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PREDICTION OF CRITICAL HEAT FLUX (CHF) FOR NON-AQUEOUS FLUIDS IN FORCED CONVECTIVE BOILING

by

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A B S T R A C T

An introduction to the critical heat flux (CHF) is presented. The mechanisms with the greatest promise for explaining CHF are described. The factors affecting the CHF such as flow parameters, geometry and miscellaneous effects are described in detail. A summary of the various empirical and theoretically-based CHF predicting methods applicable to non-aqueous fluids is presented. Also, a summary of the various CHF scaling techniques between different fluids is made. The three methods which appears to be the most promising for predicting CHF in non-aqueous fluids are selected for further study: (i) Weisman & Pei's theoretically based model for predicting CHF at low qualities, (ii) Katto's latest empirical correlation for predicting CHF in various fluids at positive dryout qualities and (iii) non-dimensional CHF table created by non-dimensionalizing Groeneveld's standard CHF table using Ahmad's & Katto's CHF scaling techniques.

A comparison of predicted CHF values with experimental CHF values for water, carbon dioxide, nitrõgen and different freon types is made. It has been found that the non-dimensional CHF table predicting method is the most accurate over a wide range of pressures, qualities and mass flows.

A C K N O W L E D G E M E N T S

I greatly appreciate the help and assistance of Dr. D.C. Groeneveld at Chalk River Nuclear Laboratories (CRNL) in producing this work. Also, I appreciate the help and comments of Dr. S.C. Cheng at the University of Ottawa. Many thanks to the HTFS personel at CRNL for providing the HPPDS computer code, which provided the physical and thermodynamic properties for the non-aqueous fluids.

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NOMENCLATURE

A	Area
B.O.	Boiling Number = $\frac{q_c}{\lambda G}$
C	Droplet Concentration (kg/m^3)
CHF	Critical Heat Flux (kW/m^2)
C_p	Specific Heat Capacity (kJ/kg°C)
D	Tube Diameter (m)
D_{he}	Heated Equivalent Diameter (= 4 × Flow Area/Heated Perimeter) (m)
D_p	average bubble diameter (m)
DNB	Departure from Nucleate Boiling
Dep	Deposition of Liquid Droplets (kg/s/m)
Ent	Entrainment of Liquid Droplets Rate (kg/s/m)
F_c	Flux Shape Factor
Fr	Froud Number $\frac{G^2}{\rho_f^2 gD}$
F_G	Mass Flux Scaling Factor = $G_{Water}/G_{Modelling\ Fluid}$
g	Gravitational Acceleration (m/s^2)
G	Mass Flux (kg/m^2/s)
h	Specific Enthalpy (kJ/kg)
ΔH_{in}	$(h_f - h_{in})$ (kJ/kg)
i_b	turbulent intensity at bubbly layer core interface
K	Inverse of Mass Flux Scaling Factor = $G_{Modelling\ Fluid}/G_{Water}$
K_k	Non-Dimensional Parameter
K_w	Deposition Coefficient (m/s)
k	Thermal Conductivity (kW/m°C)

NOMENCLATURE (continued)

L	Tube Length (m)
L_B	Equilibrium Boiling Length = $L - \frac{\Delta H_{in}\, GD}{4\, q_c}$ (m)
M	Molecular Weight, (kg/Mole)
P	Pressure (kPa)
Pe	Peclet Number $\frac{GD\, C_p}{k}$
Pr	Prandtl Number $(\frac{C_p \mu_f}{k})$
Pr	Reduced Pressure = P/P_c (kpa)
q	Heat Flux (kW/m^2)
R	Universal Gas Constant (J/mole°k)
T	Temperature (°C)
ΔT	$(T_f - T)$ (°C)
v'	radial fluctuating velocity (m/s)
v_{11}	radial velocity created by vapor generation (m/s)
V	Velocity (m/s)
V_c	Critical Volume (m^3/kg)
W	Flow Rate (kg/s)
x	Quality
$\bar{Y}$	Dimensionless Group Used in Shah's Correlation
z	Axial Distance (m)
Z_c	Critical Compressibility Factor = $P_c V_c / RT_c$
Z_d	distance from tube inlet to onset of bubble detachment (m)

NOMENCLATURE (continued)

Greek Symbols

α	void fraction $(\frac{A_g}{A})$
β	$\left\|\frac{\partial T}{\partial p}\right\|_{saturation}$ (°C/kPa)
Δ	change in
γ	$d(\rho_f/\rho_g)/dP$ (kPa^{-1})
λ	latent heat of vaporization (J/kg)
μ	viscosity (kg/s•m)
ϕ	mass flow parameter
ρ	density (kg/m^3)
σ	surface tension (W/m)
$\sigma_{v'}$	standard deviation of v'
ϕ	$\{\frac{1}{2\pi} \exp-[-\frac{1}{2}(\frac{v_{11}}{\sigma_{v'}})^2 \cdot 1 - \frac{1}{2}(\frac{v_{11}}{\sigma_{v'}}) \text{ erfc } (\frac{1}{\sqrt{2}} \frac{v_{11}}{\sigma_{v'}})\}$

Subscripts

avg	average
b	boiling
CHF	at critical heat flux
c	critical
co	critical for zero inlet subcooling
ct	constant
DNB	departure from nucleate boiling
DO	dryout
expt	experimental
eq	hydrodynamic equilibrium
f	saturated liquid
Fr	Freon
g	saturated vapor
in	inlet
K	Katto's scaling method
L	liquid
Ld	point of bubble detachment
LF	liquid film
P	predicted
W	water
γ	Ahmad's second scaling method
σ	Ahmad's first scaling method

1. INTRODUCTION TO CRITICAL HEAT FLUX

1.1 Introduction

The boiling crisis† occurs when the heated surface can no longer sustain continuous liquid contact due to high heat flux. The boiling crisis phenomenon is characterized by a sharp reduction of the local heat transfer coefficient which results from the replacement of liquid by vapour adjacent to the heat transfer surface. The value of the heat flux at which this phenomenon first occurs is known as the critical heat flux (CHF). The CHF condition manifests itself by an increase in surface temperature caused by a stable vapour layer that blankets the heated surface, or by small surface temperature spikes caused by the appearance and disappearance of dry patches. In severe cases, the temperature rise can be high enough to cause melting and rupture of the metal surface; this is known as the physical burnout. The condition of 'dryout' is extremely important in the design and performance of heat exchange equipment, such as steam generators and reboilers, in which evaporation occurs.

Fig. 1.1 illustrates the various flow regimes encountered in a uniformly heated vertical tube fed with subcooled liquid at the inlet. The heat transfer regions encountered in the tube, as well as the wall and fluid temperature variations, are also shown. The transition between the "subcooled nucleate boiling region" (region B) and the "saturated nucleate boiling region" (region C and D) is defined by the thermodynamic quality ($x(z) = 0$) where $x(z)$ is given by

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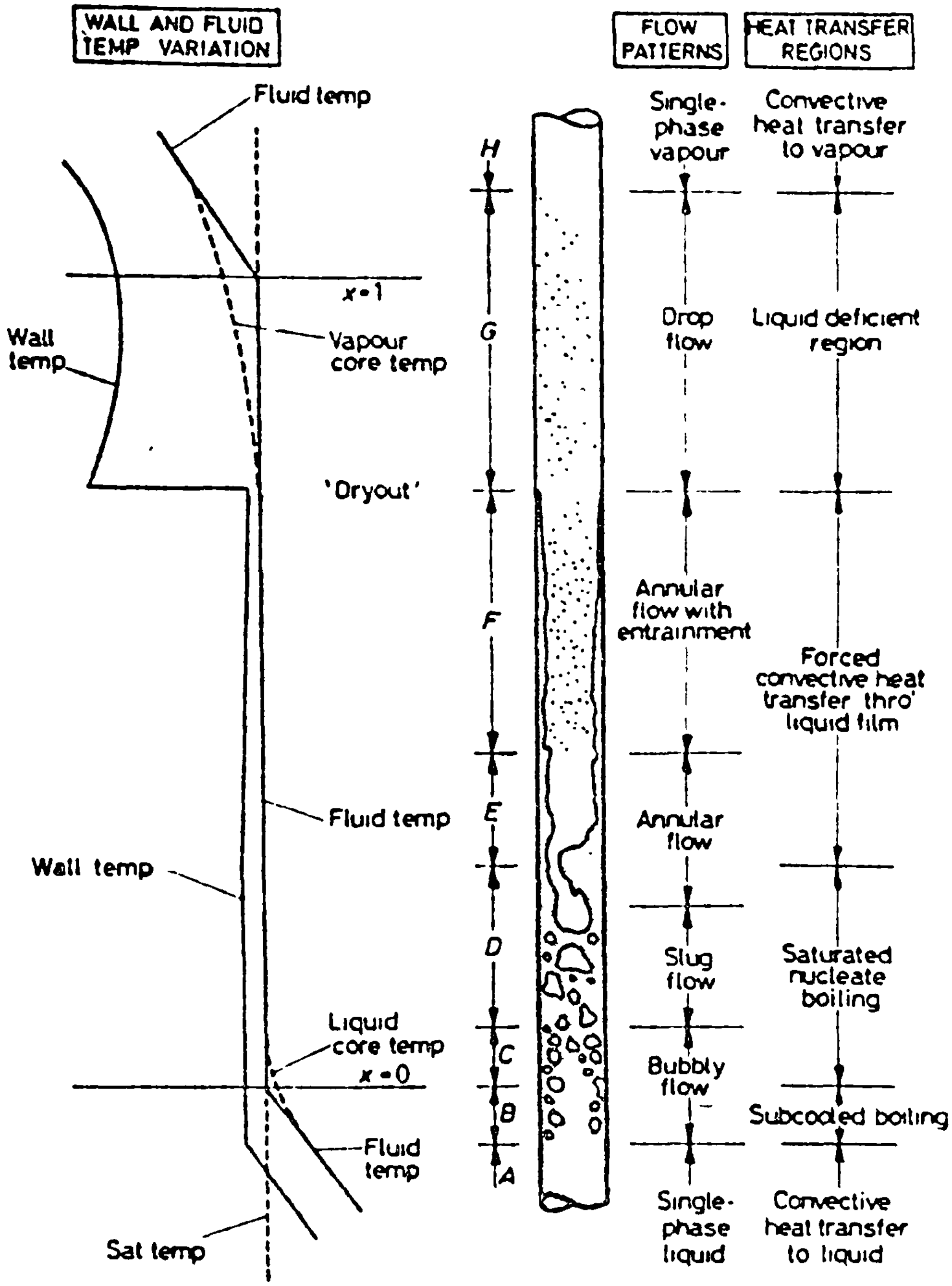
† Other terms used to refer to boiling crisis are: burnout, dryout, departure from nucleate boiling (DNB), CHF condition.



URE 1.1 REGIONS OF HEAT TRANSFER IN CONVECTIVE BOILING, COLLIER (1972)

$$x(z) = \frac{h(z) - h_f}{\lambda} \tag{1.1}$$

As the quality increases in the saturated nucleate boiling region, the flow pattern changes from bubbly flow to slug flow and then to annular flow with entrainment. In the latter region, heat is carried away from the wall by forced convection in the film to the liquid film-vapour core interface, where evaporation and entrainment occur. At some critical values of quality, the complete evaporation of the liquid film occurs. This change in heat transfer mechanism is called 'dryout' and is accompanied by a rise in the wall temperature as shown in Fig. 1.1. The variation of heat transfer coefficient with length along the tube for the conditions presented in Fig. 1.1 is shown in Fig. 1.2 (curve (i) solid line). At the dryout point, the heat transfer coefficient is suddenly reduced from a very high value in the forced convective region to a value close to the one expected by forced convection to saturated vapour. Fig. 1.2 also shows the heat transfer coefficient plotted against quality with increasing heat flux as a parameter (curves (i) - (vii)). Curve (i) relates to the conditions shown in Fig. 1.1 for a relatively low heat flux being supplied to the wall of the tube. Curve (ii) shows the influence of increasing the heat flux. Subcooled boiling is initiated sooner, dryout occurs at lower mass quality. Curve (iii) shows the influence of a further increase in heat flux. An abrupt deterioration in the cooling process takes place in the saturated nucleate boiling region. This transition is called 'departure from nucleate boiling' (DNB). Any further increase in heat flux (curves (vi) and (vii)) causes the condition of DNB to occur in

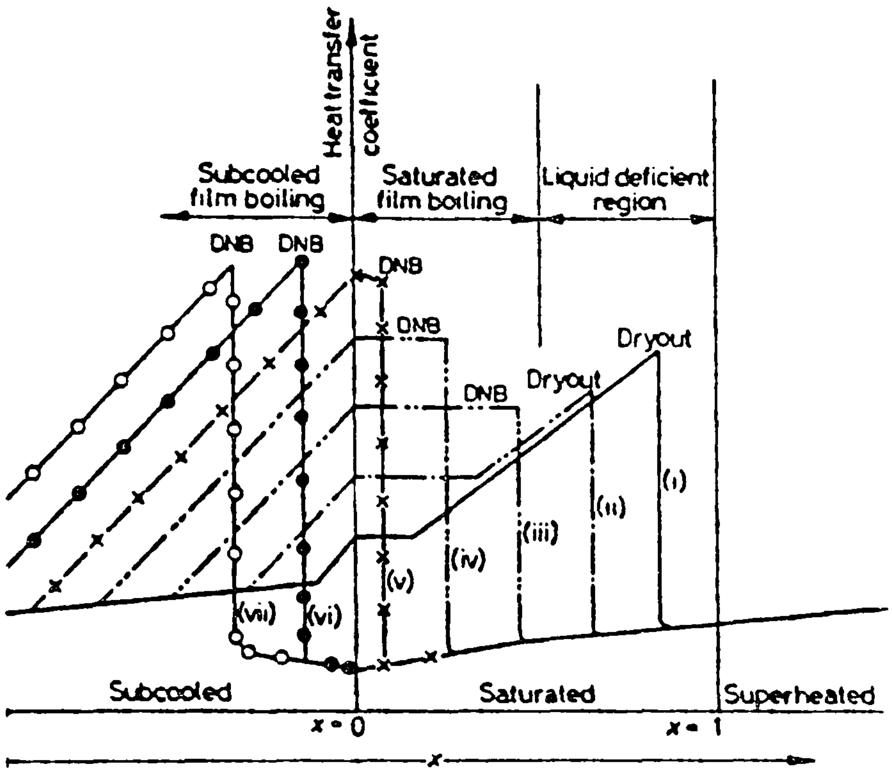


FIGURE 1.2 VARIATION OF HEAT TRANSFER COEFFICIENT WITH QUALITY WITH INCREASING HEAT FLUX AS PARAMETER, COLLIER (1972)

the subcooled region. DNB is usually accompanied with rupture or melting of the heating surface.This is known as physical burnout. The term CHF will be used to cover the three processes: DNB(subcooled), DNB(saturated) and dryout.

Fig. 1.3 illustrates the boiling curve in a temperature-controlled system. The regions of the boiling curve are: AB - single-phase heat transfer, BC - nucleate boiling, CD - transition boiling or unstable film boiling and DE - a region of stable film boiling. The heat flux at point C is called the CHF and point D corresponds to the Leidenfrost point.

Fig. 1.4 illustrates the pool boiling curve in a heat flux controlled system (i.e. when the heat flux is the independent variable and the surface temperature is the dependent one). The regions of the boiling curve are: AB - single phase heat transfer, BC - nucleate boiling, and DE - stable film boiling similar to a temperature-controlled system (Fig. 1.3). When point C is reached, any small increase in the heat flux causes the surface temperature to jump along the dotted line CF and stabilize at point F. "CF" is the temperature excursion occurring at the CHF point. If the heat flux is increased at point F, the surface temperature will increase in the direction of E (post-dryout region). However, if the heat flux is decreased at point F, the surface temperature does not return to the value at point C, but moves along the curve towards point D. It has been observed by Nukiyama (1960) that any small decrease in heat flux at point D causes the surface temperature to fall along the dotted line DG. The transition lines CF and DG can be passed only in the directions shown by the arrows in Fig. 1.4.

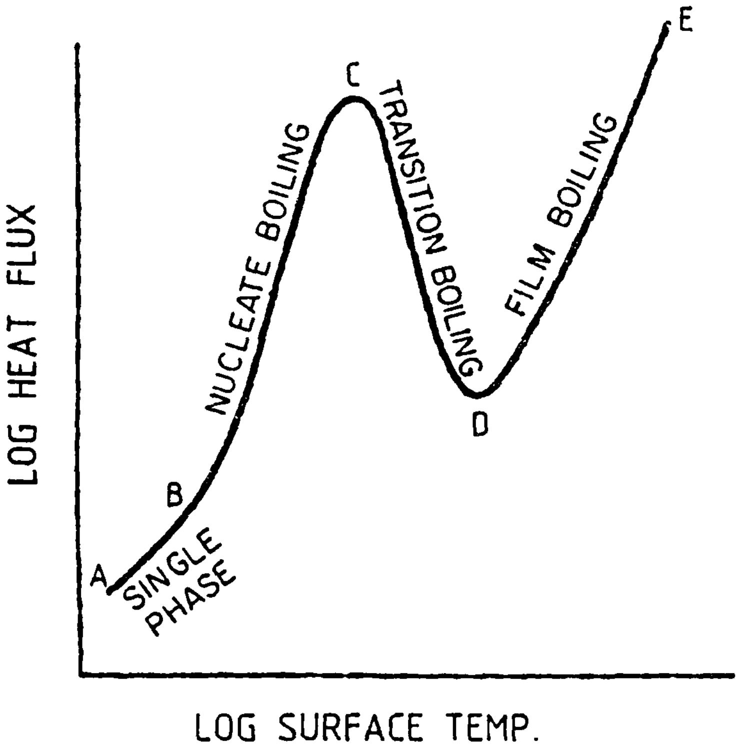


FIGURE 1.3 BOILING CURVE OF A TEMPERATURE CONTROLLED SURFACE. MACBETH (1968)

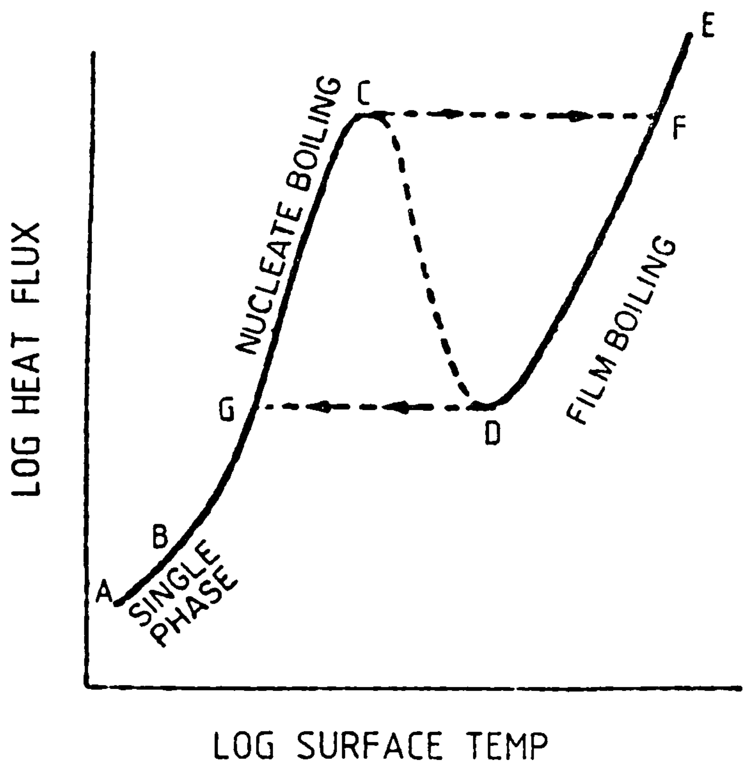


FIGURE 1.4 BOILING CURVE OF A HEAT-FLUX-CONTROLLED SURFACE WITH POOL BOILING, MACBETH (1968)

Fig. 1.5 illustrates the flow boiling curve in a heat flux-controlled system using Freon-12 in a uniformly heated tube with vertical upflow. The temperature excursion, which indicates dryout, was detected by a thermocouple located at the end of the heated channel (the location of dryout in uniformly heated tubes is at the end of the heated length). When the heat flux is decreased from the stable film boiling region (Fig. 1.5), Stevens et al. (1964) observed that the system follows the same jump and returns to nucleate boiling by way of the CHF point.

