms.Tin.Tev.Vu'2.Tdrop
7219 PRINTER IS 1
7222 BEEP
7225 INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)".Go_on
7228 IF Go_on=1 THEN 7102
7231 END IF
7234 ASSIGN 3File TO *

```

```

7237 PRINTER IS 701
7240 PRINT
7243 PRINT USING "10X." "NOTE: ".ZZ." data sets are stored in file ".ISA";J.F
ile$
7246 PRINTER IS 1
7249 SUBEND
7252 SUB Uoort
7255 PRINTER IS 1
7258 BEEP
7261 INPUT "Enter Uo File Name".File$
7264 BEEP
7267 INPUT "Number of Data Runs".Nrun
7270 INPUT "Do You Want a Plot File?(1-Y,0=N)".Iplot
7273 BEEP
7276 IF Iplot=1 THEN
7279 INPUT "Give Plot File Name".P_files
7282 CREATE BDAT P_files.4
7285 ASSIGN @Plot TO P_files
7288 END IF
7291 PRINTER IS 701
7294 PRINT
7297 PRINT
7300 PRINT USING "10X." "Water Vel      Uo""
7303 ASSIGN @File TO File$
7306 IF Iplot=1 THEN ASSIGN @File1 TO P_files
7309 FOR I=1 TO Nrun
7312 ENTER @File:Vw.Uo
7315 IF Iplot=1 THEN OUTPUT @File1:Vw.Uo
7318 PRINT USING "15X.D.DD.6X.MZ.3DE":Vw.Uo
7321 NEXT I
7324 ASSIGN @File TO *
7327 ASSIGN @File1 TO *
7330 PRINT USING "10X." "NOTE: ".ZZ." data sets are stored in file ".ISA";Nru
n.File$
7333 IF Iplot=1 THEN
7336 PRINT USING "10X." "NOTE: ".ZZ." X-Y Pairs are stored in file ".ISA";Nru
n.P_files
7339 END IF
7342 PRINTER IS 1
7345 SUBEND
7348 SUB Select
7351 COM /Idp/ Idp
7354 BEEP
7357 PRINTER IS 1
7360 PRINT USING "4X." "Select option:"""
7363 PRINT USING "6X." " 0 Taking data or re-processing old data""
7366 PRINT USING "6X." " 1 Plotting data on Log-Log ""
7369 PRINT USING "6X." " 2 Plotting data on Linear""
7372 PRINT USING "6X." " 3 Make cross-plot coefft file""
7375 PRINT USING "6X." " 4 Re-circulate water""
7378 PRINT USING "6X." " 5 Purge""
7381 PRINT USING "6X." " 6 T-Drop correction""
7384 PRINT USING "6X." " 7 Print Uo File""
7387 PRINT USING "6X." " 8 Modify X-Y file""
7390 PRINT USING "6X." " 9 Move""
7393 PRINT USING "6X." "10 Comb""
7396 PRINT USING "6X." "11 Fixup""
7399 INPUT Idp
7402 IF Idp=0 THEN CALL Main
7405 IF Idp=1 THEN CALL Plot

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7408 IF Idp=2 THEN CALL Plin
7411 IF Idp=3 THEN CALL Coef
7414 IF Idp=4 THEN CALL Main
7417 IF Idp=5 THEN CALL Purg
7420 IF Idp=6 THEN CALL Tdcn
7423 IF Idp=7 THEN CALL Uoprt
7426 IF Idp=8 THEN CALL Xymod
7429 IF Idp=9 THEN CALL Move
7432 IF Idp=10 THEN CALL Comb
7435 IF Idp=11 THEN CALL Fixup
7438 SUBEND
7441 SUB Xymod
7444 PRINTER IS 1
7447 BEEP
7450 INPUT "ENTER FILE NAME",File$
7453 ASSIGN @File1 TO File$
7456 BEEP
7459 INPUT "ENTER NUMBER OF X-Y PAIRS",Np
7462 BEEP
7465 INPUT "ENTER NEW FILE NAME",File2$
7468 CREATE BDAT File2$.5
7471 ASSIGN @File2 TO File2$
7474 BEEP
7477 INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
7480 IF Ndel=0 THEN 7492
7483 FOR I=1 TO Ndel
7486 BEEP
7489 INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
7492 NEXT I
7495 FOR J=1 TO Np
7498 ENTER @File1:X.Y
7501 FOR I=1 TO Ndel
7504 IF Nd(I)=J THEN 7516
7507 NEXT I
7510 OUTPUT @File2:X.Y
7513 PRINT J.X.Y
7516 NEXT J
7519 PRINTER IS 701
7522 ASSIGN @File1 TO *
7525 ASSIGN @File2 TO *
7528 SUBEND
7531 SUB Move
7534! FILE NAME: MOVE
7537!