1.2. CHF Mechanisms

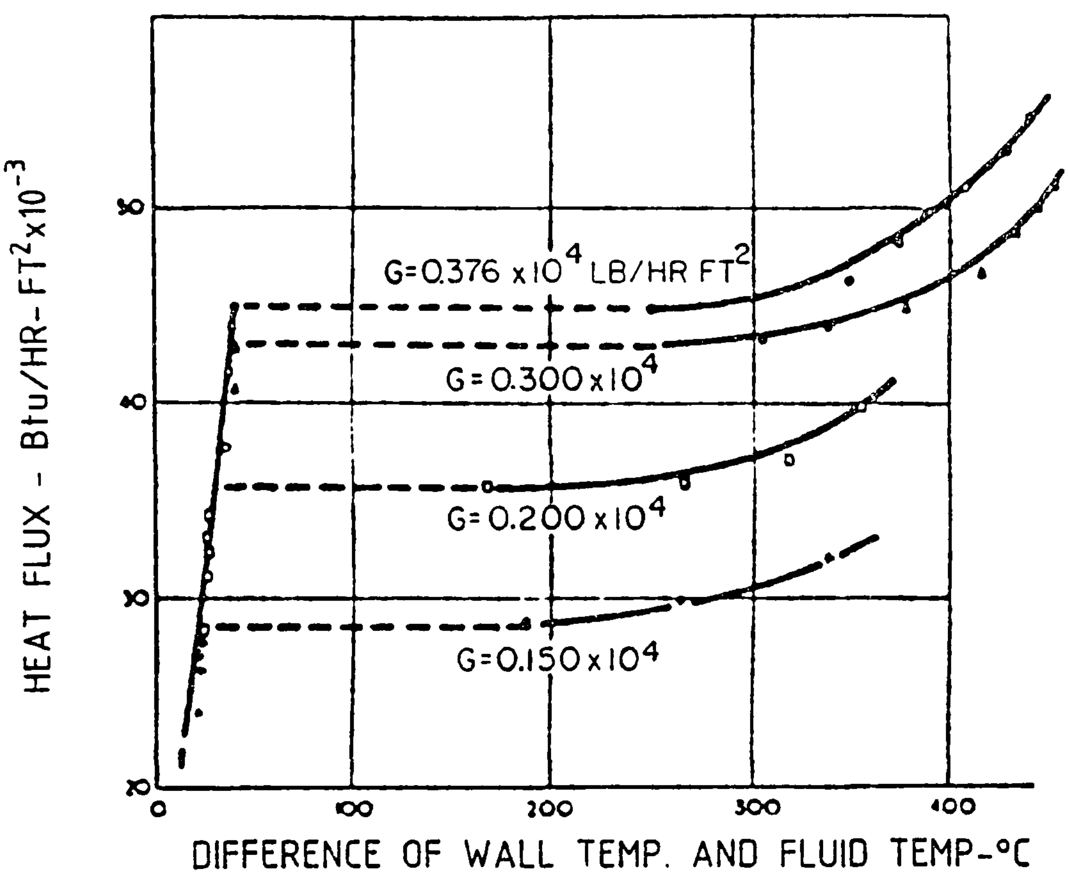
1.2.1 General

The CHF mechanisms depend on flow regimes, which in turn are dependent on pressure, flow rate and quality. Fig. 1.6 shows the variation of CHF mechanism with quality, while Fig. 1.7 illustrates the various CHF mechanisms in forced convective flow. Three different mechanisms (two for DNB, one for dryout) give the greatest promise for explaining CHF. The three mechanisms are described as follows:

1.2.2 DNB (Departure from Nucleate Boiling) Types of Dryout

(i) Nucleation Induced

At high subcooling and mass flux, heat is transferred efficientl by nucleate boiling. Bubbles grow and collapse at the wall.



URE 1.5 BOILING CURVES FOR FREON 12 IN A HEAT-FLUX-CONTROLLED UNIFORMLY HEATED TUBE L = 51 in., d = 0.633 in., P = 155 psia, Δh = 13 Btu/lb., MACBETH (1968)

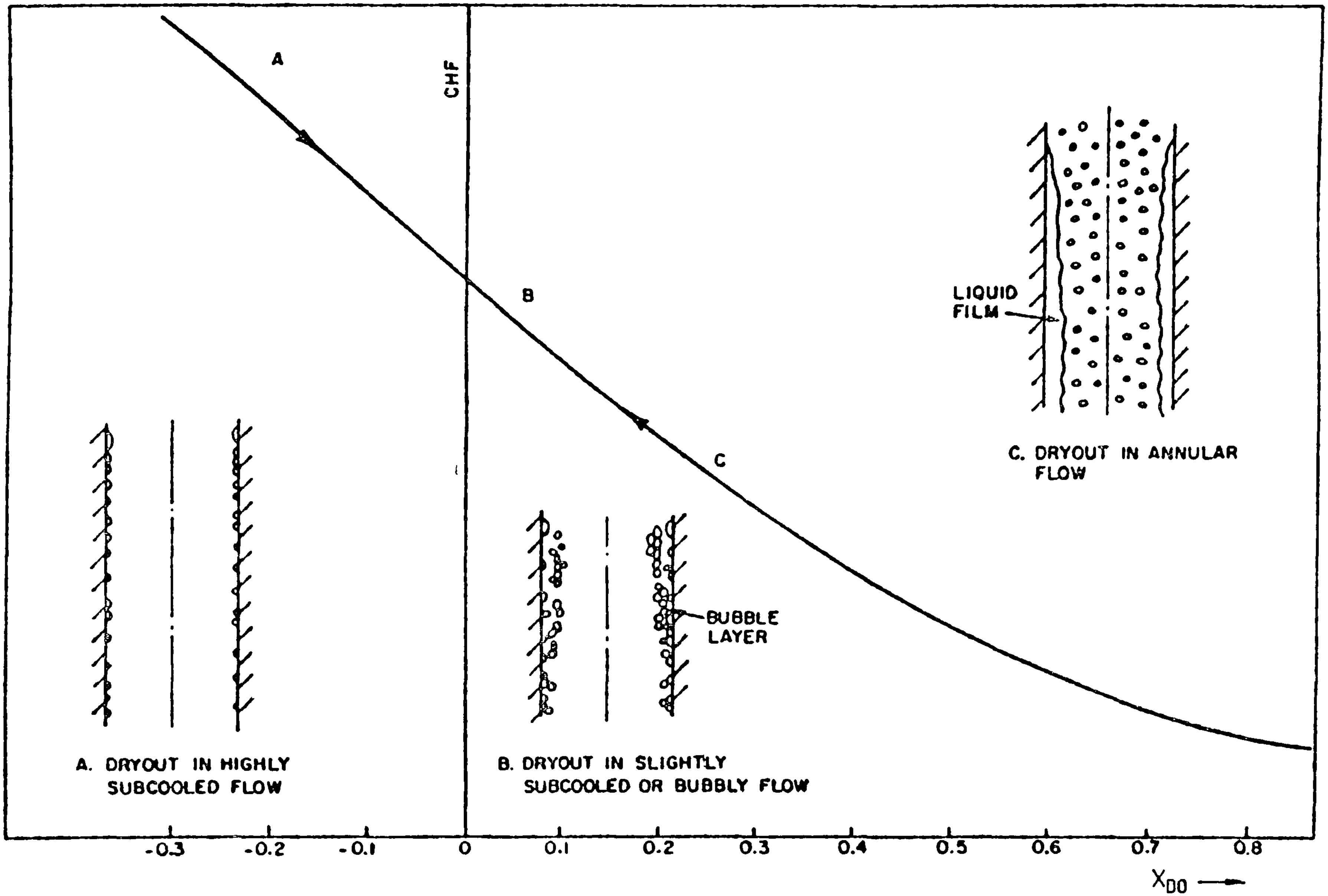
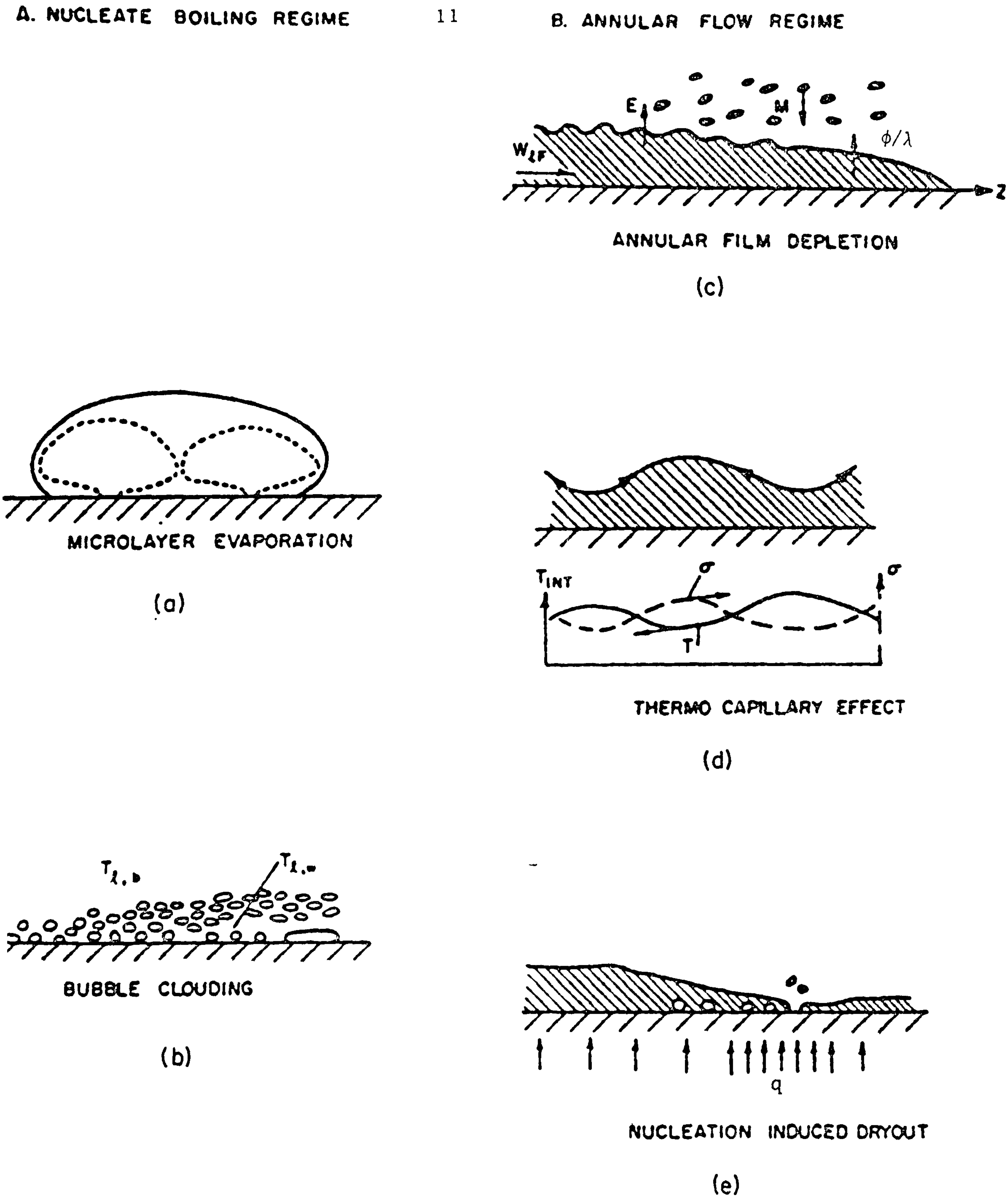


FIGURE 1.6 EFFECT OF QUALITY ON CRITICAL HEAT FLUX, GROENVELD (1981)



:E 1.7 CHF MECHANISMS FOR FORCED CONVECTIVE CONDITIONS, GROENVELD (1981)

DNB occurs at very high surface heat flux. Collier (1972) and Tong (1972) suggested that dryout is caused by the spreading of a drypatch following microlayer evaporation under a bubble and the coalescence of adjacent bubbles Fig. 1.7(a). No experimental support of this mechanism and no quantitative predictions have been developed. However, Tong (1972) has shown that the CHF depends only on local conditions and is not affected by upstream conditions such as axial flux distribution or degree of subcooling. For water in heat flux controlled systems, this type of CHF could be accompanied by rupture and melting of the heated surface.

(ii) Near-Wall Bubble Crowding and Vapour Blanketing

In flows with moderate to low subcooling, the number of bubbles generated near the heated surface increases with increasing heat flux. A bubble boundary layer is often formed near the heated surface. At high heat flux, the bubble layer thickens (Tong & Hewitt (1972)) to the point where it inhibits heat transfer from the wall. This causes DNB with bubble coalescence and vapour blanketing Fig. 1.7(b). Experimental observations have confirmed the thickening of the bubbly layer at CHF (Tong & Hewitt (1972)).

1.2.3 CHF Mechanisms in Annular Flow Regime

The annular dispersed flow regime occurs at high mass flux and high void fraction. The liquid flows as a film (W_{LF}) covering the walls of the tube with entrained liquid droplets moving at a higher velocity in the vapour core (Fig. 1.7c). The mechanisms of mass transfer from or to the liquid film are:

- Evaporation (q/λ) of liquid in the film;
- Entrainment Ent of liquid droplets from the film to the vapour core;
- Deposition Dep of entrained liquid droplets from the vapour core onto the liquid film.

The variation of liquid film flow rate with distance is given by

$$\frac{d\ W_{LF}}{dz} = \text{Dep} - \text{Ent} - \frac{q}{\lambda} \tag{1.2}$$

As CHF is approached, the film becomes very thin. It is assumed that the (dW_{LF}/dz) term is negligible, compared with the other terms in eq. (1.2). If the evaporation rate (q/λ) exceeds the net deposition (Dep-Ent), the liquid film must breakdown, leading to dryout. The temperature rise in this case is moderate and physical burnout is not normally expected. The liquid film breakdown may also be caused by one of the following effects:

i) Breakdown due to Thermal Capillarity Effects

The heat transfer coefficient through the liquid film is non-uniform due to the existence of surface waves (Fig. 1.7(d)). One might expect that the liquid-vapour interface will have a maximum temperature in the valley, leading to surface tension gradients. The liquid moves away from regions of low surface tension (corresponding to the valley in the film) to regions of high surface tension leading to dryout in the valley of the wave.

ii) Film Disruption due to Nucleate Boiling within the Film

Hewitt (1963) (as quoted by Groeneveld (1981)) has shown that in annular flow, nucleate boiling (i.e., the formation of bubbles at the channel wall) and liquid film evaporation can occur simultaneously. Nucleate boiling bubbles can affect CHF in two ways. The first is, that bubbles can grow and rupture the liquid-vapor interface, leading to a dry spot that cannot be re-wetted in some cases due to the high drypatch temperature. The second is, the nucleate boiling bubbles leaving the liquid-vapor interface tend to produce a cloud of liquid droplets that add to those already entrained (Fig. 1.7(e)). Hewitt (1963) (as quoted by Tong and Hewitt (1972)) produced results confirming that the action of bubbles in triggering film breakdown is of relatively minor importance in the overall picture of CHF and that the indirect action of nucleate boiling bubbles in promoting entrainment of liquid droplets from the film can be significant.

iii) Minimum Wetting Rate

In adiabatic two-phase annular flow, if the liquid film flow rate falls below the "minimum wetting rate", film breakdown will occur. This film breakdown is basically a surface tension effect (Groeneveld (1981)). In diabatic systems, film breakdown may be caused by a combined effect of this and the thermocapillary effect described earlier.

Macbeth (1968) presented experimental results showing the variation of wall film flow rate with heat flux and mass velocity (Fig. 1.8). It can be seen that the liquid film flow rate decreases steadily with increasing heat flux until it reaches zero or very close to zero at burnout. Therefo:e, it has been confirmed that in the annular flow regime, burnout occurs when the liquid film flow rate tends to zero under the effects of evapor :ion, entrainment and deposition. At burnout, the liquid film

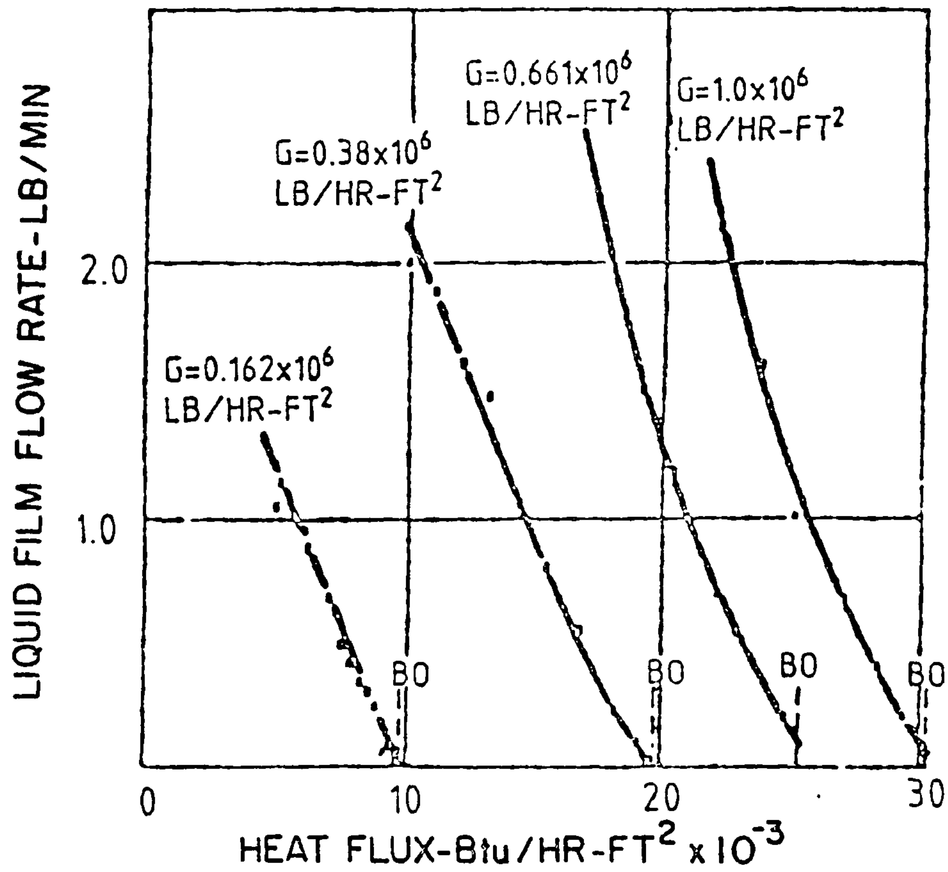


FIGURE 1.8 VARIATION OF WALL FILM RATE WITH HEAT FLUX AND MASS VELOCITY, STANIFORTH et al. (1965-1966)

becomes so thin that it breaks up into rivulets which cause dry spots and consequently wall temperature excursion.

1.2.4 Detection of CHF Location

The simplest way of detecting the CHF location is by monitoring the channel-wall temperature using a thermocouple in the area where CHF is likely to occur. In uniformly heated channels, CHF usually occurs at the channel outlet. Fig. 1.9 shows four distinct types of CHF. The first, "fast-dryout", occurs when the temperature rise is very rapid (Fig. 1.9.a). The wall temperature becomes dangerously high unless the channel power is quickly interrupted. Fast dryout is usually followed by physical burnout. The second, "stable dryout" (Fig. 1.9(b)) is accompanied by a moderate temperature excursion, and is usually followed by a film boiling regime. The third and fourth types of dryout are both "slow dryout". In the third, the temperature rise is accompanied by the temperature oscillations (Fig. 1.9c) and in the fourth (Fig. 1.9d) the temperature rise is gradual. Macbeth (1968) suggested that the temperature oscillations observed in the slow dryout process are due perhaps to the vapor-blanketed area alternatively contracting and enlarging. A thick wall has sufficient thermal inertia to damp out the effect and indicates smooth signals from the thermocouple. Macbeth (1968) also suggested that slow dryouts are usually associated with high quality CHF conditions, while fast dryouts are usually associated with subcooled or low-quality conditions.

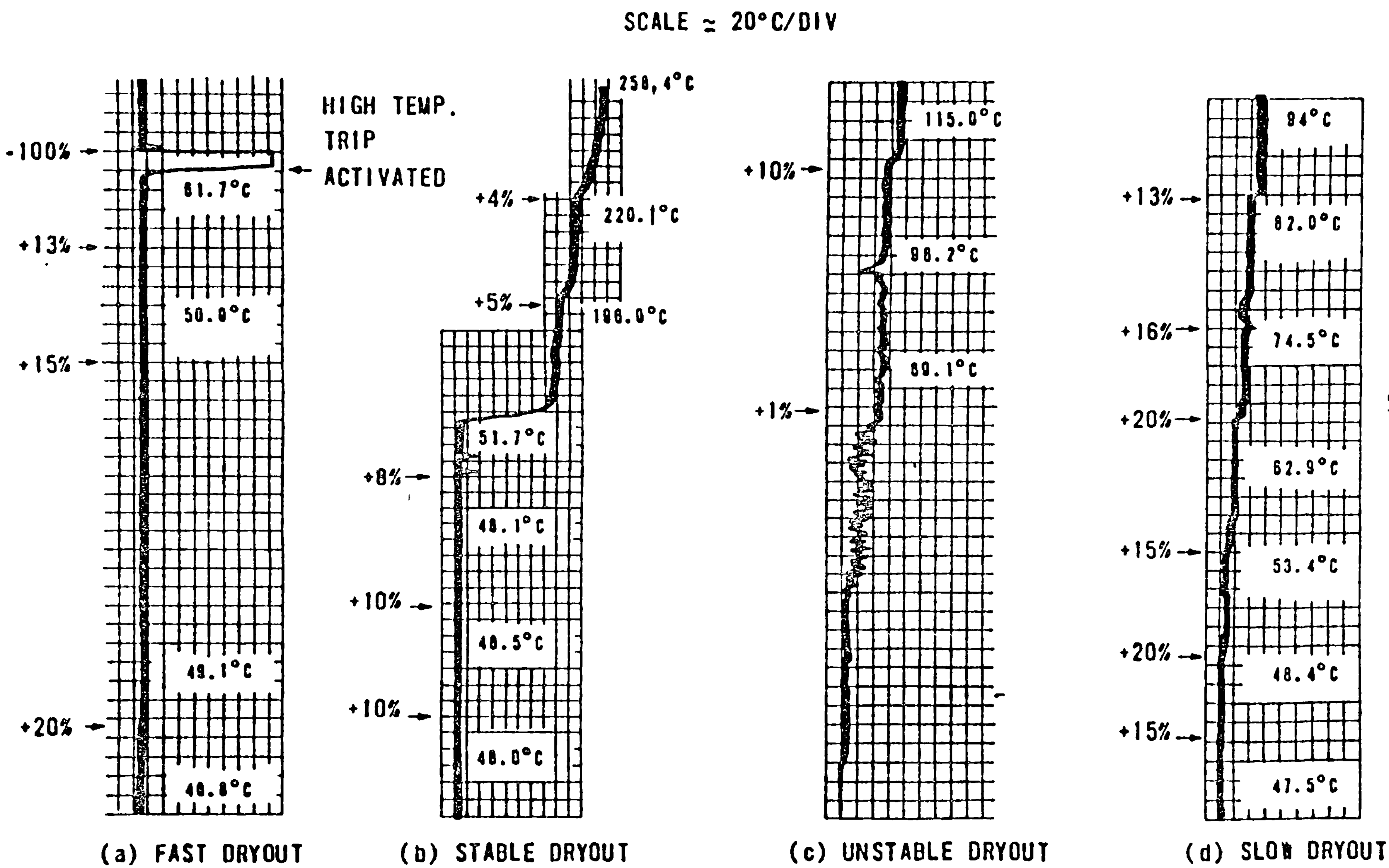


FIGURE 1.9 EXAMPLES OF THERMOCOUPLE TRACES OBTAINED AT DRYOUT IN FREON-12 (% INDICATES INCREASE IN TEST SECTION POWER), GROENVELD (1981)

1.3. Parametric Effects on CHF

1.3.1 General

The factors affecting the CHF can be divided into three categories:

i) Flow parameters (pressure, mass flux, local quality and inlet enthalpy)

ii) Geometry effects (cross sectional area, heated length)

iii) Miscellaneous (gravity, heated surface properties, heat flux distribution, flow orientation, etc.).

The effects on CHF will be expressed, where possible, in terms of CHF vs. inlet subcooling and CHF vs. dryout quality.

1.3.2 Effect of Inlet Subcooling and Exit Quality on CHF

Fig. 1.10 shows the variation of CHF with inlet subcooling for fixed tube length and diameter. The CHF values are plotted against the inlet subcooling with mass flux as a parameter. It appears that the CHF increases linearly with inlet subcooling. This relationship is found in most cases; however, it is by no means universal. The same data as shown in Fig. 1.10 are plotted in Fig. 1.11 in terms of the exit condition. It is observed that the CHF decreases with increasing quality. This trend continues until 100% quality where the CHF is zero.

1.3.3 Effect of Mass Flux

Fig. 1.10 shows that an increase in mass flux causes an increase in CHF for a given inlet subcooling. Fig. 1.12 illustrates the effect of mass flux on CHF. Note that at low mass flux values the CHF is

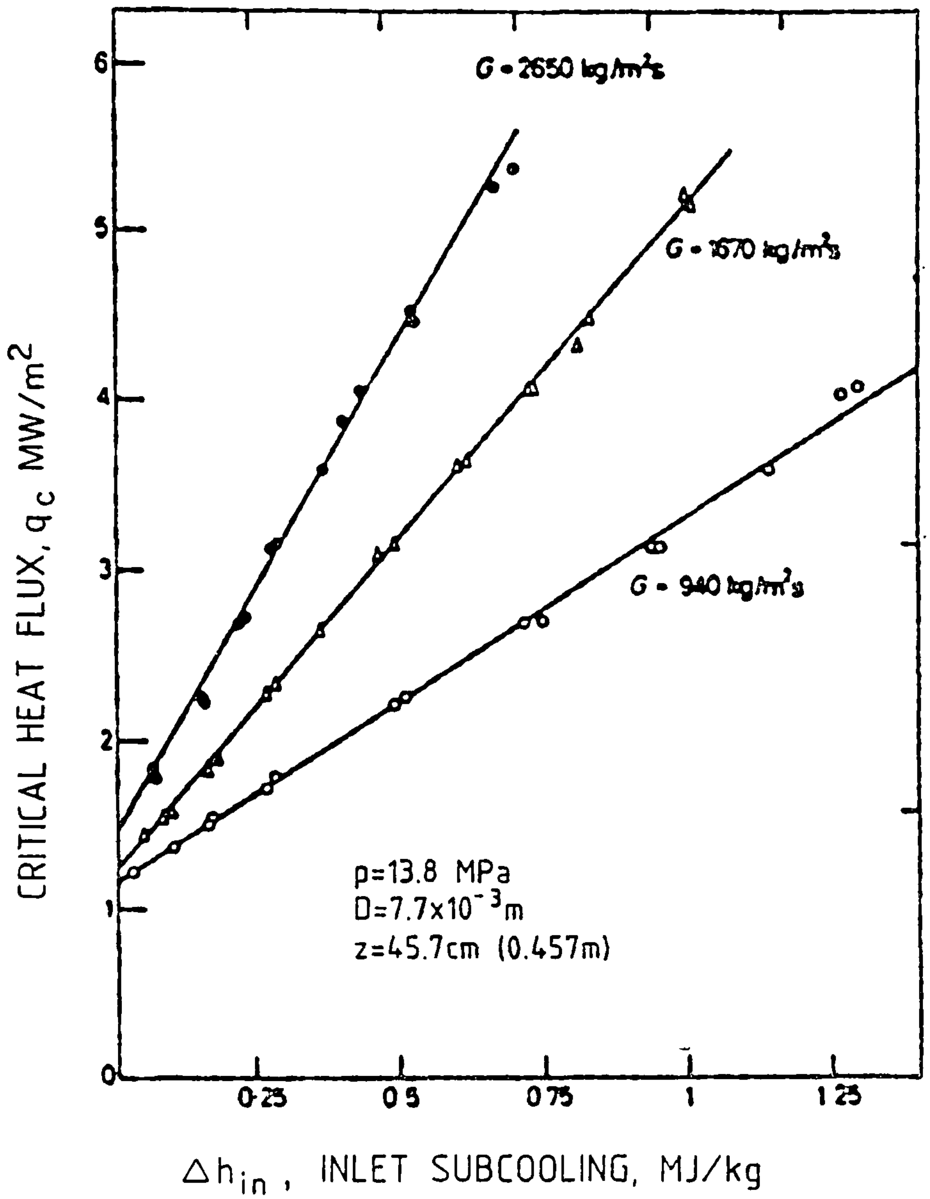


FIGURE 1.10 THE EFFECT OF INLET SUBCOOLING ON CRITICAL HEAT FLUX, COLLIER (1972)

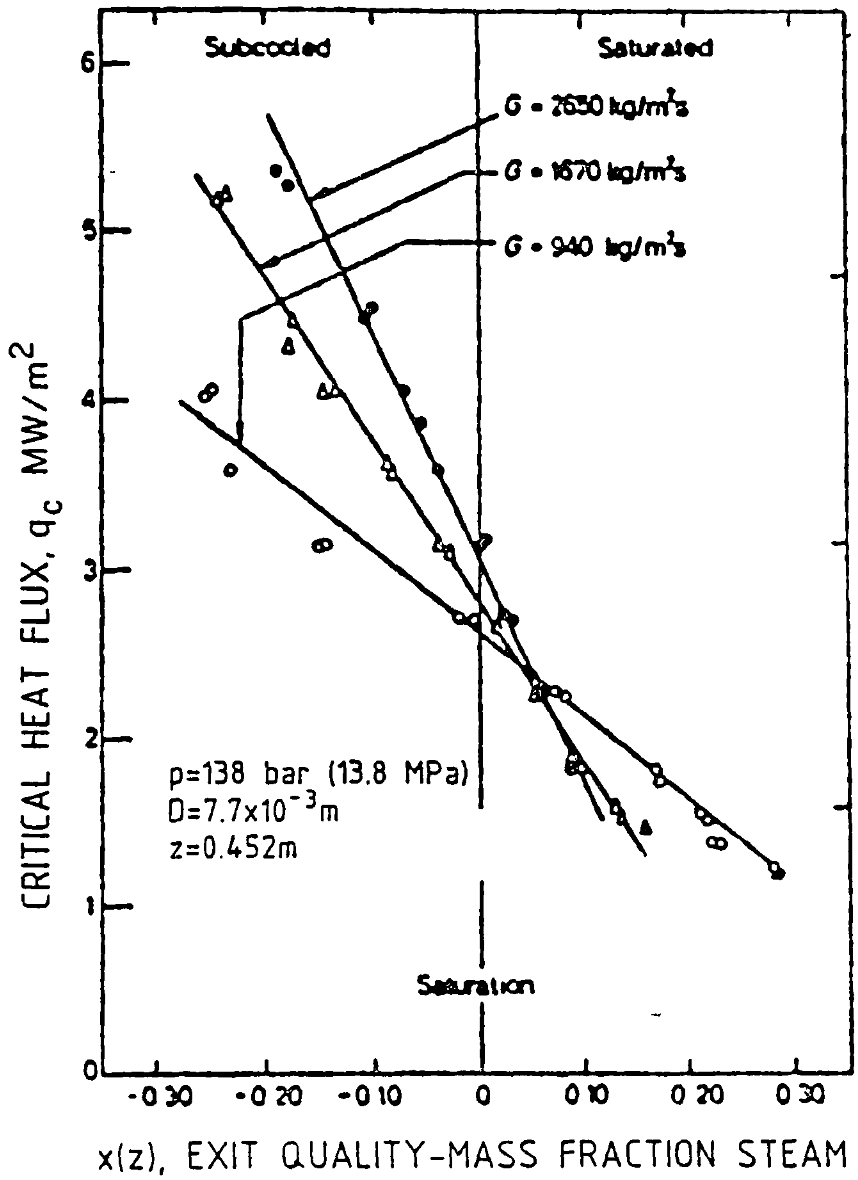


FIGURE 1.11 THE INFLUENCE OF EXIT QUALITY ON CRITICAL HEAT FLUX, COLLIER (1972)

almost directly proportional to the mass flux. The region over which this proportionality applies, is called the "low mass velocity region". In this region, the CHF is approximated by

$$q_c = G \cdot D(\lambda + \Delta H_{in})/4L \tag{1.3}$$

for a uniform axial heat flux distribution. This line corresponds to $X_c = 1.0$; it represents the physical upper limit of the CHF. At high mass flux, the CHF is slightly affected by mass velocity. Fig. 1.11 shows that, in the subcooled region, the CHF increases with an increase in mass flux at constant dryout quality. In the saturated region, there is initially a cross-over while at higher dryout qualities the CHF decreases with an increase in mass flux. This cross-over can be explained by considering the CHF mechanisms: at low quality, the CHF is caused by bubble clouding or microlayer evaporation; an increase in mass flux will increase the removal rate of bubbles from the wall. This tends to delay dryout. At higher quality, the CHF is caused by liquid film depletion: an increase in flow velocity will result in a wavier liquid film and hence an increase in the entrainment rate which leads to an early liquid film depletion.

1.3.4 Effect of Pressure

Pressure has a strong effect on the CHF due to its effect on the thermodynamic properties of the fluid. Fig. 1.13 illustrates this effect: the maximum CHF value for water is reached between 4 and 7 MPa for a given mass flux and dryout quality. The same trend is also valid for pool boiling and can be predicted using Zuber's (1959) correlation

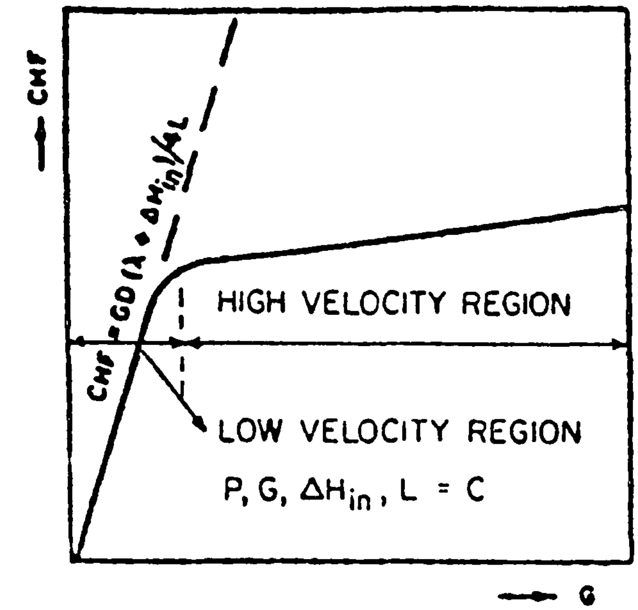


FIGURE 1.12 VARIATION OF CHF WITH MASS FLUX, COLLIER (1972)

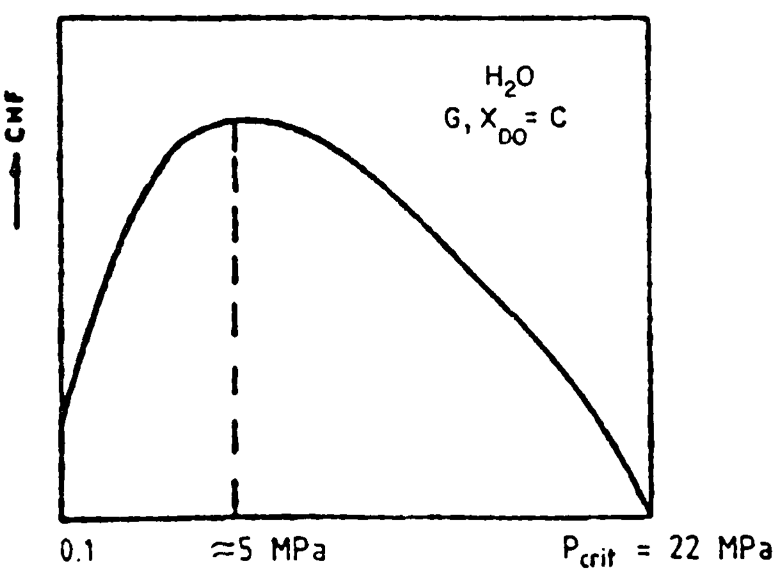


FIGURE 1.13 EFFECT OF PRESSURE ON CHF, KUTATELADZE (1963)

$$q_C = C\,\lambda\,\rho_g^{1/2}\left[\sigma \cdot g(\rho_f - \rho_g)\right]^{1/4} \tag{1.4}$$

At low pressures, ρ_g decreases with decreasing pressure resulting in a low CHF value. At high pressure (near the critical pressure), the CHF approaches zero since σ, λ and $\rho_f - \rho_g$ all approach zero.

1.3.5 Geometry Effects

i) The Effect of Length on CHF

Fig. 1.14 shows the variation of CHF with length and inlet subcooling for fixed mass velocity and tube diameter. It is observed that the CHF increases as the tube length decreases for constant inlet subcooling. For long tubes ($L > 1$ m), the relationship between the CHF and inlet subcooling is linear. This linearity breaks down for short tubes. If the same set of data is replotted as CHF vs. outlet quality as shown in Fig. 1.15, it is observed that the data points for different lengths all fall on the same curve. It is concluded from this observation that the effect of tube length on the CHF for fixed exit quality is small.

ii) The Effect of Diameter on CHF

The effects of tube diameter on the relationships between the CHF and inlet subcooling and between the CHF and the exit quality for fixed values of mass flux, tube length and pressure are illustrated in Figs. 1.16 and 1.17, respectively. It is observed that the CHF increases as the tube diameter increases at constant inlet subcooling. The relationship between the CHF and inlet subcooling is linear for small tube diameters ($D < 12.8 \times 10^{-3}$ m), but for larger diameters a marked curvature is observed.