7540 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)
7543 DIM Told$(66)[14],N(66),Vr(66),Ir(66)
7546 BEEP
7549 INPUT "OLD FILE TO MOVE".D2_files
7552 ASSIGN @File2 TO D2_files
7555 ENTER @File2:Nrun.Date$.Ldtc1,Ldtc2.Itt
7558 FOR I=1 TO Nrun
7561 ENTER @File2:Bop(I),Told$(I)
7564 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)
7567 ENTER @File2:Vr(I),Ir(I)
7570 NEXT I
7573 ASSIGN @File2 TO *
7576 BEEP
7579 INPUT "SHIFT DISK AND HIT CONTINUE".Ok

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7532 BEEP
7535 INPUT "INPUT BDAT SIZE",Size
7538 CREATE BDAT D2_files$.Size
7591 ASSIGN @File1 TO D2_files$
7594 OUTPUT @File1:Nrun.Date$.Ldte1.Ldte2.Itt
7597 FOR I=1 TO Nrun
7600 OUTPUT @File1:8op(I),Told$(I)
7603 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)
7606 OUTPUT @File1:Vr(I),Ir(I)
7609 NEXT I
7612 ASSIGN @File1 TO *
7615! RENAME "TEST" TO D2_files$
7618 BEEP 2000..2
7621 BEEP 4000..2
7624 BEEP 4000..2
7627 PRINT "DATA FILE MOVED"
7630 SUBEND
7633 SUB Comb
7636! FILE NAME: COMB
7639!
7642 DIM Emf(12)
7645 BEEP
7648 INPUT "OLD FILE TO FIXUP".D2_files$
7651 ASSIGN @File2 TO D2_files$
7654 D1_files$="TEST"
7657 CREATE BDAT D1_files$.30
7660 ASSIGN @File1 TO D1_files$
7663 ENTER @File2:Nrun.Date$.Ldte1.Ldte2.Itt
7666 IF K=0 THEN OUTPUT @File1:Nrun.Date$.Ldte1.Ldte2.Itt
7669 FOR I=1 TO Nrun
7672 ENTER @File2:8op.Told$.Emf(*).Vr.Ir
7675 OUTPUT @File1:8op.Told$.Emf(*).Vr.Ir
7678 NEXT I
7681 ASSIGN @File2 TO *
7684! RENAME "TEST" TO D2_files$
7687 BEEP 2000..2
7690 BEEP 4000..2
7693 BEEP 4000..2
7696 BEEP
7699 INPUT "WANT TO ADD ANOTHER FILE (1-Y,0-N)?".Ok
7702 IF Ok=1 THEN
7705 K=1
7708 BEEP
7711 INPUT "GIVE NEW FILE NAME".Nfiles$
7714 ASSIGN @File2 TO Nfiles$
7717 GOTO 7663
7720 END IF
7723 ASSIGN @File2 TO *
7726 SUBEND
7729 SUB Fixup
7732! FILE: FIXUP
7735! DATE: February 18, 1986
7738!