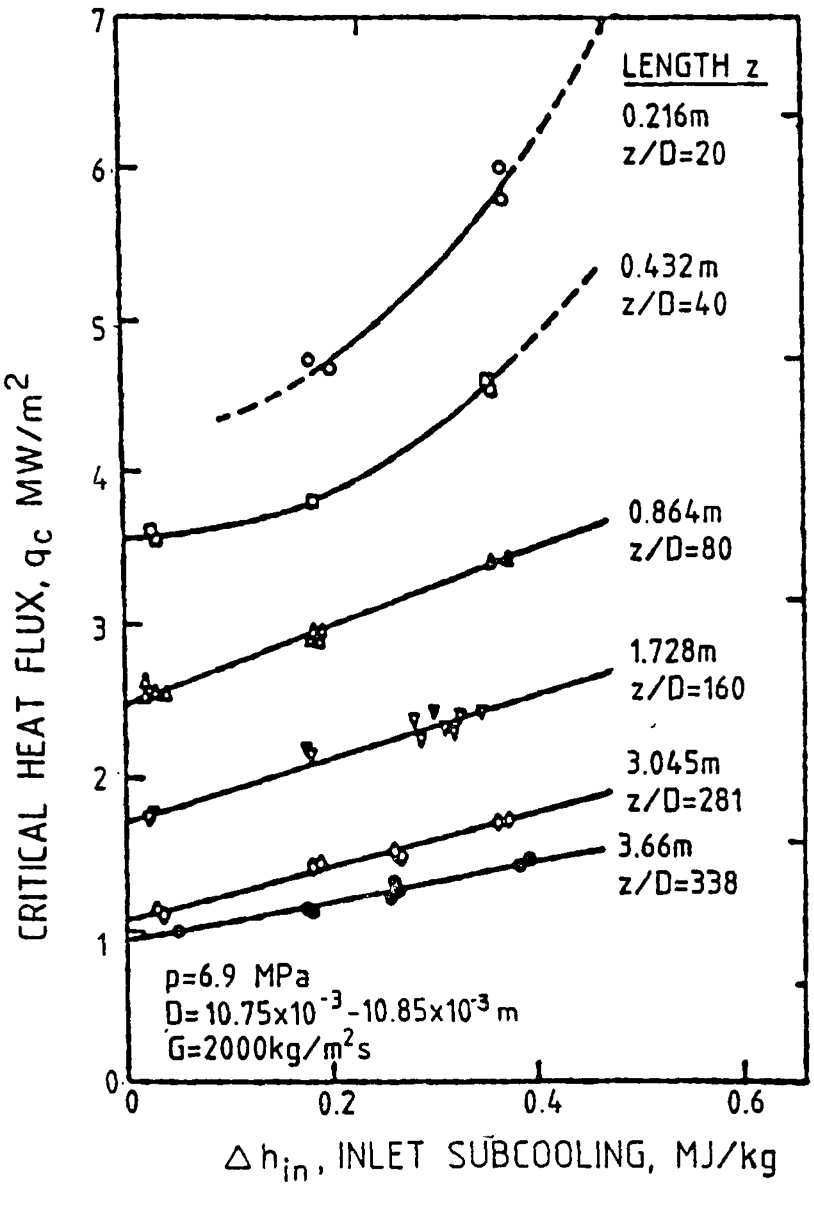


FIGURE 1.14 THE EFFECT OF TUBE LENGTH ON CRITICAL HEAT FLUX AT FIXED INLET CONDITIONS, COLLIER (1972)

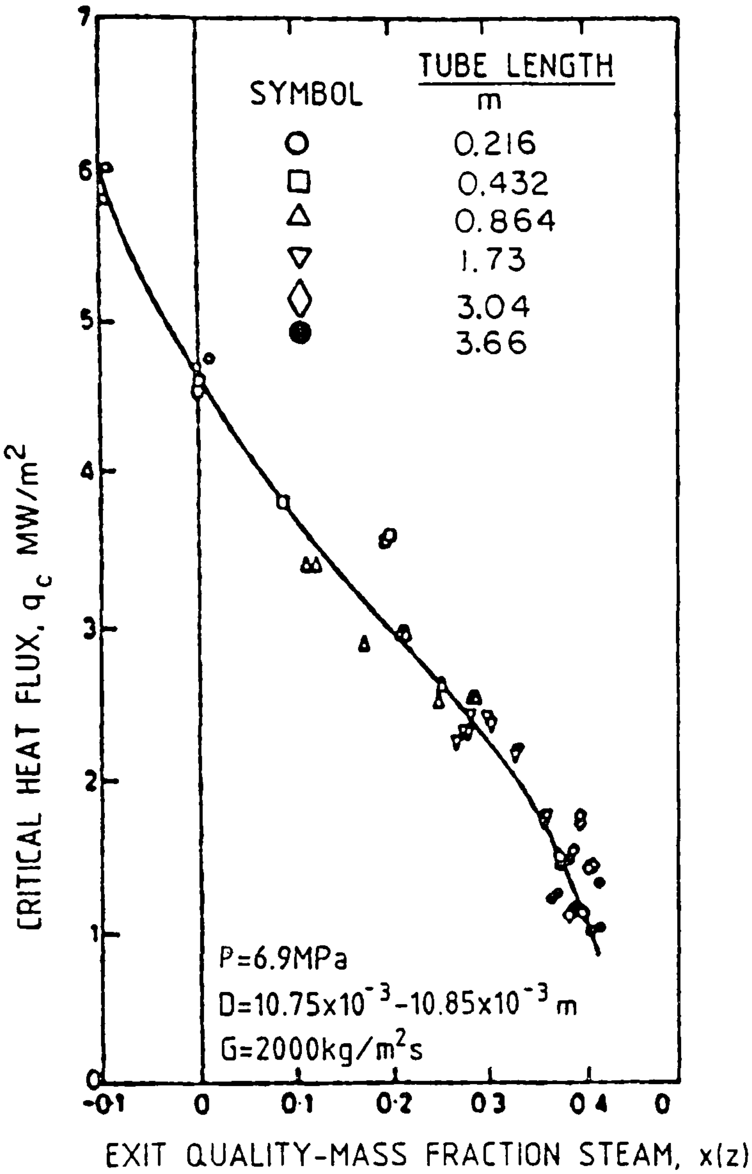


FIGURE 1.15 THE EFFECT OF TUBE LENGTH ON CRITICAL HEAT FLUX AT FIXED EXIT CONDITIONS, COLLIER (1972)

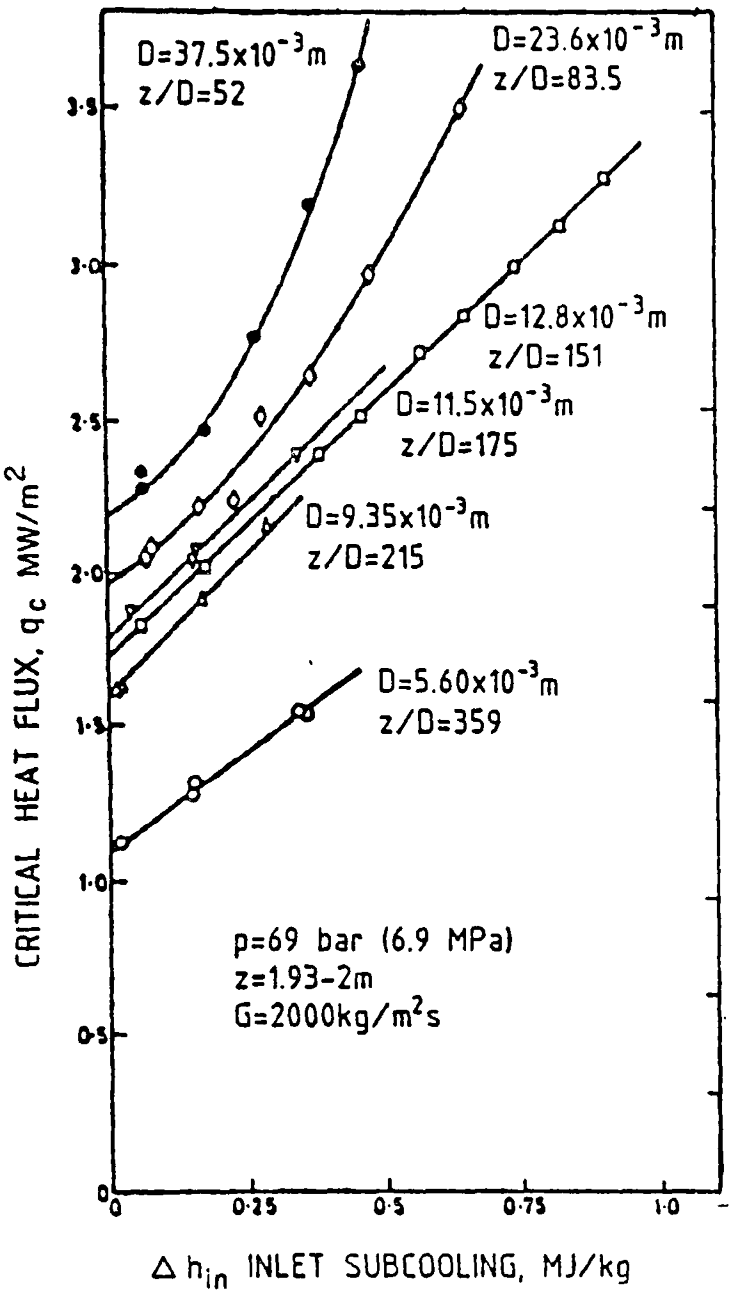


FIGURE 1.16 THE INFLUENCE OF TUBE DIAMETER ON CRITICAL HEAT FLUX AT FIXED INLET CONDITIONS, COLLIER (1972)

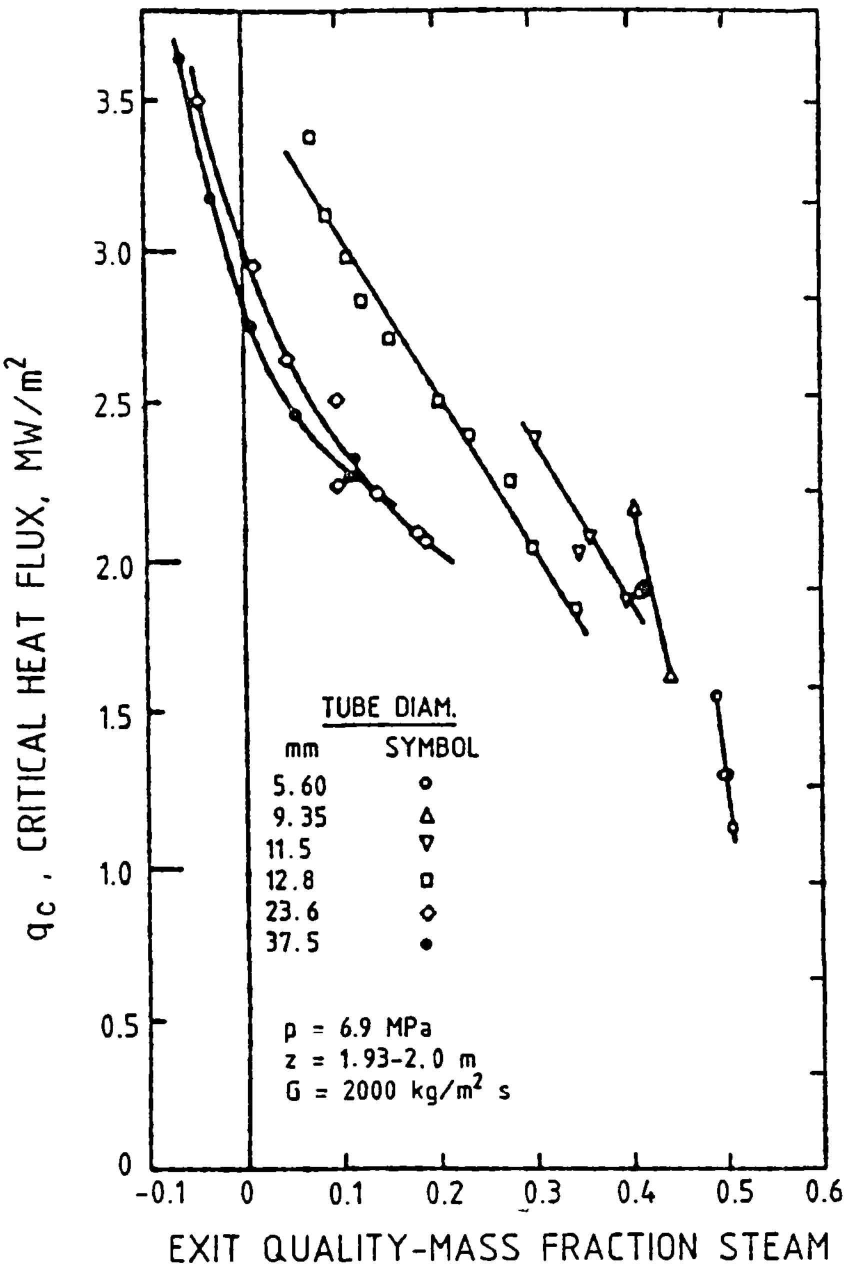


FIGURE 1.17 THE INFLUENCE OF TUBE DIAMETER ON CRITICAL HEAT FLUX AT FIXED EXIT CONDITIONS, COLLIER (1972)

The same data are plotted as CHF vs. exit quality in Fig. 1.17. It is observed that the CHF decreases with increasing tube diameter for a given exit quality.

1.3.6 Effect of Heat Flux Distribution

The effect of axial flux distribution (AFD) on the CHF has been studied by many researchers (e.g. Collier (1972), Tong (1972), Groeneveld (1981)). All these studies point out that AFD effect depends strongly on the CHF mechanisms. Fig. 1.18 illustrates the AFD or (flow memory effects) on the CHF. The effect is expressed as a flux shape factor, F_c, calculated for a set of hot-patch CHF data (Tong, 1972). These data were collected from a 0.686 m-long rectangular test section with a 0.0127 or 0.038 m hot patch located at 0.0095 m from the exit. The hot patch peak to average heat flux ratio was 2:1. The AFD effect (or flux-shape correction factor) F_c, is defined as the ratio of CHF in a uniformly heated tube to the CHF in the same tube with a heat flux of a hot patch. Since the hot patch heat flux is about double that of the upstream heat flux, an F_c value of 0.5 indicates a perfect AFD effect, whereas an F_c value of 1.0 indicates a zero AFD effect. It is observed that the AFD effect is weak in the subcooled region and strong in the high quality region. Therefore it is concluded that the CHF in the subcooled region is strongly affected by the local heat flux and weakly by the AFD. Conversely, the CHF in the high quality region is affected strongly by AFD and weakly by the local heat flux at the dryout location.

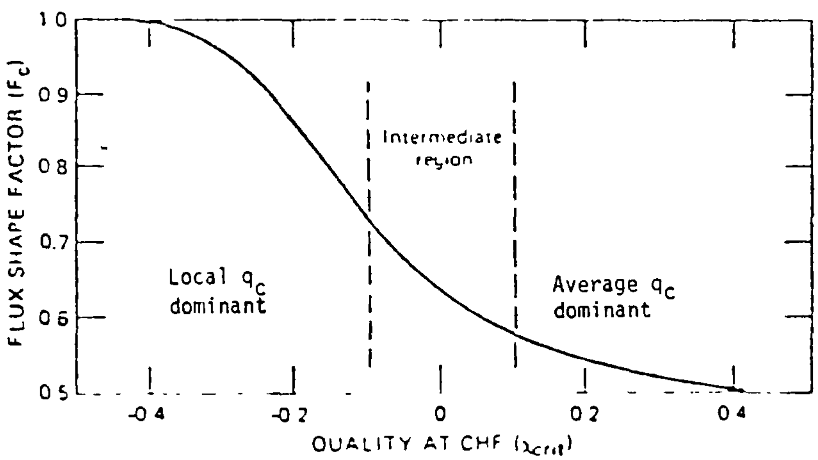


FIGURE 1.18 FLUX SHAPE FACTOR, AS FUNCTION OF QUALITY AT CHF POINT FOR HOT-PATCH HEAT-FLUX DISTRIBUTION, TONG (1972)

1.3.7 Other Effects

i) Effect of channel orientation

The effect of test section inclination on CHF can be significant at low flow due to the buoyancy effects. Macbeth (1968) suggested that the CHF at low flow can be influenced significantly by the channel orientation due to the relative motion between vapor and liquid in the channel. Groeneveld (1981) suggested that the effect of channel orientation on CHF is significant only for mass fluxes less than 3 000 kg $m^{-2}s^{-1}$. Also, the CHF value was found to increase when the inclination angle (from the horizontal) was increased. By comparing CHF values during upflow and downflow a slightly reduced CHF value for downflow was found.

ii) Effect of surface conditions and liquid purity

Macbeth (1968) reported many CHF experiments with different surface materials, different finishes, degrees of aging and different fluids in various states of purity. He concluded that the above mentioned factors have no significant effects on CHF. However, Groeneveld (1981) reported opposing effects of surface roughness on CHF. In the subcooled region, the near-wall mixing is improved by roughening the surface leading to a higher CHF value. In the high quality region, the CHF decreases by roughening the wall. This is caused by (i) an increase in the entrainment rate due to a wavier liquid film, or (ii) a decrease in the film flow rate due to protrusions from the heated surface acting as liquid film trippers.

2. CHF Prediction Methods Applicable to Non-Aqueous Fluids

2.1 General

CHF prediction methods applicable to non-aqueous fluids can be divided into three groups:

i) Fluid to fluid modeling of CHF: This is a technique that enables the CHF of a given system to be predicted using a modelling fluid rather than the working fluid (e.g. Barnett (1964), Stevens & Kirby (1964), Ahmad 1973).

ii) Empirical dimensionless correlations: These are empirically derived dimensionless correlations that predict the CHF in a system regardless of the fluid type (e.g. Katto (1983), Shah (1979), Kutateladze (1963)).

iii) Theoretical Models: These are theoretical models based on the mechanism of CHF. They predict the CHF in a system within a dryout quality range regardless of the fluid type used (e.g. Weisman and Pei (1983), Whalley et al. (1973)).

2.2 Fluid to Fluid Modeling of CHF

2.2.1 General

Fluid modeling is a technique that enables the thermal and hydraulic behaviour of a given system to be predicted using a modeling fluid rather than the working fluid. The working fluid can be replaced by a modeling fluid having a lower latent heat of vaporization. This reduces the operating pressure and the test section power considerably. For example, water at 7 MPa ($\rho_f/\rho_g = 20.6$) can be replaced by Freon-12 at the same liquid to vapor density ratio which occurs at 1 MPa. Also, the latent heat of Freon-12 is approximately 1/20th that of water. This allows a tremendous reduction in the dryout power, and therefore in the cost. The fluids chosen for such modeling are usually members of the fluorocarbon family (Freons) because of their low latent heat and relatively safe use. Also, the physical properties of freons are well known because they have been used extensively as refrigerants.

2.2.2 Barnett's Laws to Scale CHF in Flow Boiling

The first systematic analysis to model water CHF behaviour with Freon was initiated in the United Kingdom by Barnett (1963). Barnett attempted to construct a model based on the laws of dimensional analysis by considering the parameters in a given set which would be compatible with the degrees of freedom available in an experiment. Barnett (1964) suggested fourteen possible sets of laws to scale CHF in flow boiling. The sets are listed in Table 2.1 with the assumed important physical properties and the scaling factors between water at 7 MPa, (1000 psia) and Freon-12 at 1 MPa, (155 psia). Barnett assumed that L/D, ρ_f/ρ_g and $\Delta H_{in}/\lambda$ have the same values in both systems. Barnett tested the fourteen sets of scaling laws and showed that scaling law 4 gave the best results. Scaling law 4 is given by

$$\frac{q_c \gamma^{1/2}}{\lambda\ \rho_f^{1/2}} = F\left(\frac{L}{D}, \frac{D\ Cp_f\ \rho_f^{1/2}}{K_f\ \gamma^{1/2}}, \frac{G\ \gamma^{1/2}}{\rho_f^{1/2}}, \frac{\rho_f}{\rho_g}, \frac{\Delta H_{in}}{\lambda}\right) \tag{2.1}$$

When each of the dimensionless parameters on the RHS of eq. (2.1) has the same value in both the Freon-12 and water systems, then the value of the dimensionless parameter on the LHS of equation (2.1) is the same in both systems.