7741 DIM Emf(12)
7744 BEEP
7747 INPUT "OLD FILE TO FIXUP".D2_files$
7750 ASSIGN @File2 TO D2_files$
7753 D1_files$="TEST"
7756 CREATE BDAT D1_files$.20
7759 ASSIGN @File1 TO D1_files$

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```

7762 ENTER @File2:Nrun,Date$,Ldte1,Ldte2,Itt
7765 Nruno=27
7768 OUTPUT @File1:Nruno,Date$,Ldte1,Ldte2,Itt
7771 FOR I=1 TO Nrun
7774 ENTER @File2:Boo,Told$,Emf(*),Vr,Ir
7777 IF I=1 THEN 7783
7780 OUTPUT @File1:Boo,Told$,Emf(*),Vr,Ir
7783 NEXT I
7786 ASSIGN @File2 TO +
7789 ASSIGN @File1 TO +
7792! RENAME "TEST" TO D2_files
7795 BEEP 2000..2
7798 BEEP 4000..2
7801 BEEP 4000..2
7804 SUBEND

```

APPENDIX C

EXAMPLES OF REPRESENTATIVE DATA RUNS

The two following data runs (TXE222 and GTB185) are representative samples of the data taken over the course of the investigation. The first data run for the Thermoexcel-E surface was for a decreasing heat-flux condition and an oil concentration of three percent. The second data run was for the GEWA-T surface was also for a decreasing heat-flux condition but with an oil concentration of one percent.

Month, date and time :05:06:11:41:20

NOTE: Program name : DRP4
Disk number : 13
Old file name: TXE222
This data set taken on : 02:18:13:42:58
Tube Number: 10

Data Set Number = 1 Bulk Oil % = 3.0 02:18:13:48:44
TC No: 1 2 3 4 5 6 7 8
Temp : 8.71 9.45 9.00 8.48 9.70 8.12 10.21 8.59
Twa Tliad Tliad2 Tvapr Psat Tsump
8.74 2.23 2.17 2.06 -1.27 -18.3
Thetab Htube Qdp
6.541 1.455E+04 9.519E+04

Data Set Number = 2 Bulk Oil % = 3.0 02:18:13:49:57
TC No: 1 2 3 4 5 6 7 8
Temp : 8.51 9.01 8.42 8.00 9.68 8.29 10.33 8.51
Twa Tliad Tliad2 Tvapr Psat Tsump
8.55 2.24 2.22 2.09 -1.73 -18.3
Thetab Htube Qdp
6.319 1.508E+04 9.531E+04

Data Set Number = 3 Bulk Oil % = 3.0 02:18:13:50:51
TC No: 1 2 3 4 5 6 7 8
Temp : 8.68 8.88 8.33 7.89 9.84 8.07 10.22 8.64
Twa Tliad Tliad2 Tvapr Psat Tsump
8.53 2.26 2.19 2.07 -1.74 -18.8
Thetab Htube Qdp
6.305 1.511E+04 9.526E+04

Data Set Number = 4 Bulk Oil % = 3.0 02:18:14:02:37
TC No: 1 2 3 4 5 6 7 8
Temp : 6.93 7.05 6.71 6.48 7.23 6.24 7.63 6.56
Twa Tliad Tliad2 Tvapr Psat Tsump
6.66 2.25 2.21 2.14 -1.73 -18.5
Thetab Htube Qdp
4.433 1.414E+04 6.269E+04

Data Set Number = 5 Bulk Oil % = 3.0 02:18:14:03:13
TC No: 1 2 3 4 5 6 7 8
Temp : 6.32 7.18 6.30 6.56 7.35 6.25 7.65 6.52
Twa Tliad Tliad2 Tvapr Psat Tsump
6.71 2.28 2.25 2.18 -1.69 -18.4
Thetab Htube Qdp
4.444 1.408E+04 6.258E+04

Data Set Number = 6 Bulk Oil % = 3.0 02:18:14:13:56
TC No: 1 2 3 4 5 6 7 8
Temp : 5.50 5.65 5.41 5.26 5.58 4.90 5.84 5.06
Twa Tliad Tliad2 Tvapr Psat Tsump
5.28 2.32 2.28 2.35 -1.66 -16.3
Thetab Htube Qdp