TABLE 2.1: Possible Sets of Scaling Laws, Barnett (1964)

Set No.	Physical properties assumed important in addition to λ, ρ_L, ρ_V	Resulting dimensionless equation assuming $\phi_B \quad f(L, D, G, P, \Delta H)$	Implied ratio of variables in water at 1000 lb/in^2 and Freon 12 at 155 lb/in^2 (abs) i.e. the scaling factor F			
			$F_L = F_D$	F_G	$F_{\Delta H}$	F_ϕ
1	Cp_L, (liquid specific heat) K_L, (liquid thermal conductivity) β, (rate of change of saturation temperature with pressure)	$\frac{\phi_B \beta^{\frac{1}{2}} Cp_L^{\frac{1}{2}}}{\lambda^{\frac{3}{2}} \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D Cp_L^{\frac{1}{2}} \lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}{K_L \beta^{\frac{1}{2}}}, \frac{G \beta^{\frac{1}{2}} Cp_L^{\frac{1}{2}}}{\lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.583	2.33	11.72	27.32
2	Cp_L, K_L	$\frac{\phi_B}{\rho_L \lambda^{\frac{3}{2}}} = f\left(\frac{L}{D}, \frac{D Cp_L \rho_L \lambda^{\frac{1}{2}}}{K_L}, \frac{G}{\rho_L \lambda^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.669	2.053	11.72	24.03
3	Cp_L, K_L, σ (surface tension)	$\frac{\phi_B K_L}{\lambda \sigma \rho_L Cp_L} = f\left(\frac{L}{D}, \frac{D \sigma \rho_L Cp_L^2}{K_L^2}, \frac{G K_L}{\sigma \rho_L Cp_L}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	1.155	1.189	11.72	13.92
4	Cp_L, K_L, γ (rate of change of $\frac{\rho_L}{\rho_V}$ with pressure)	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D Cp_L \rho_L^{\frac{1}{2}}}{K_L \gamma^{\frac{1}{2}}}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.717	1.914	11.72	22.43
5	β, K_L, γ	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} \quad f\left(\frac{L}{D}, \frac{D \lambda \gamma^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}{\beta, K_L}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.482	1.914	11.72	22.43
6	σ, μ_L (viscosity of liquid)	$\frac{\phi_B \mu_L}{\lambda \sigma \rho_L} = f\left(\frac{L}{D}, \frac{D \sigma \rho_L}{\mu_L^2}, \frac{G \mu_L}{\sigma \rho_L}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.1016	4.007	11.72	46.95
7	σ, μ_V (viscosity of vapour)	$\frac{\phi_B \mu_V}{\lambda \sigma \rho_L} = f\left(\frac{L}{D}, \frac{D \sigma \rho_L}{\mu_V^2}, \frac{G \mu_V}{\sigma \rho_L}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	1.488	1.407	11.72	12.27
8	μ_L, γ	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D \rho_L^{\frac{1}{2}}}{\mu_L \gamma^{\frac{1}{2}}}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.2128	1.914	11.72	22.43
9	μ_L, K_L, β	$\frac{\phi_B \beta^{\frac{1}{2}} K_L^{\frac{1}{2}}}{\lambda^{\frac{3}{2}} \rho_L^{\frac{1}{2}} \mu_L^{\frac{1}{2}}} \quad f\left(\frac{L}{D}, \frac{D \lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}{K_L^{\frac{1}{2}} \beta^{\frac{1}{2}} \mu_L^{\frac{1}{2}}}, \frac{G \beta^{\frac{1}{2}} K_L^{\frac{1}{2}}}{\lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}} \mu_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.3204	1.270	11.72	14.87
10	μ_V, γ	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D \rho_L^{\frac{1}{2}}}{\mu_V \gamma^{\frac{1}{2}}}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.8144	1.914	11.72	22.43
11	σ, γ	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D}{\sigma \gamma}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.4455	1.914	11.72	22.43
12	Cp_V, K_V, β	$\frac{\phi_B \beta^{\frac{1}{2}} Cp_V^{\frac{1}{2}}}{\lambda^{\frac{3}{2}} \rho_L^{\frac{1}{2}}} - f\left(\frac{L}{D}, \frac{D Cp_V^{\frac{1}{2}} \lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}{K_V \beta^{\frac{1}{2}}}, \frac{G \beta^{\frac{1}{2}} Cp_V^{\frac{1}{2}}}{\lambda^{\frac{1}{2}} \rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.3710	1.968	11.72	23.06
13	Cp_V, K_V, γ	$\frac{\phi_B \gamma^{\frac{1}{2}}}{\lambda \rho_L^{\frac{1}{2}}} = f\left(\frac{L}{D}, \frac{D Cp_V \rho_L^{\frac{1}{2}}}{K_V \gamma^{\frac{1}{2}}}, \frac{G \gamma^{\frac{1}{2}}}{\rho_L^{\frac{1}{2}}}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.3814	1.914	11.72	22.43
14	Cp_V, K_V, σ	$\frac{\phi_B K_V}{\lambda \sigma \rho_L Cp_V} = f\left(\frac{L}{D}, \frac{D \sigma \rho_L Cp_V^2}{K_V^2}, \frac{G K_V}{\sigma \rho_L Cp_V}, \frac{\rho_L}{\rho_V}, \frac{\Delta H}{\lambda}\right)$	0.6269	2.487	11.72	29.13

Scaling law 4 assumed that Cp, K and γ are the important physical properties in addition to λ, ρ_f and ρ_g. Also, scaling law 4 related the Freon 12 and water CHF data with less than ±5% error. The results of the comparison of water and water equivalent of Freon-12 CHF data for different length to diameter ratio are shown in Fig. 2.1. Barnett also advised that scaling law 4 may be improved by introducing another dimensionless term involving β.

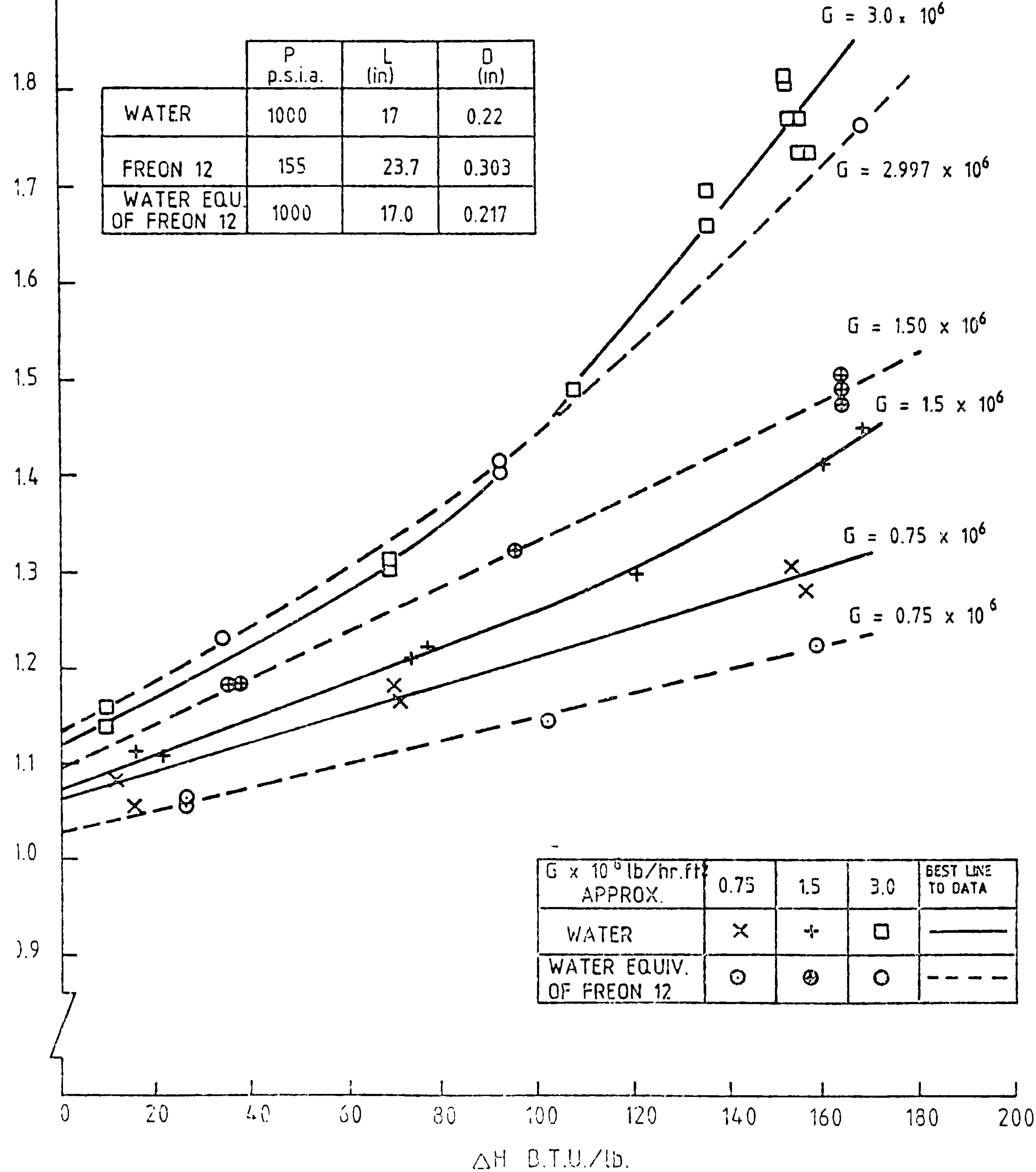
2.2.3 Stevens and Kirby Freon-12 - Water Scaling Technique

Stevens and Kirby (1964) developed a graphical correlation to scale CHF in uniformly heated round tubes. The correlation was developed for Freon-12 at (1. MPa, 155 psi) (abs) and water equivalent of (7 MPa, 1000 psi) (abs), based upon equal liquid-to-vapor density ratios for both fluids. Stevens & Kirby plotted water and Freon-12 CHF data as dryout quality vs. a function of flow and geometry. They observed that the data fall on the same curve if the water function was multiplied by a constant factor. The scaling relation has the following form:

$$\left[GD^{0.25}\left(\frac{D}{L}\right)^{0.59}\right]_{\text{Freon-12}} = K\left[GD^{0.25}\left(\frac{D}{L}\right)^{0.59}\right]_{\text{Water}} \qquad (2.2)$$

where $K = 0.658$.

Fig. 2.2 shows a plot of thermodynamic quality vs. $GD^{0.25}$ $)^{0.59} \times 10^{-4}$ for Freon-12 data at a subcooling ratio $(\Delta H_{in}/\lambda)$ of 0.2. lso, Fig. 2.2 shows water data at the same subcooling ratio plotted as th odynamic quality vs. $K\ GD^{0.25}\left(\frac{D}{L}\right)^{0.59} \times 10^{-4}$, where $K = 0.658$. Steve & Kirby obtained similar results for zero subcooling ratio.



	P p.s.i.a.	L (in)	D (in)
WATER	1000	17	0.22
FREON 12	155	23.7	0.303
WATER EQU. OF FREON 12	1000	17.0	0.217

G x 10^6 lb/hr.ft^2 APPROX.	0.75	1.5	3.0	BEST LINE TO DATA
WATER	×	+	□	———
WATER EQUIV. OF FREON 12	⊙	⊕	○	- - -

FIGURE 2.1 TEST OF SCALING LAWS 4., BARNETT (1963)

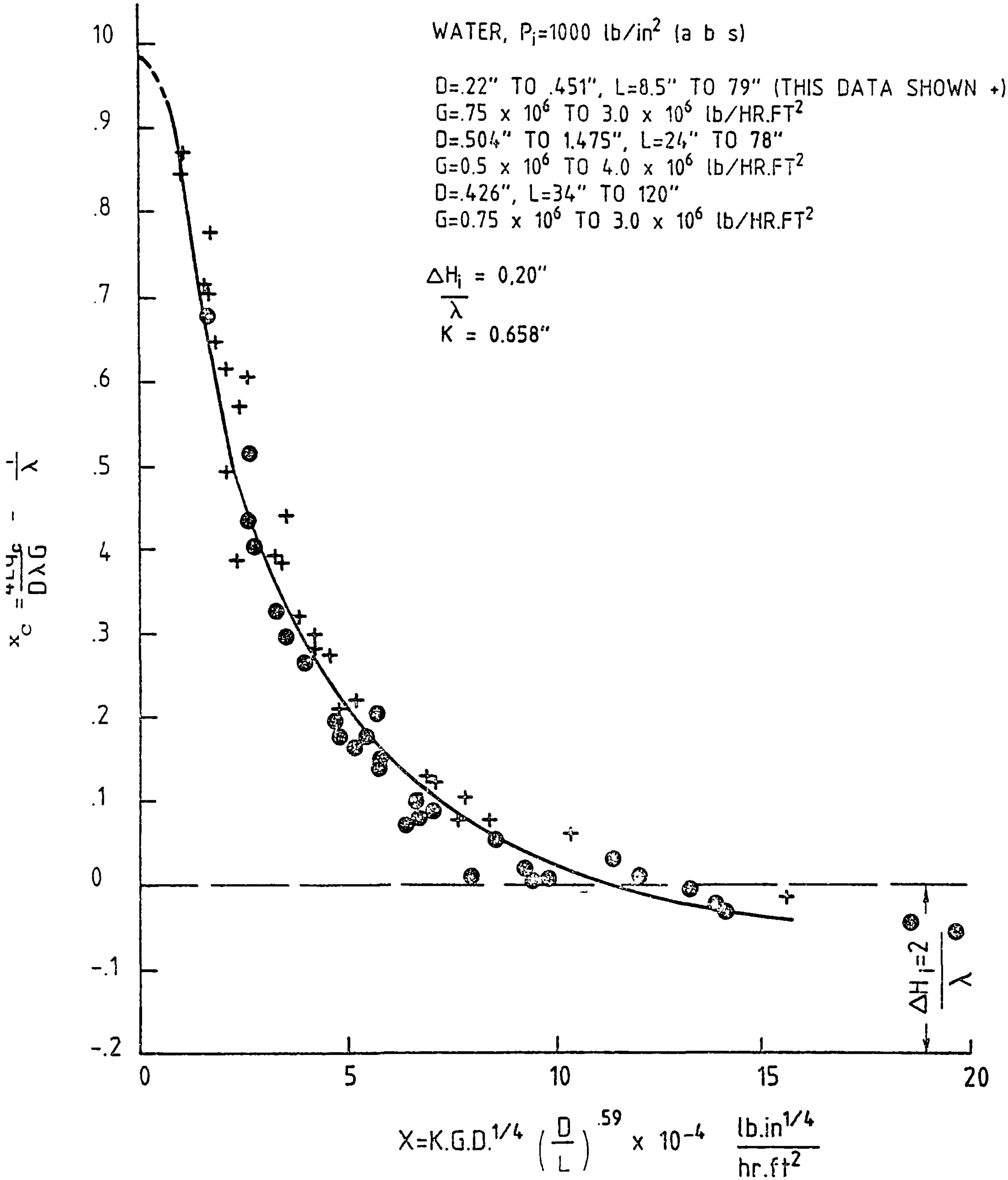


FIGURE 2.2 CORRELATION OF WATER DATA SUPERIMPOSED UPON BEST CURVE FOR FREON-12 DATA. STEVENS & KIRBY (1964)

Therefore, according to Stevens and Kirby water CHF results at (7 MPa, 1000 psi) (abs) can be obtained from Freon-12 ones at (1 MPa, 155 psi) (abs) if

$$(\rho_f/\rho_g)_W = (\rho_f/\rho_g)_{Fr-12}$$

$$(\frac{L}{D})_W = (\frac{L}{D})_{Fr-12}$$

$$(\frac{\Delta H_{in}}{\lambda})_W = (\frac{\Delta H_{in}}{\lambda})_{Fr-12}$$

$$\left(K.GD^{1/4}(\frac{D}{L})^{0.59}\right)_W = \left(GD^{1/4}(\frac{D}{L})^{0.59}\right)_{Fr-12}$$

where K = 0.658.

Then:

$$(\frac{q_c}{\lambda G})_W = (\frac{q_c}{\lambda G})_{Fr-12} \qquad (2.3)$$

Fig. 2.3 illustrates the comparison between Freon-12 CHF data at 1 MPa and the equivalent water data at 7 MPa calculated using Stevens and Kirby scaling technique. Also, Stevens and Kirby obtained similar results for a large range of diameter, length to diameter ratio and inlet subcooling ratio. For all the results compared by Stevens and Kirby, the accuracy of prediction falls within the range of uncertainty in the water CHF data. Eq. (2.2) implies that only geometric ratio can be scaled. However, in later work in complex geometries (19-rod clusters), Stevens et al. (1966) indicated that the best results were obtained with identical geometries for both fluids.

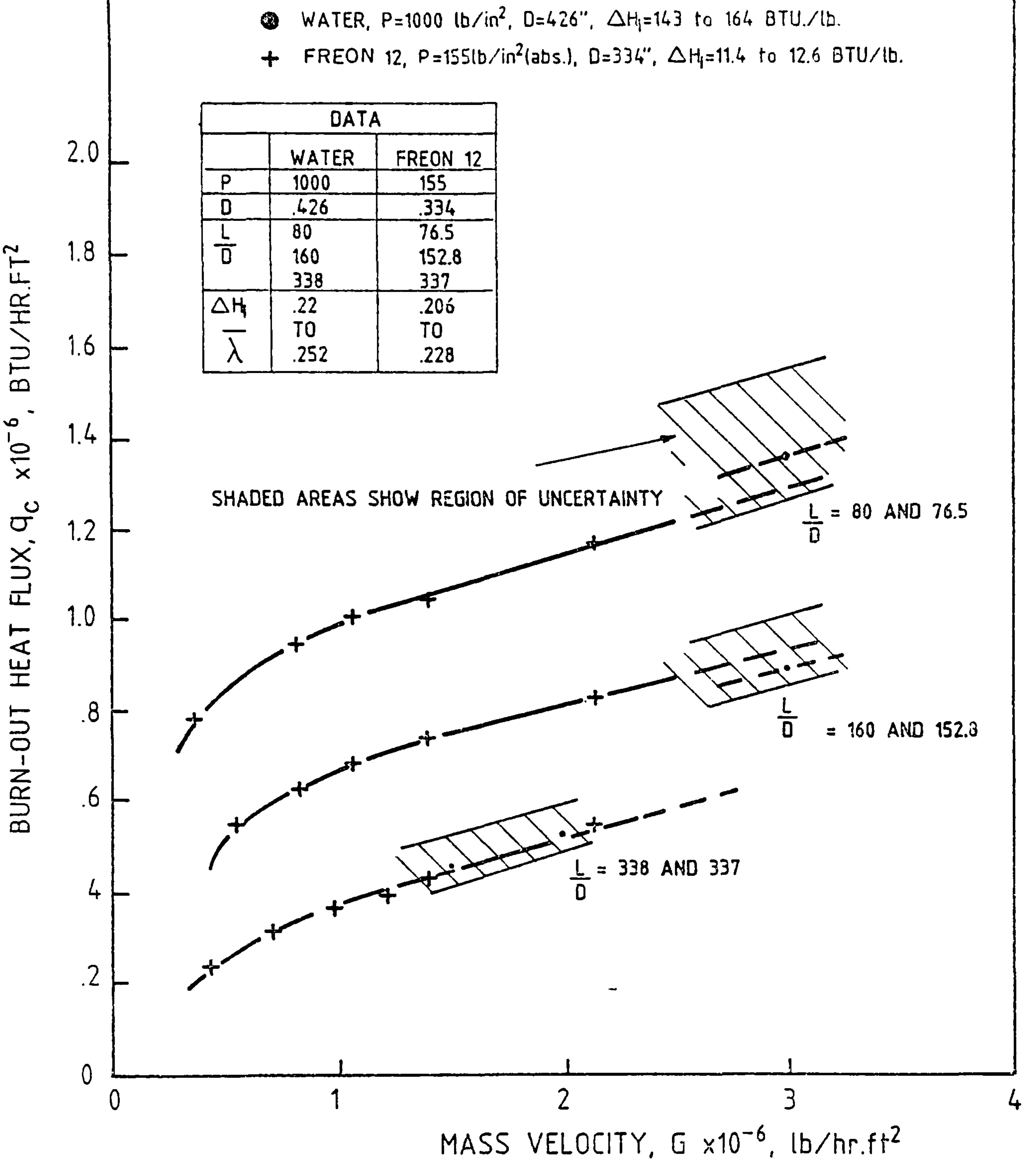


FIGURE 2.3. COMPARISON BETWEEN CHF DATA FOR WATER AND WATER-EQUIVALENT FREON-12 DATA. STEVENS & KIRBY (1964).

2.2.4 Staub's Modeling Correlation for Round Tubes

Staub (1969) proposed a modification to the Stevens and Kirby graphical correlation. He replaced the tube length in the term ($GD^{1/4}(D/L)^{0.59}$) by the equilibrium boiling length (L_b) starting at zero equilibrium quality. Fig. 2.4 shows Freon-12 CHF data given by Stevens et al. (1965) plotted as X_c vs. $GD^{1/4}(D/L)^{0.59}$. Also, Fig. 2.4 shows the same data and Freon-22 CHF data given by Staub (1969) plotted as X_c vs. $GD^{1/4}(D/L_b)^{0.59}$, where L_b is the boiling length. Good agreement between the experimental Freon-12 data and the modified correlation of Staub is observed (error ±4%). Also, Staub demonstrated that the scaling factor (K = 0.658) used by Stevens & Kirby to convert the value of $GD^{1/4}(D/L)^{0.59}$ from the water to the Freon correlation does not appreciably vary with pressure in the range tested (water equivalent: 3.2 MPa - 10 MPa, (500 - 1400 psia)).

2.2.5 Coffield Subcooled DNB Investigation of Freon-113

Coffield (1969) extended the application of CHF modelling to subcooled liquid conditions. He tried two modeling techniques. The first one is based on dimensional analysis developed by Barnett (1964): it has the following form

$$\frac{q_c \gamma^{1/2}}{\lambda \rho_f^{1/2}} = F\left(\frac{L}{D}, \frac{D C_{pf} \rho_f^{1/2}}{K_f \gamma^{1/2}}, \frac{G \gamma^{1/2}}{\rho_f^{1/2}}, \frac{\rho_f}{\rho_g}, \frac{\Delta H_{in}}{\lambda} \right) \quad (2.4)$$

The results obtained from Barnett's method are shown in Figs. 2.5 for a water pressure of 7 MPa (1000 psia). The second is the empirical technique developed by Stevens & Kirby (1964) and is summarized in Section

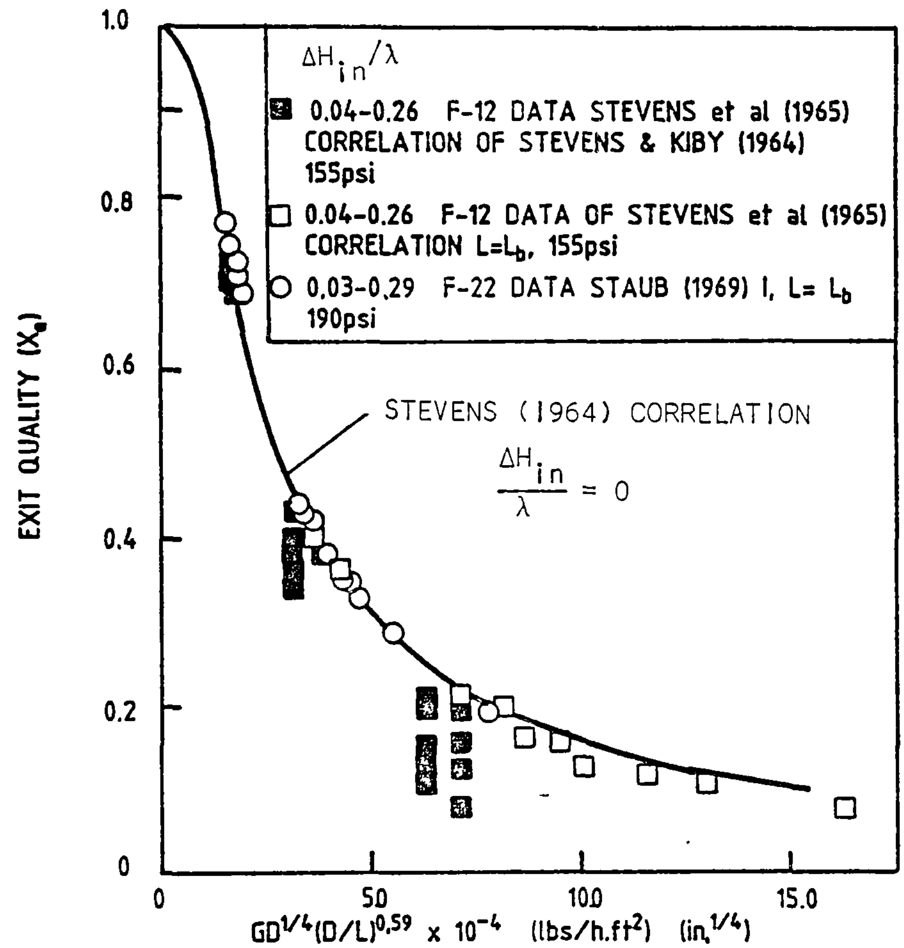


FIGURE 2.4 CRITICAL DATA WITH FREONS AT VARIOUS INLET SUBCOOLING USING THE CORRELATION OF STEVENS & KIRBY (1964) AS WELL AS THE MODIFIED OF STAUB (1964). STAUB (1969).

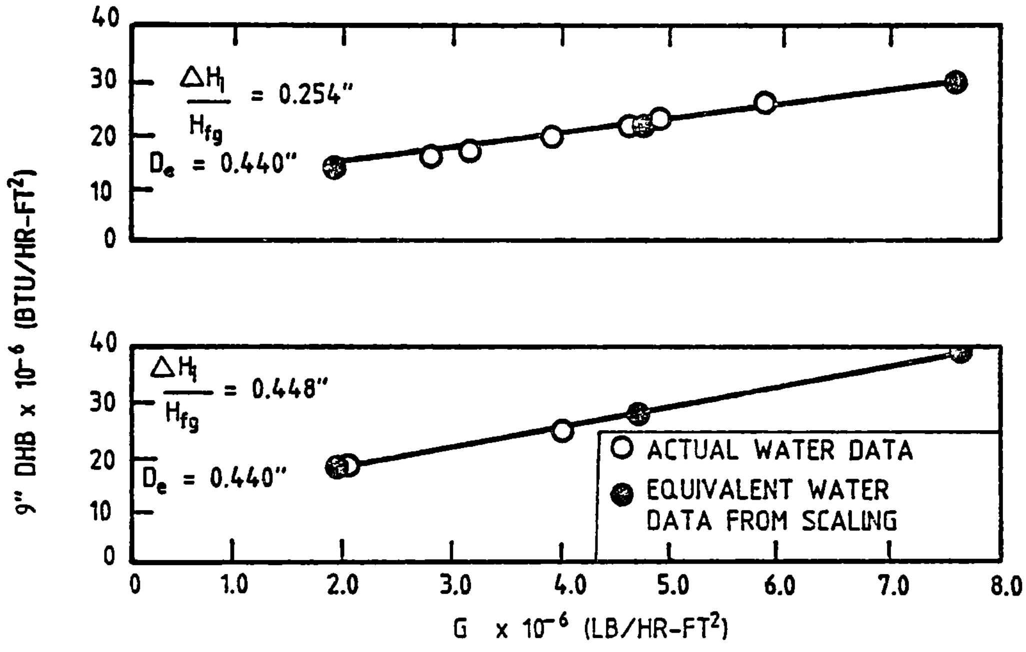


FIGURE 2.5 CHF RESULTS OBTAINED FROM BARNETT'S METHOD FOR WATER PRESSURES OF 7 MPa (1000 PSIA). COEFFIELD (1969).

2.2.3. The scaling factors K (used in the Stevens & Kirby technique) were determined empirically in Figs. 2.6 to be 0.684, 0.690 and 0.715 for ρ_f/ρ_g values of 20.6, 11.8 and 7.2, respectively. The maximum discrepancy between the actual data and the scaled data is about 15% for both techniques.

2.2.6 Dix's Technique for Freon-Water Modeling of CHF in Round Tubes

Dix (1970) developed empirical Freon-water modeling relations for CHF in exactly matching round tube geomtries. His study was based on comparing Freon-114 CHF data with a water CHF correlation proposed by Biasi (1967). Dix found that mass flux scaling factors are a function of pressure (density ratio), length to diameter ratio, and mass velocity. His mass flux scaling factor for Freon-114 has the following form

$$K = \frac{G_{Freon}}{G_{Water}} = C_T(1.0-0.09\ G_W \times 10^{-6})(1.04-0.05\ \frac{L}{D} \times 10^{-2})(1.41-0.02\ \rho_f/\rho_g) \tag{2.5}$$

where C_T is the modeling constant that depends on the Freon type. C_T = 0.74 for Freon-114. The resulting rms error in critical heat flux prediction for all the Freon-114 data was found to be 4.2% (Dix (1970)).

Also, Dix found mass flux scaling factors for other Freon types at 7 MPa. The range of the scaling factors K, the modeling constant C_T, the number of points and the rms error are listed in table 2.2.

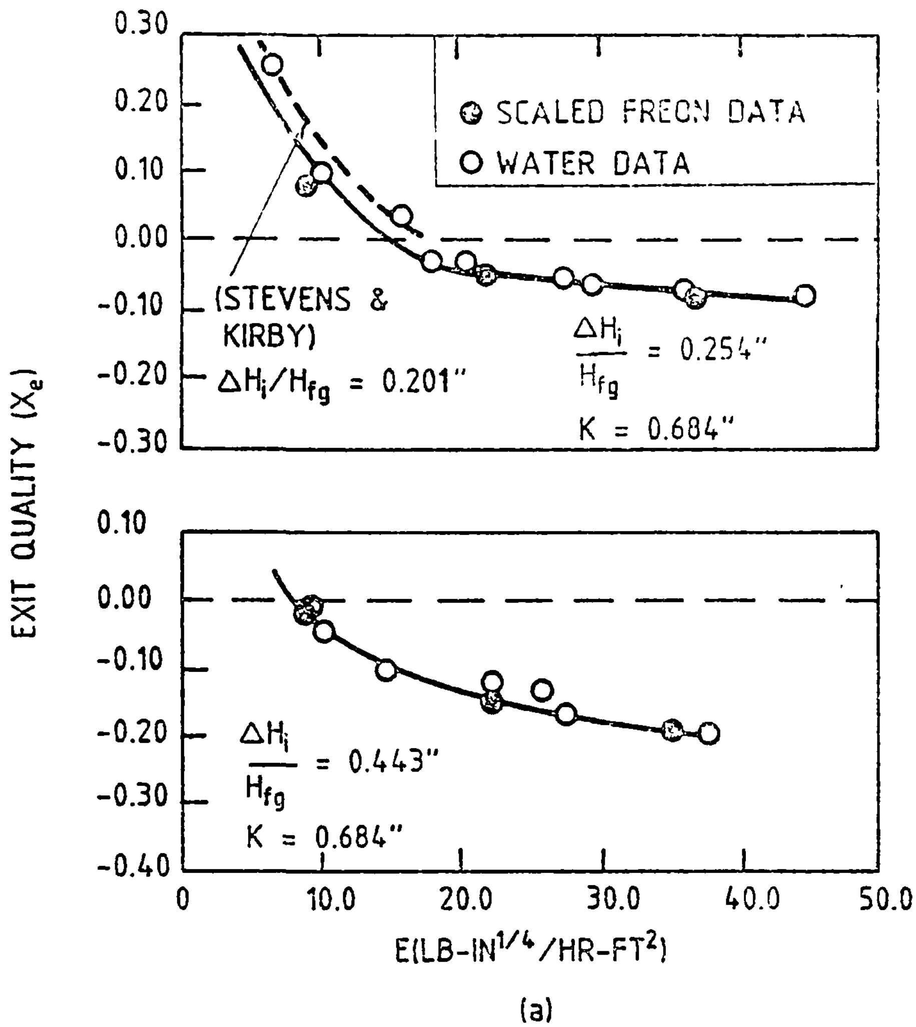


FIGURE 2.6(A) CORRELATION CURVES FOR DETERMINING K FACTOR IN METHOD OF STEVENS & KIRBY FOR ρ_f/ρ_g = 11.8 AND 7.2 RESPECTIVELY. COEFFIELD (1969).

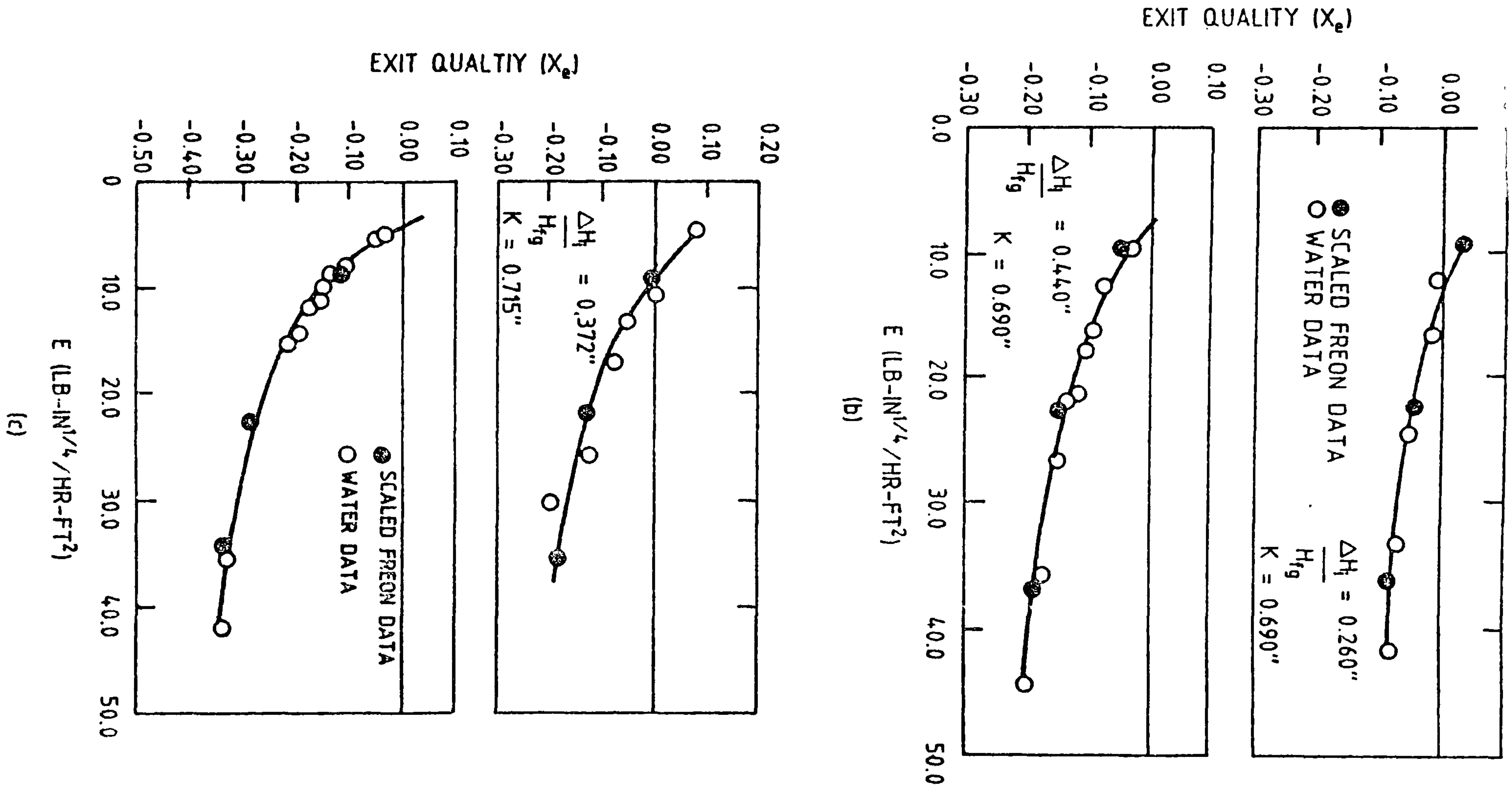


FIGURE 2.6(B) & (C) CORRELATION CURVES FOR DETERMINING K FACTOR IN SCALING METHOD OF STEVENS & KIRBY FOR ρ_f/ρ_g = 11.8 AND 7.2 RESPECTIVELY. COEFFIELD (1969)

Table 2.2. Freon Modeling Constants and Critical Heat Flux Prediction Errors, Dix (1970)

Freon	Modeling Constant C_T	K-Range	No. of Points	rms Error
F-114	0.740	0.54 - 0.87	424	4.2%
F-12	0.800	0.51 - 0.80	973	6.3%
F-22	0.807	0.65 - 0.72	11	3.6%
F-21	0.920	0.61 - 0.90	557	8.5%

2.2.7 Ahmad Scaling Technique

Ahmad (1973) developed a technique based on dimensional analysis to scale CHF between different fluids. The technique was tested for various freons, water, potassium and carbon dioxide over a wide range of pressure, mass flux and inlet subcooling, and in both the subcooled and high quality regions. Ahmad showed that the effects of buoyancy, liquid and vapor thermal conductivities, liquid and vapor Prandtl numbers and secondary properties (such as β and γ) are negligible as far as modelling of CHF is concerned. Also, Ahmad combined the effect of Reynolds number, Weber-Reynolds number ($\mu_f^2/\sigma D\rho_f$) and liquid-vapor viscosity ratio in one term, thus creating a compensated distortion technique of the following form:

$$\frac{q_c}{\lambda G} = F\left(\psi_{CHF}, \frac{\Delta H_{in}}{\lambda}, \rho_f/\rho_g, L/D\right) \tag{2.6}$$

where

$$\psi_{CHF} = \left(\frac{GD}{\mu_f}\right) \times \left(\frac{\mu_f^2}{\sigma D\rho_f}\right)^{n_1} \times \left(\mu_f/\mu_g\right)^{n_2} \tag{2.7}$$

where n_1 and n_2 were determined from experimental data to be 2/3 and -1/5, respectively.