2.981 1.304E+04 3.888E+04

Data Set Number = 7 Bulk Oil % = 3.0 02:18:14:14:29
 TC No: 1 2 3 4 5 6 7 8
 Temp: 5.45 5.60 5.37 5.31 5.51 4.88 5.82 5.02
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 5.26 2.29 2.26 2.35 -1.58 -16.2
 Thetab Htube Qdp
 2.387 1.299E+04 3.381E+04

Data Set Number = 8 Bulk Oil % = 3.0 02:18:14:20:33
 TC No: 1 2 3 4 5 6 7 8
 Temp: 4.25 4.33 4.22 4.16 4.49 4.07 4.58 4.06
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 4.20 2.24 2.16 2.64 -1.77 -15.8
 Thetab Htube Qdp
 1.998 1.176E+04 2.349E+04

Data Set Number = 9 Bulk Oil % = 3.0 02:18:14:21:05
 TC No: 1 2 3 4 5 6 7 8
 Temp: 4.33 4.41 4.26 4.23 4.52 4.10 4.65 4.11
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 4.25 2.28 2.23 2.71 -1.71 -15.8
 Thetab Htube Qdp
 2.004 1.169E+04 2.344E+04

Data Set Number = 10 Bulk Oil % = 3.0 02:18:14:26:17
 TC No: 1 2 3 4 5 6 7 8
 Temp: 3.68 3.68 3.59 3.54 3.80 3.51 3.85 3.47
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 3.59 2.33 2.27 2.95 -1.66 -16.4
 Thetab Htube Qdp
 1.293 1.137E+04 1.469E+04

Data Set Number = 11 Bulk Oil % = 3.0 02:18:14:26:48
 TC No: 1 2 3 4 5 6 7 8
 Temp: 3.56 3.61 3.55 3.51 3.75 3.44 3.80 3.39
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 3.53 2.28 2.21 2.34 -1.72 -16.4
 Thetab Htube Qdp
 1.285 1.142E+04 1.467E+04

Data Set Number = 12 Bulk Oil % = 3.0 02:18:14:33:11
 TC No: 1 2 3 4 5 6 7 8
 Temp: 3.06 3.07 3.02 3.00 3.12 2.98 3.14 2.90
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 3.01 2.43 2.11 3.43 -1.69 -17.1
 Thetab Htube Qdp
 .739 1.120E+04 8.283E+03

Data Set Number = 13 Bulk Oil % = 3.0 02:18:14:33:43
 TC No: 1 2 3 4 5 6 7 8
 Temp: 3.00 3.01 2.94 2.92 3.05 2.90 3.08 2.81
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 2.94 2.36 2.05 3.41 -1.77 -17.2
 Thetab Htube Qdp
 .738 1.136E+04 8.386E+03

Data Set Number = 14 Bulk Oil % = 3.0 02:18:14:40:43
 TC No: 1 2 3 4 5 6 7 8
 Temp: 2.70 2.74 2.73 2.71 2.80 2.71 2.79 2.61
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 2.71 2.41 2.03 3.79 -1.75 -17.3
 Thetab Htube Qdp
 .488 1.078E+04 5.257E+03

Data Set Number = 15 Bulk Oil % = 3.0 02:18:14:41:19
 TC No: 1 2 3 4 5 6 7 8
 Temp: 2.66 2.70 2.65 2.67 2.74 2.66 2.71 2.54
 Twa Tliqd Tliqd2 Tvaor Psat Tsumo
 2.65 2.39 2.00 3.78 -1.77 -18.0
 Thetab Htube Qdp
 .458 1.145E+04 5.244E+03

Month, date and time :05:06:11:47:44

NOTE: Program name : DRPa
Disk number : 10
Old file name: GT8185
This data set taken on : 11:25:11:35:33
Tube Number: 9

Data Set Number = 1 Bulk Oil % = 1.0 11:25:15:46:12
TC No: 1 2 3 4 5 6 7 8
Temp : 8.27 8.61 7.83 7.87 7.93 7.82 9.85 7.81
Twa Tliqd Tliqd2 Tvaer Psat Tsump
7.97 2.23 2.23 2.24 -1.73 -16.6