The effect of mass flux, inlet subcooling, pressure and geometry are incorporated in the four dimensionless parameters ψ_{CHF}, $\Delta H_{in}/\lambda$, ρ_f/ρ_g and L/D respectively. Therefore for two different systems if:

$$(\psi_{CHF})_1 = (\psi_{CHF})_2$$

$$(\Delta H_{in}/\lambda)_1 = (\Delta H_{in}/\lambda)_2$$

$$(\rho_f/\rho_g)_1 = (\rho_f/\rho_g)_2$$

$$(L/D)_1 = (L/D)_2$$

$$\left(\frac{q_c}{\lambda G}\right)_1 = \left(\frac{q_c}{\lambda G}\right)_2 \tag{2.8}$$

By rearranging the dimensionless parameters ψ_{CHF} becomes:

$$\psi_{CHF} = \left[\left(\frac{G^2 D}{\rho_f \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-0.133} \times \left(\frac{GD}{\mu_g}\right)^{-0.2}\right] \tag{2.9}$$

where

$\frac{G^2 D}{\rho_L \sigma}$ is the Weber number

$\frac{GD}{\mu_f}$ and $\frac{GD}{\mu_g}$ are the superficial liquid and vapor Reynolds number respectively.

Since accurate surface tension values for many fluids are not available, Ahmad proposed an alternative mass flux scaling parameter

$$\psi_{CHF} = \left[\left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2}\,\mu_f}{D\,\rho_f^{1/2}}\right)^{2/3} \times \left(\frac{\mu_f}{\mu_g}\right)^{1/8}\right] \tag{2.10}$$

Also, Ahmad indicated that eqs. (2.9) and (2.10) are comparable over a wide range of pressure. Ahmad recommended that for complex geometries the cross section of the two systems should be identical, but for circular geometries it is possible to model systems with slightly different diameters.

According to Ahmad's model, if the non-dimensional parameters ρ_f/ρ_g, $\Delta H_{in}/\lambda$ and L/D are the same in two different systems then the relationships between $q_c/\lambda G$ and ϕ_{CHF} should be identical. This is illustrated in Fig. 2.7 which shows a plot of CO_2, Freon-12 and water CHF data in uniformly heated tubes. Similar plots for Freon-113 and potassium are shown in Figs. 2.8 and 2.9.

2.3 Empirical Dimensionless Correlations

2.3.1 General

The empirical dimensionless correlations rely on experimental CHF data to optimize their constants. They are usually based on assumptions that oversimplify the complexity of the CHF phenomena. The correlations are derived for predicting CHF in a system regardless of the fluid type.

2.3.2 Kutateladze's Correlation for Predicting CHF in Pool Boiling

Kutateladze (1963) described the hydrodynamics of the two-phase boundary layer by the momentum and continuity equations for the liquid and vapor phases. The equations were written based on the following assumptions:

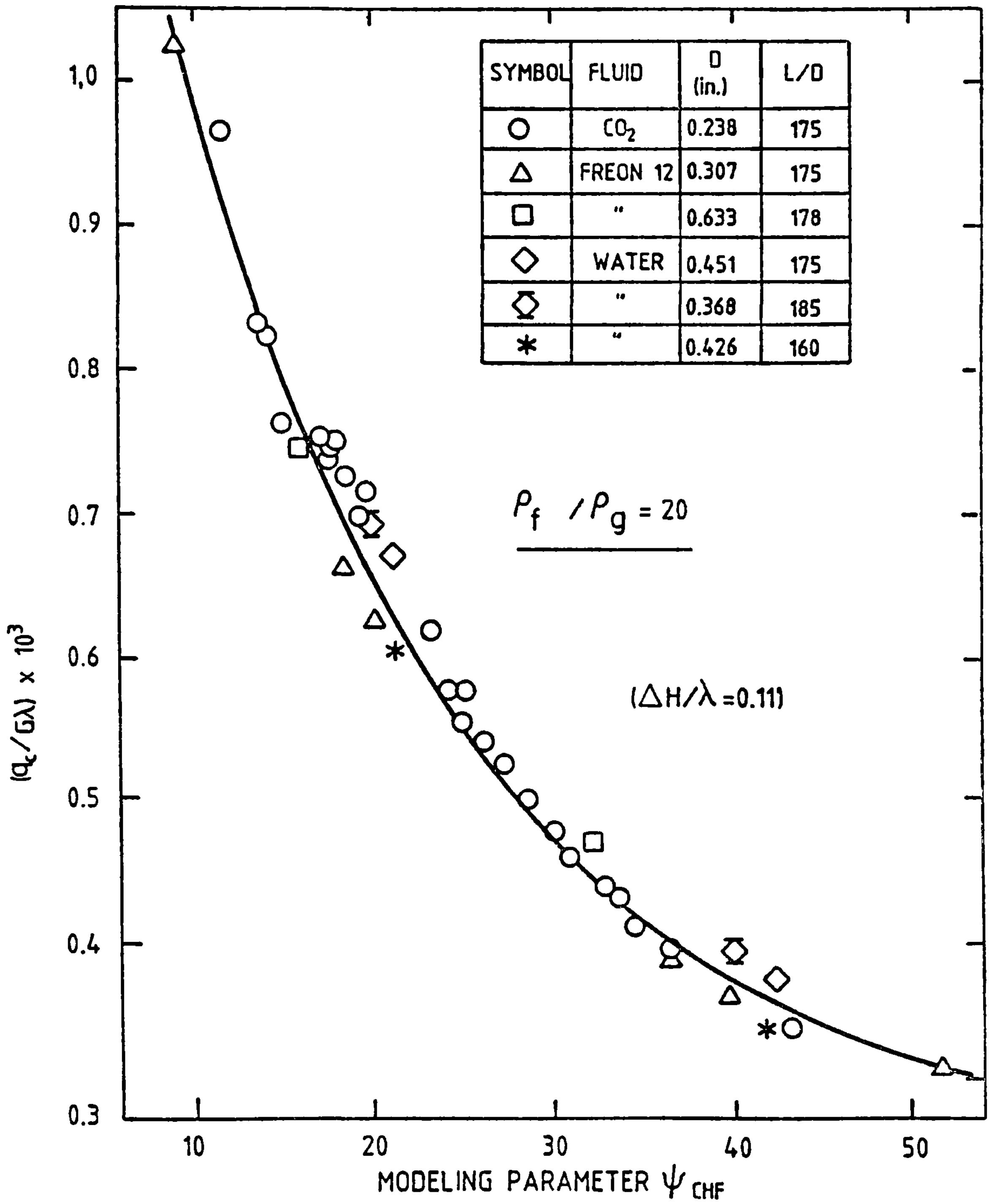


FIGURE 2.7 COMPARISON OF WATER, CO2 AND FREON-12 DATA (IN TUBES) AT WATER EQUIVALENT PRESSURE 1000 PSIA (ρ_f/ρ_g = 20). AHMAD (1973).

SYMBOL	FLUID	D (in.)	L/D
▲	POTASSIUM	0.158	80
△	WATER	"	"
□	WATER	"	"

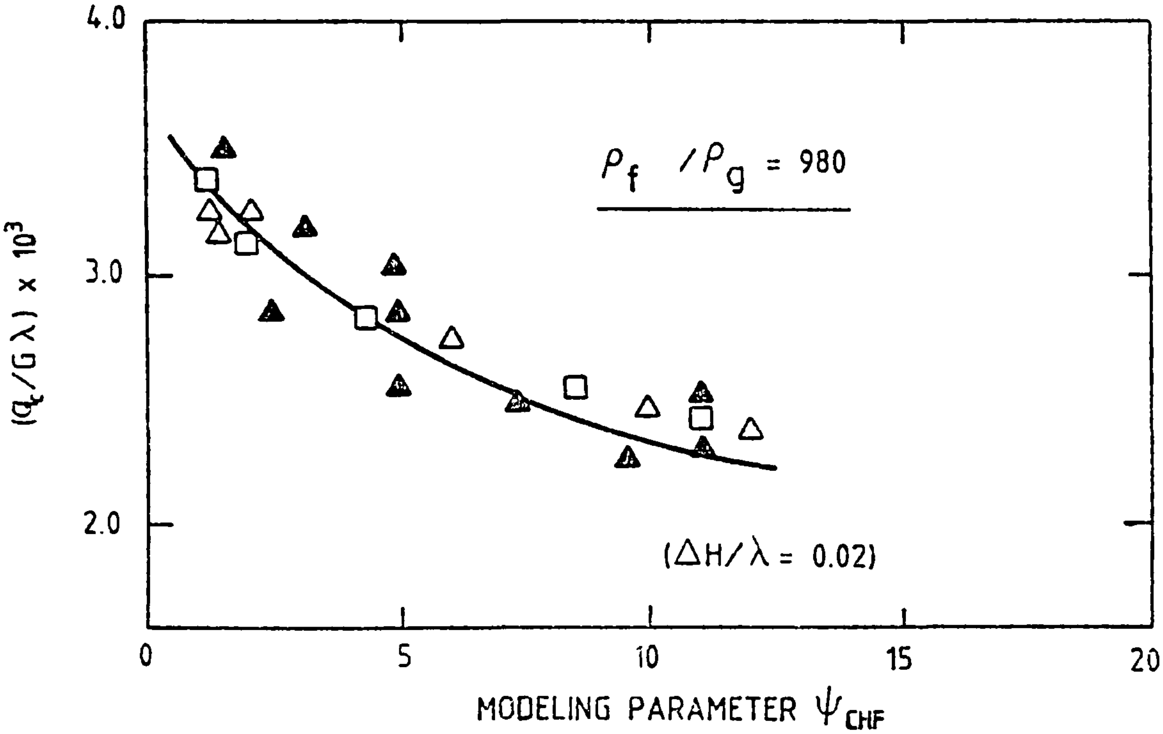


FIGURE 2.8 COMPARISON OF WATER AND POTASSIUM DATA (IN TUBES) AT WATER EQUIVALENT PRESSURE 24 LB/IN^2 ABS. (ρ_f/ρ_g = 980). AHMAD (1973).

SYMBOL	FLUID	D (in.)	L/D
▲	FREON 113	0.402	75
□	WATER	0.673	77
△	"	0.687	67
▽	"	0.304	59
◇	"	0.075	80
○	"	0.186	65

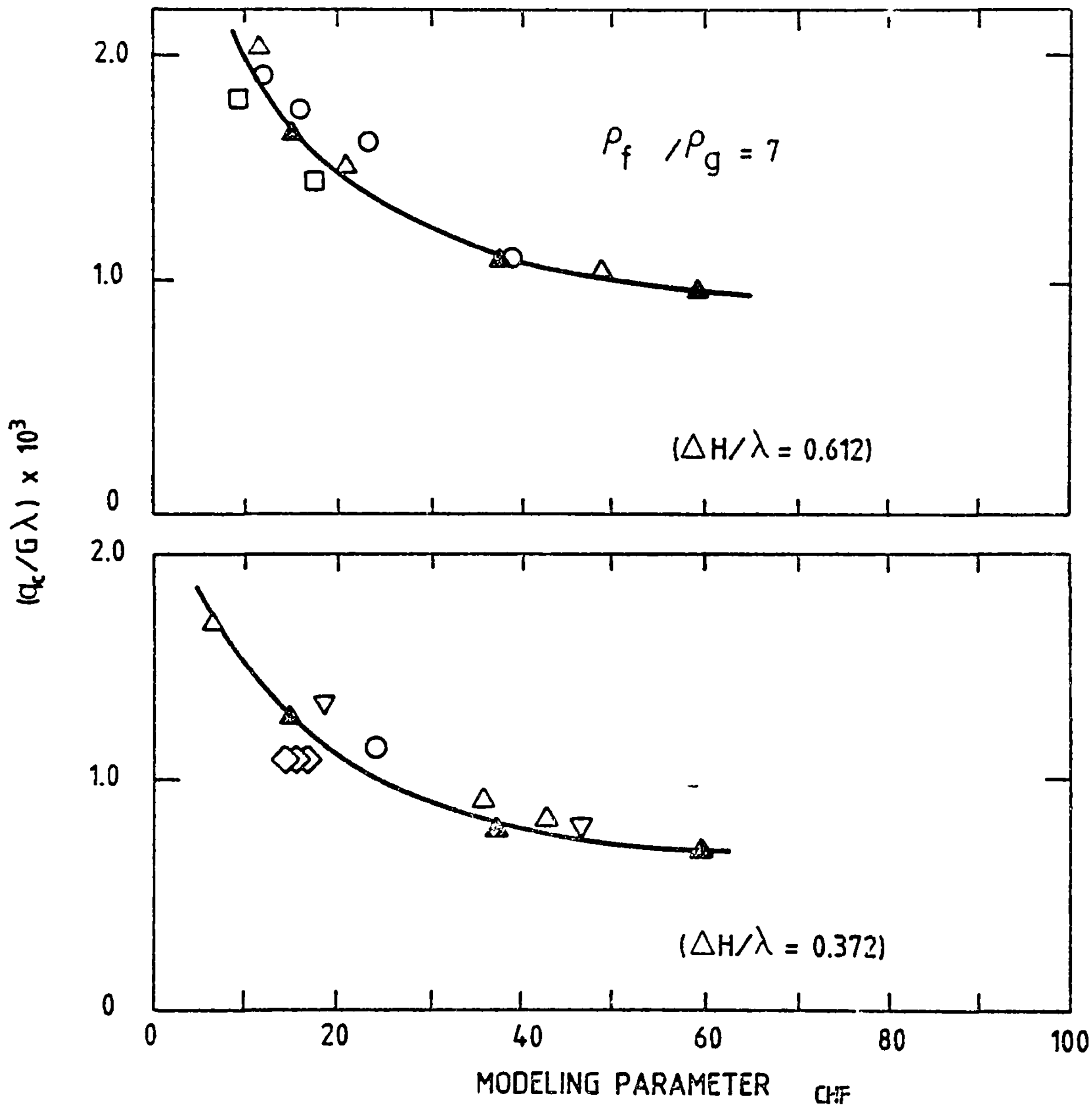


FIGURE 2.9 COMPARISON OF WATER AND FREON-113 SUBCOOLED DATA (IN TUBES) AT WATER EQUIVALENT PRESSURE 2000 LB/IN^2 ABS. (ρ_f/ρ_g = 2). AHMAD (1973).

1. For heat fluxes near the CHF, the viscosity effects in both the liquid and vapor phases are negligible due to the highly turbulent state caused by intensive vaporization.
2. The liquid velocity near the heated surface is considerably lower than the average vapor velocity due to wall resistance.
3. The liquid and vapor phases are considered to be incompressible.
4. The buoyancy term caused by the difference in the densities of the phases was introduced into the vapor momentum equation.

From the obtained equations, Kutateladze formed a set of dimensionless parameters. Then, by neglecting the liquid velocity, pressure drop and transient effects on the CHF in free convection, he derived the following equation:

$$\frac{q_{co}}{\lambda \sqrt{g^2 \rho_g \left(1 + \frac{\rho_g}{\rho_f}\right)} \sqrt[4]{\sigma_g(\rho_f - \rho_g)}} = K_1 = \text{const.} \tag{2.11}$$

where q_{co} is the CHF at zero subcooling and K_1 is called the stability number. Experimental data plotted in Fig. 2.10 indicates the constant value of K_1 predicted by eq. (2.11) for various fluids. Zuber presented an analytical method for predicting K_1 by making some additional assumptions. He showed that K_1 lies in the range:

$$\sqrt{\frac{\pi}{128\sqrt{3}}} < K_1 < \sqrt{\frac{\pi}{128}} \tag{2.12}$$

Fig. 2.11 shows that Zuber's result agrees well with experimental data for a number of fluids plotted as K_1 vs. Ar^*. The equation of the solid line in Fig. 2.10 is given by Borishanskiy as:

$$K_1 = 0.13 + 4\ Ar^{-0.4}\ . \tag{2.13}$$

It shows a slight increase in the value of K_1 at small values of Ar. Also, Kutateladze introduced the effect of subcooling on CHF. He assumed that the CHF in subcooled liquid is composed of two portions. The first portion is the one given to the saturated liquid to reach CHF given by eq. (2.11) and the second is the one given to the subcooled liquid replacing the detached vapor bubbles from the heated surface to reach saturation. Kutateladze showed that the amount of liquid circulated in the boundary region is a function of the liquid to vapor density and it can be correlated in the following manner:

$$q_{c_{\Delta T}} = q_{co}\left[1 + 0.065\ \left(\frac{\rho_f}{\rho_g}\right)^{0.8}\ \frac{C_p\ \Delta T}{\lambda}\right] \tag{2.14}$$

Kutateladze suggested a similar correlation for predicting CHF in forced convective boiling in round tubes. However, his correlation was not presented clearly and was not tested with any fluid.

---

* The symbol Ar was not defined in Kutateladze's book. However, it is assumed to be Archimedes number, which represents the ratio of buoyancy to viscous forces. $\left(Ar = \frac{g \times L^3 \times \rho_o}{\mu^2} (\rho - \rho_0)\right)$ where L is a characteristic length and ρ_o is the fluid density.