Thetab Htube Qdp
5.739 1.581E+04 9.073E+04

Data Set Number = 2 Bulk Oil % = 1.0 11:25:15:46:48
TC No: 1 2 3 4 5 6 7 8
Temp : 8.30 8.65 7.86 7.90 7.98 7.85 9.88 7.84
Twa Tliqd Tliqd2 Tvaer Psat Tsump
8.00 2.28 2.27 2.28 -1.68 -16.6
Thetab Htube Qdp
5.728 1.582E+04 9.062E+04

Data Set Number = 3 Bulk Oil % = 1.0 11:25:15:54:05
TC No: 1 2 3 4 5 6 7 8
Temp : 6.93 7.13 6.62 6.62 6.64 6.50 7.78 6.54
Twa Tliqd Tliqd2 Tvaer Psat Tsump
6.66 2.21 2.22 2.77 -1.75 -17.0
Thetab Htube Qdp
4.448 1.348E+04 5.995E+04

Data Set Number = 4 Bulk Oil % = 1.0 11:25:15:54:55
TC No: 1 2 3 4 5 6 7 8
Temp : 6.95 7.15 6.61 6.62 6.62 6.49 7.77 6.50
Twa Tliqd Tliqd2 Tvaer Psat Tsump
6.66 2.22 2.23 2.81 -1.74 -16.8
Thetab Htube Qdp
4.430 1.353E+04 5.993E+04

Data Set Number = 5 Bulk Oil % = 1.0 11:25:16:03:48
TC No: 1 2 3 4 5 6 7 8
Temp : 6.09 6.19 5.82 5.81 5.77 5.74 6.37 5.66
Twa Tliqd Tliqd2 Tvaer Psat Tsump
5.82 2.24 2.23 3.18 -1.73 -17.4
Thetab Htube Qdp
3.583 1.036E+04 3.712E+04

Data Set Number = 6 Bulk Oil % = 1.0 11:25:16:04:22
TC No: 1 2 3 4 5 6 7 8
Temp : 6.11 6.23 5.84 5.84 5.80 5.77 6.42 5.73
Twa Tliqd Tliqd2 Tvaer Psat Tsump
5.85 2.27 2.26 3.22 -1.69 -17.4
Thetab Htube Qdp
3.588 1.034E+04 3.712E+04

Data Set Number = 7 Bulk Oil % = 1.0 11:25:16:10:15
TC No: 1 2 3 4 5 6 7 8
Temp : 5.41 5.52 5.19 5.32 5.25 5.16 5.50 5.12
Twa Tliqd Tliqd2 Tvaer Psat Tsump
5.24 2.24 2.20 3.61 -1.74 -17.7
Thetab Htube Qdp
3.020 7.320E+03 2.211E+04

Data Set Number = 8 Bulk Oil % = 1.0 11:25:16:12:11
TC No: 1 2 3 4 5 6 7 8
Temp : 5.25 5.32 4.98 5.13 5.06 4.95 5.29 4.90
Twa Tliqd Tliqd2 Tvaer Psat Tsump
5.04 2.14 2.05 3.56 -1.88 -17.7
Thetab Htube Qdp
2.949 7.480E+03 2.206E+04

Data Set Number = 9 Bulk Oil % = 1.0 11:25:16:17:23
TC No: 1 2 3 4 5 6 7 8
Temp : 5.05 5.14 4.81 5.05 4.94 4.81 4.95 4.78
Twa Tliqd Tliqd2 Tvaer Psat Tsump
4.90 2.25 2.22 3.45 -1.73 -17.7
Thetab Htube Qdp
2.663 5.114E+03 1.362E+04

Data Set Number = 10 Bulk Oil % = 1.0 11:25:16:18:04
TC No: 1 2 3 4 5 6 7 8
Temp : 5.10 5.20 4.83 5.09 4.99 4.85 5.00 4.85
Twa Tliqd Tliqd2 Tvaer Psat Tsump
4.95 2.30 2.27 3.44 -1.67 -17.6
Thetab Htube Qdp
2.657 5.103E+03 1.356E+04

Data Set Number = 11 Bulk Oil Z = 1.0 11:25:16:24:54
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.75 4.88 4.42 4.84 4.75 4.61 4.62 4.58
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.66 2.30 2.29 3.15 -1.66 -16.3
 Thetab Htube Qdp
 2.360 3.273E+03 7.725E+03

Data Set Number = 12 Bulk Oil Z = 1.0 11:25:16:25:38
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.76 4.98 4.42 4.94 4.74 4.61 4.60 4.58
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.66 2.30 2.29 3.13 -1.66 -16.0
 Thetab Htube Qdp
 2.360 3.264E+03 7.702E+03

Data Set Number = 13 Bulk Oil Z = 1.0 11:25:16:31:21
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.45 4.54 4.09 4.60 4.39 4.34 4.36 4.28
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.37 2.27 2.27 2.95 -1.69 -14.9
 Thetab Htube Qdp
 2.094 2.361E+03 4.944E+03

Data Set Number = 14 Bulk Oil Z = 1.0 11:25:16:31:59
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.46 4.55 4.12 4.61 4.43 4.38 4.38 4.32
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.39 2.30 2.29 2.94 -1.66 -14.8
 Thetab Htube Qdp
 2.096 2.352E+03 4.931E+03

Data Set Number = 15 Bulk Oil Z = 1.0 11:25:16:37:53
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.19 4.29 3.84 4.38 4.07 4.06 4.00 3.99
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.09 2.23 2.23 2.83 -1.73 -14.8
 Thetab Htube Qdp
 1.863 1.582E+03 2.946E+03

Data Set Number = 16 Bulk Oil Z = 1.0 11:25:16:38:28
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.20 4.30 3.83 4.36 4.07 4.05 3.98 3.99
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 4.09 2.23 2.22 2.82 -1.74 -14.8
 Thetab Htube Qdp
 1.862 1.582E+03 2.946E+03

Data Set Number = 17 Bulk Oil Z = 1.0 11:25:16:44:56
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.97 4.04 3.67 4.17 3.77 3.81 3.67 3.74
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 3.85 2.19 2.19 2.71 -1.78 -15.2
 Thetab Htube Qdp
 1.660 1.146E+03 1.901E+03

Data Set Number = 18 Bulk Oil Z = 1.0 11:25:16:45:33
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.97 4.04 3.68 4.19 3.78 3.82 3.66 3.72
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 3.85 2.19 2.19 2.71 -1.77 -15.2
 Thetab Htube Qdp
 1.660 1.147E+03 1.904E+03

Data Set Number = 19 Bulk Oil Z = 1.0 11:25:16:51:19
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.69 3.73 3.50 3.77 3.40 3.46 3.25 3.32
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 3.51 2.19 2.18 2.58 -1.78 -15.4
 Thetab Htube Qdp
 1.326 8.573E+02 1.137E+03

Data Set Number = 20 Bulk Oil Z = 1.0 11:25:16:53:16
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.77 3.81 3.57 3.84 3.46 3.54 3.32 3.38
 Twa Tliqd Tliqd2 Tvaor Psat Tsump
 3.58 2.25 2.25 2.62 -1.71 -15.7
 Thetab Htube Qdp
 1.335 8.630E+02 1.152E+03

APPENDIX D

UNCERTAINTY ANALYSIS

The uncertainty of the heat-transfer coefficient at 60 kW/m² and 8 kW/m² for data runs of the GEWA-T tube (GTB185 with one percent oil concentration) and of the Thermoexcel-E (TXE222 with three percent oil concentration) are analyzed below. The method of analysis is based on Kline-McClintock [Ref. 20] method of uncertainty analysis.

The heat-transfer coefficient is:

$$h = (q_c) / (\bar{T}_{w_o} - T_{sAT}) \quad (D.1)$$

and

$$T_{w_o} - T_{sAT} = T_{w_i} - [Q_c \ln (D_2/D_1)] / (2 \pi k L) - T_{sAT} \quad (D.2)$$

where

- h = heat-transfer coefficient
- q_c = heat flux corrected for end loss
- $\bar{T}_{w_o}$ = average outer tube wall temperature
- T_{sAT} = saturation temperature
- T_{w_i} = average inner tube wall temperature
- Q_c = heat input corrected for end losses
- D_1 = tube internal diameter
- D_2 = tube external diameter
- k = tube wall thermal conductivity
- L = length of tube's heated surface

To begin the analysis, a dummy variable is assigned to the conduction term as follows:

$$\text{DELT} = [Q_c \ln (D_2/D_1)] / (2 \pi k L) \quad (\text{D.3})$$

In accordance with Kline and McClintock, the uncertainty of the heat-transfer coefficient is:

$$\delta h_h = \left[\left(\frac{\delta q_c}{q_c} \right)^2 + \left(\frac{\delta T_{w1}}{T_{w0} - T_{SAT}} \right)^2 + \left(\frac{\delta \text{DELT}}{T_{w0} - T_{SAT}} \right)^2 + \left(\frac{\delta T_{SAT}}{T_{w0} - T_{SAT}} \right)^2 \right]^{1/2} \quad (\text{D.4})$$

The uncertainty for the conduction term is estimated since the logarithmic error is negligible when compared to the other error of the analysis. The uncertainty of the conduction term is as follows:

$$\frac{\delta \text{DELT}}{\text{DELT}} = \left[\left(\frac{\delta Q_c}{Q_c} \right)^2 + \left(\frac{\delta k}{k} \right)^2 + \left(\frac{\delta L}{L} \right)^2 \right]^{1/2} \quad (\text{D.5})$$

$$\text{where } Q_c = q_c \pi D_2 L \quad (\text{D.6})$$

The uncertainty of this term is as follows:

$$\frac{\delta Q_c}{Q_c} = \left[\left(\frac{\delta q_c}{q_c} \right)^2 + \left(\frac{\delta D_2}{D_2} \right)^2 + \left(\frac{\delta L}{L} \right)^2 \right]^{1/2} \quad (\text{D.7})$$

Table 4 contains a listing of the computed terms of equations D.1 through D.7 for selected data runs for the GEWA-T and the Thermoexcel-E tubes at specified heat-flux setting of 60 kW/m² and 8 kW/m². The algorithm in the data-

TABLE 4
UNCERTAINTY ANALYSIS

File Name	GTB185		TXE222	
Heat Flux	60 kW/m2	8 kW/m2	60 kW/m2	8 kW/m2
Oil %	1%	1%	3%	3%
$\frac{\delta Q_c}{Q_c}$	0.015	0.015	0.015	0.015
$\frac{\delta k}{k}$	0.03	0.03	0.03	0.03
$\frac{\delta L}{L}$	0.0025	0.0025	0.0025	0.0025
DELTA	0.486	0.064	0.486	0.064
$\frac{\delta \text{DELTA}}{\text{DELTA}}$	0.069	0.520	0.069	0.526
$T_{w,i} \text{ (C)}$	6.845	4.678	6.904	2.964
$T_{w,i} \text{ (C)}$	0.49	0.065	0.49	0.065
$T_{s,a,t} \text{ (C)}$	2.215	2.295	2.265	2.205
$T_{s,a,t} \text{ (K)}$	0.1	0.1	0.1	0.1
$\frac{\delta T_{w,i}}{T_{w,o} - T_{s,a,t}}$	0.111	0.028	0.111	0.088
$\frac{\delta \text{DELTA}}{T_{w,o} - T_{s,a,t}}$	0.008	0.014	0.008	0.046
$\frac{\delta T_{s,a,t}}{T_{w,o} - T_{s,a,t}}$	0.023	0.042	0.023	0.135
$\frac{\delta q_c}{q_c}$	0.02	0.02	0.02	0.02
$\frac{\delta h}{h}$	0.115	0.056	0.115	0.169
$h \text{ (W/m}^2 \text{ K)}$	13480	3273	14140	11200

reduction program used this approach and assumed that all the eight wall thermocouples were used to calculate the heat-transfer coefficient.

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