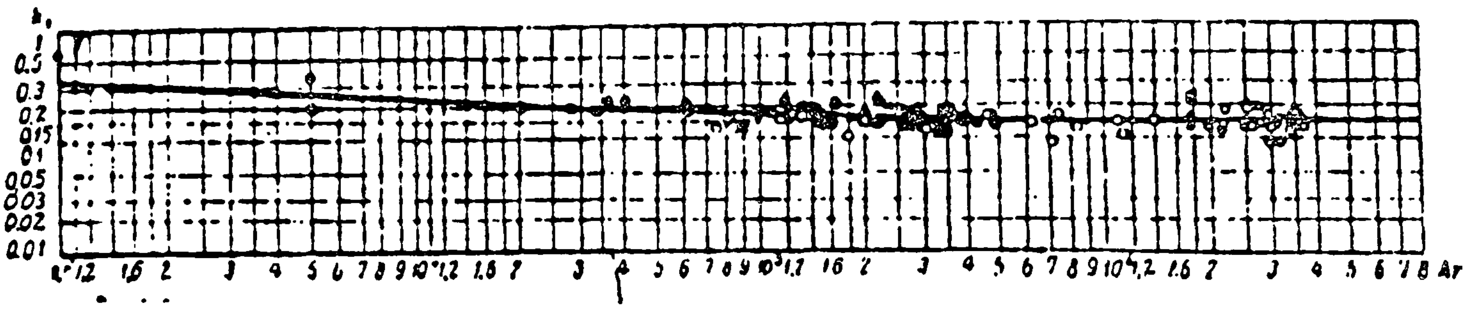


FIGURE 2-10 A PLOT OF $k = f(Ar_*)$ FOR BOILING OF A LARGE VOLUME OF SATURATED LIQUID, ACCORDING TO V.M. BORISHANSKIY. THE EQUATION FOR THE SOLID LINE IS $k = 0.13 + 4A_{r*}^{-0.4}$. WATER: O-KAZAKOVA (p = 1 - 205 ATM); □--KUTATELADZE, BORISHANSKIY, SCHNEIDERMANN (p = 1 - 30 ATM). ETHANOL: ∅-CICHELLI AND BONILLA (p = 1 - 60 ATM); ⊕-BORISHANSKIY, BOBROVICH (p = 33 - 53 ATM); ∇-STYRIKOVICH, POLYAKOV (p = 1 ATM). BENEZENE: ⊖-CICHELLI AND BONILLA (p = 1 - 40 ATM); △-STYRIKOVICH, POLYAKOV. HEPTANE: ◐-CICHELLI AND BONILLA (p = 1 - 16 ATM); X - STYRIKOVICH, POLYAKOV (p = 1 ATM). PENTANE: ●-CICHELLI AND BONILLA (p = 2 - 30 ATM). PROPANE: ⊕● -CICHELLI AND BONILLA (p = 19 - 29 ATM). (KUTATELADZE (1963)

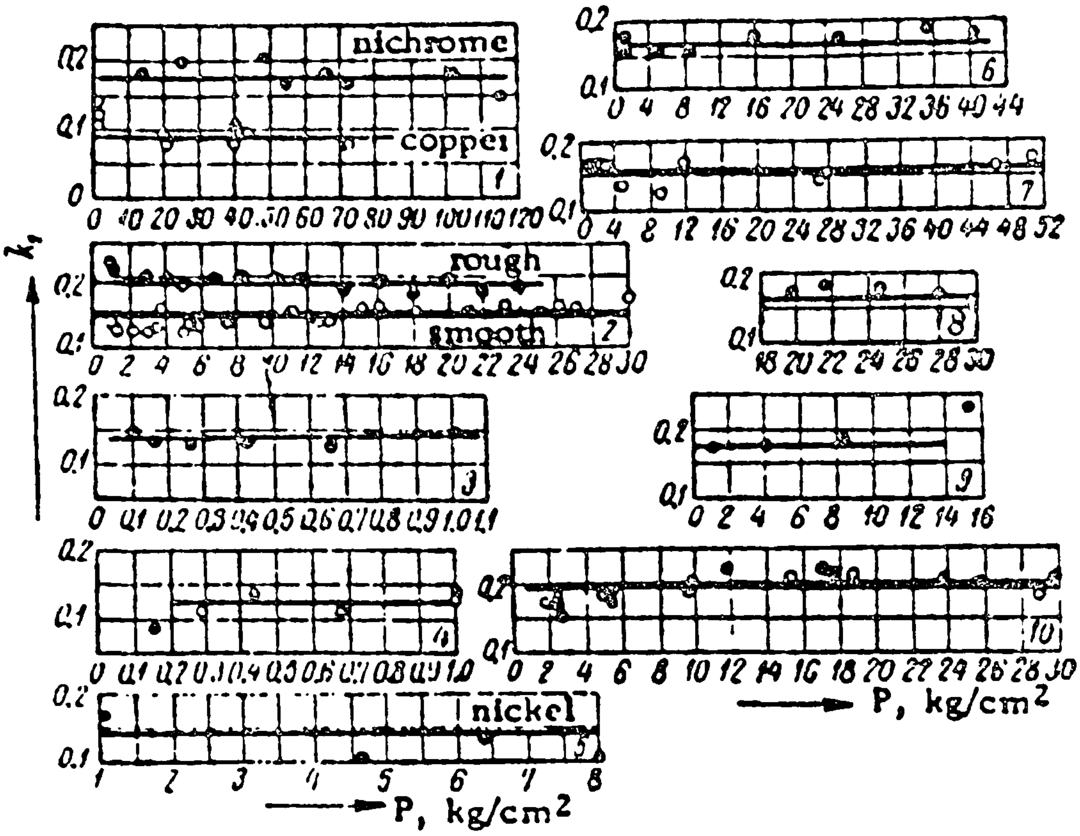


FIGURE 2-11 VALUES OF THE GROUP K ACCORDING TO DATA OF VARIOUS STUDIES. EXPERIMENTS WITH WATER: 1-KAZAKOVA; 2-KUTATELADZE; 3-BRAUNLICH; 4-McADAMS; 5-FARBER. EXPERIMENTS WITH ORGANIC LIQUIDS OF CICHELLI AND BoNILLA: 6-BENEZENE; 7-ETHANOL; 8-PROPANE; 9-HEPTANE; 10-PENTANE. KUTATELADZE (1963).

2.3.3 Zuber's Correlation for Predicting CHF in Pool Boiling

In pool boiling, at the CHF point, pictures showed a regular spacing of "bubbles" or columns of liquid rising from the liquid-vapor interface of the vapor film (1959). Zuber (1959) assumed that at CHF, the volume flow rate of liquid towards the heating surface equals the volume flow rate of vapor away from the surface. Based on this assumption Zuber suggested the following correlation for predicting CHF in pool boiling in a saturated liquid:

$$\frac{q_c}{\rho_g \lambda} = 0.18\left[\frac{\sigma(\rho_f-\rho_g)g}{\rho_g^2}\right]^{1/4} \times \left[\frac{\rho_f}{\rho_f+\rho_g}\right]^{1/2}, \quad \text{m/s} \tag{2.15}$$

where 0.18 is determined empirically.

2.3.4 Hauptmann's Correlation for Modeling CHF in Flow Boiling

A correlation for modeling CHF in flow boiling was developed by Hauptmann (1983). The correlation employs only one variable fluid property μ_f and other system parameters and constant fluid properties. The correlation is based on the assumption that thermodynamic, hydrodynamic and geometrical similarities are required to achieve true fluid-to-fluid modeling. Hauptmann showed that the reduced critical heat flux q^*_{cr} is a function of the following parameters:

$$q^*_{cr} = q_c/(RT_c P_c^2/M)^{1/2} = a\, P_r^b (GD/\mu_f)^c\, (L_B/D)^d\, (Z_c)^e \tag{2.16}$$

where Z_c is the critical compressibility factor (P_cV_c/RT_c) and the constants a, b, c, d and e are to be optimized using experimental CHF data. Hauptmann used carbon dioxide and water CHF data in round tubes to optimize the constants. Only data with L_B /D greater than 35 and exit quality in the range 5% - 75% were included. Hauptmann used the least squares fit and matrix inversion techniques to compute the constants listed in table 2.3.

Table 2.3. Hauptmann's Correlation Constants for Single Tubes

a	b	c	d	e
0.0001505	-0.6138664	0.2172085	-0.4894932	0.361891

Figs. 2.12(a) and (b) illustrate the comparison between the reduced heat fluxes predicted by Hauptmann's correlation and the measured ones for carbon dioxide and water data. The rms errors are 11.2% and 12.7% for carbon dioxide and water, respectively. Fig. 2.12(c) illustrates the comparison between Freon-12 reduced heat fluxes predicted by Hauptmann's correlation (with constants determined from carbon dioxide and water data) and the experimental ones. The rms error in prediction is 10.3%.

2.3.5 Shah's Generalized Graphical Method for Predicting CHF in Uniformly Heated Vertical Tubes

Shah (1979) presented a general correlation for calculating CHF in different fluids in vertical tubes during subcooled and saturated boiling.

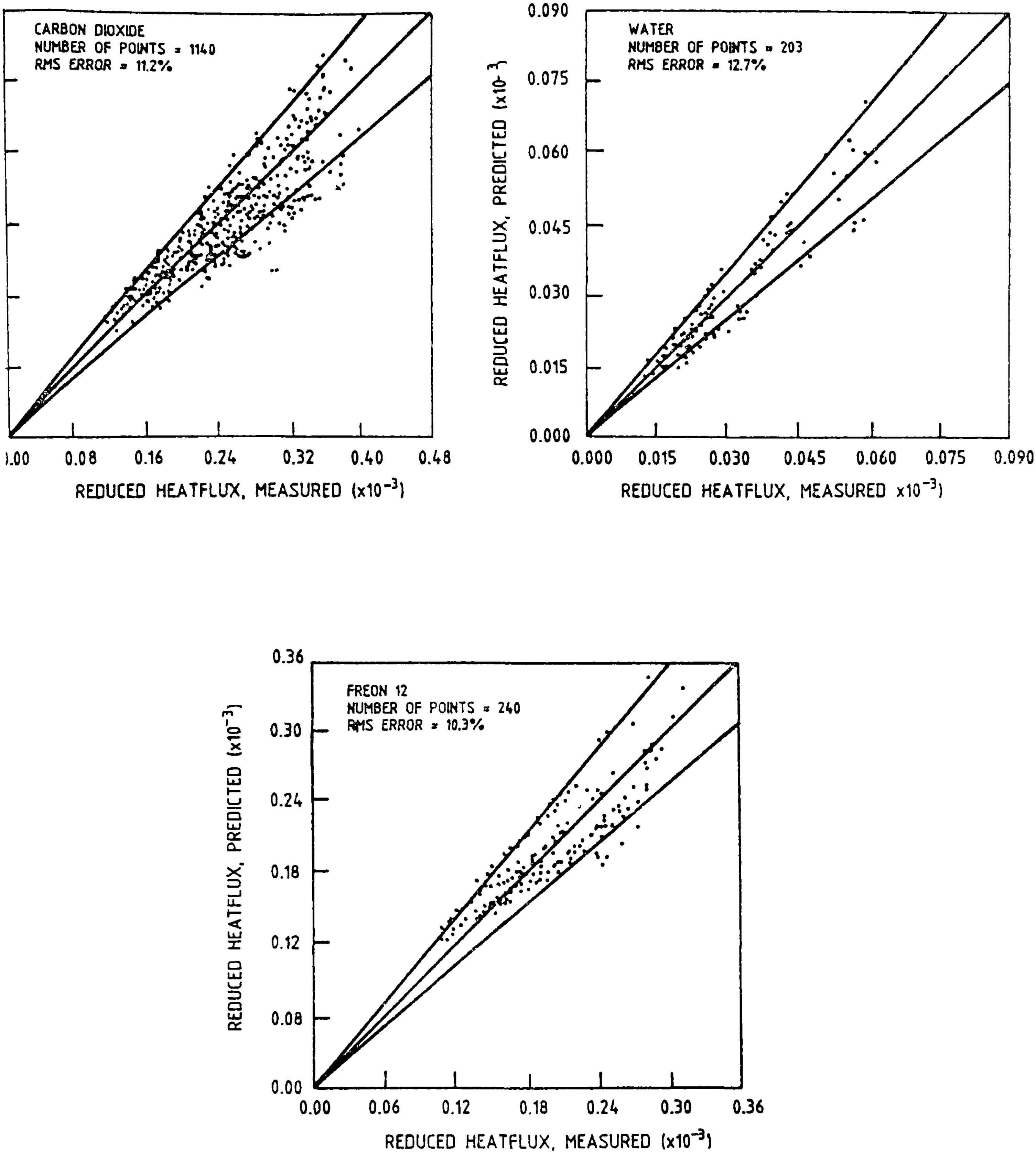


FIGURE 2.12 HAUPTMANN CORRELATION APPLIED TO CARBON DIOXIDE, WATER AND FREON-12 DATA (SINGLE TUBE). HAUPTMANN (1983).

Shah applied a trial-and-error method to select the following dimensionless groups which were used in his graphical correlation

$$BO = \frac{q_c}{\lambda G} \qquad \text{(Boiling number)}$$

$$Y = G^{1.8} D^{0.6} \left(\frac{Cp}{K\, \rho_f^{0.8}\, g^{0.4}}\right) \left(\frac{\mu_f}{\mu_g}\right)^{0.6} \tag{2.17}$$

$$Pe = Re \cdot Pr = \left(\frac{GD\ Cp}{\kappa}\right)_f$$

$$Fr = \frac{G^2}{\rho_f^2\, gD}$$

$$P_r = P/P_c$$

and x_{in}, x_c and L_c/D.

Shah's correlation is shown in Fig. 2.13 - 2.15. The correlation can be used in the following manner.

1. If $Y > 10^5$

   Fig. 2.13 provides the value of Bo_o, which is the boiling number at zero quality. If the experimental value of x_c is known, the value of BO_x/BO_o can be obtained from Fig. 2.15 where Bo_x is the boiling num ber at the critical vapor quality x. Then Bo_x can now be calculated

2. If $Y < 10^5$

   Fig. 2.14 directly yields the value of Bo for the given x_{in} and L_c/D. In this case, the value of x_c is not needed.

Shah's correlation was composed with experimental data from more than 30 sources including 11 different fluids. The mean deviation was found to be 15% with 90% of data within ±30%. The range of selected data was:

Reduced pressure :	0.0012 - 0.94		
Mass flux :	6 - 24, 300	$kg/m^2 \cdot s$	(2.18)
Critical quality :	$-2.6 \rightarrow 0.96$		
Inlet quality :	$-3.0 \rightarrow$ positive values		

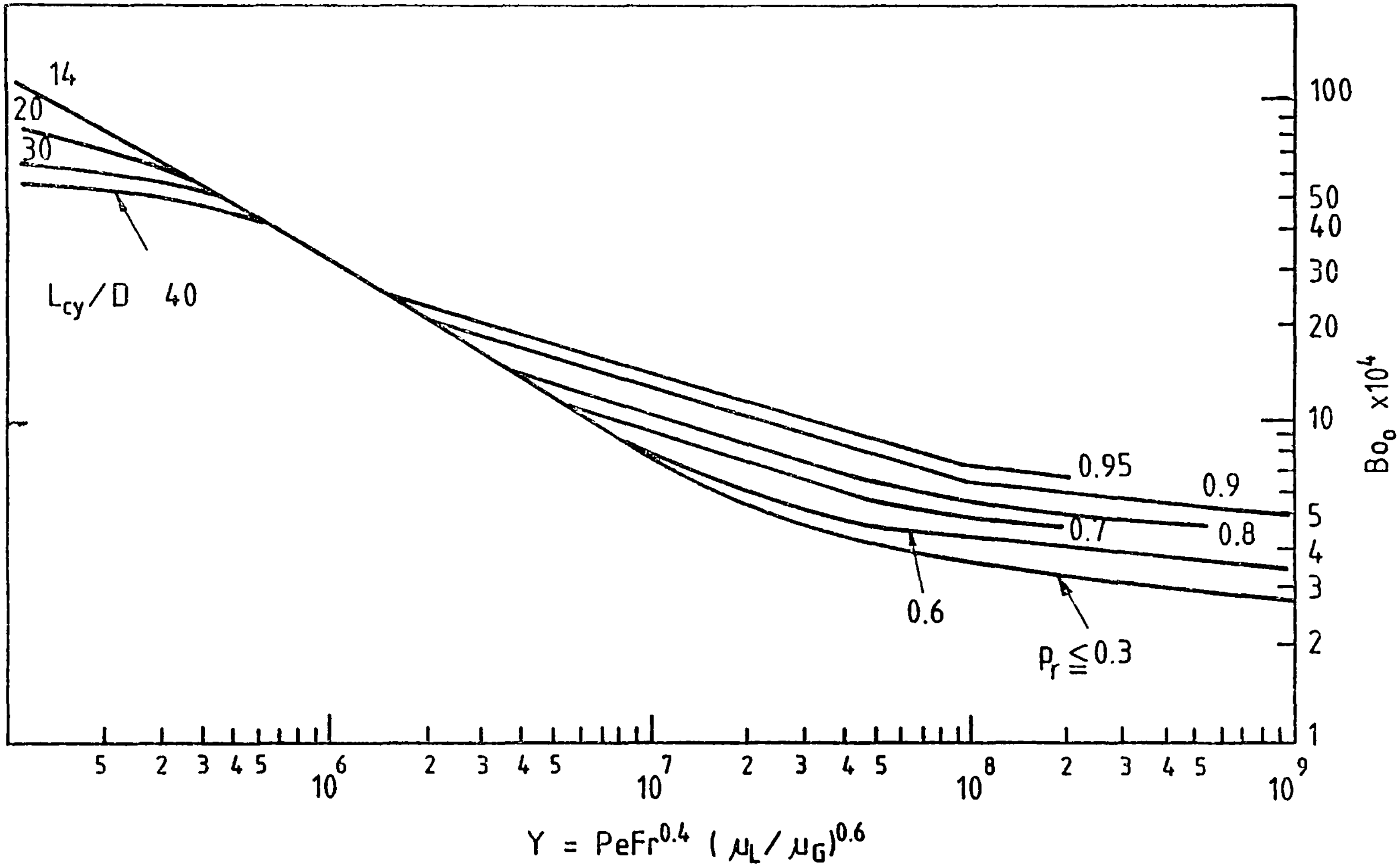


FIGURE 2.13 PART 1 OF SHAH'S CORRELATION. BOILING NUMBER AT $x_{cr} = 0$ FOR $Y > 10^5$. SHAH (1979).

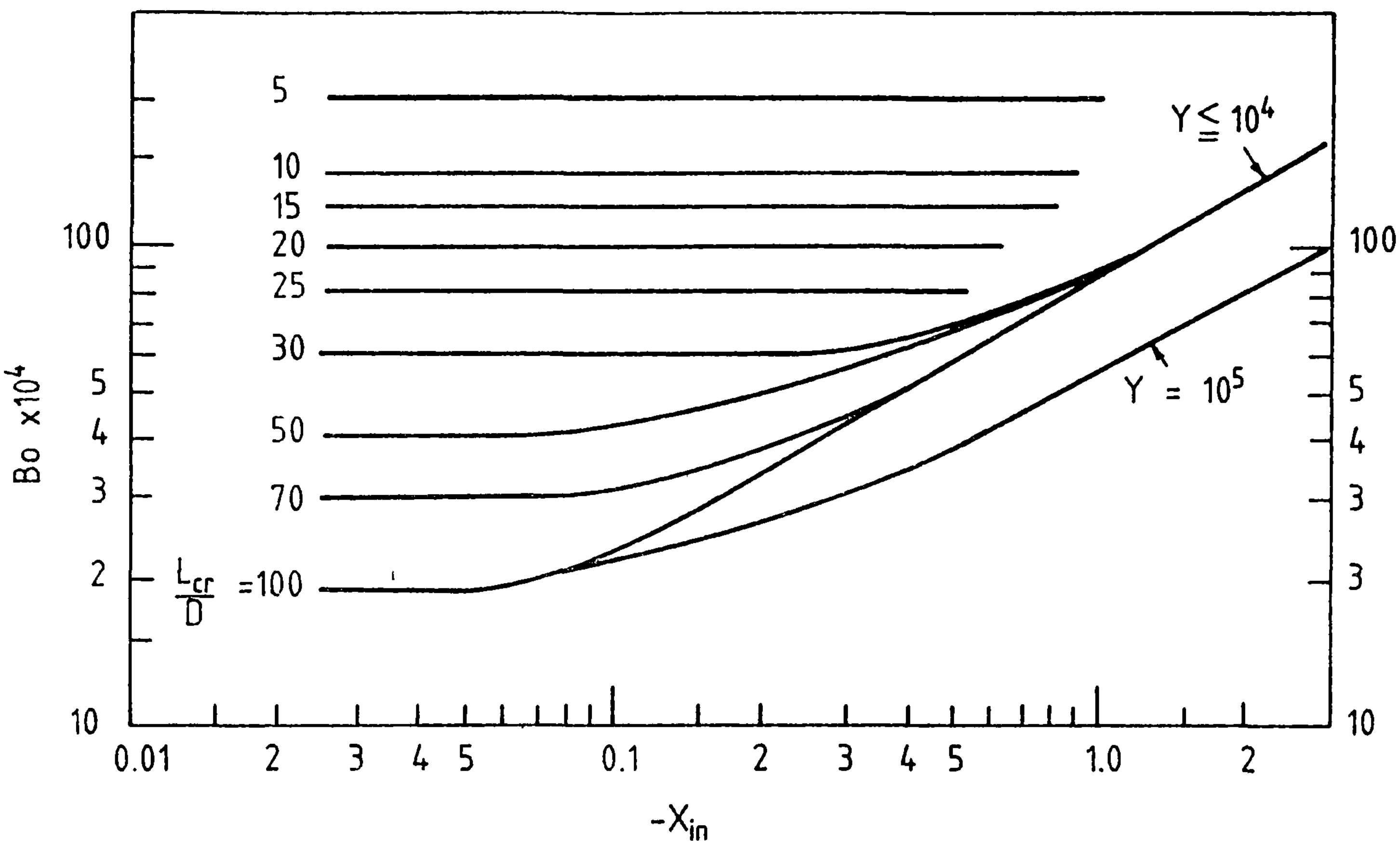


FIGURE 2.14 PART 2 OF SHAH'S CORRELATION. BOILING NUMBER FOR $Y < 10^5$.
SHAH (1979).

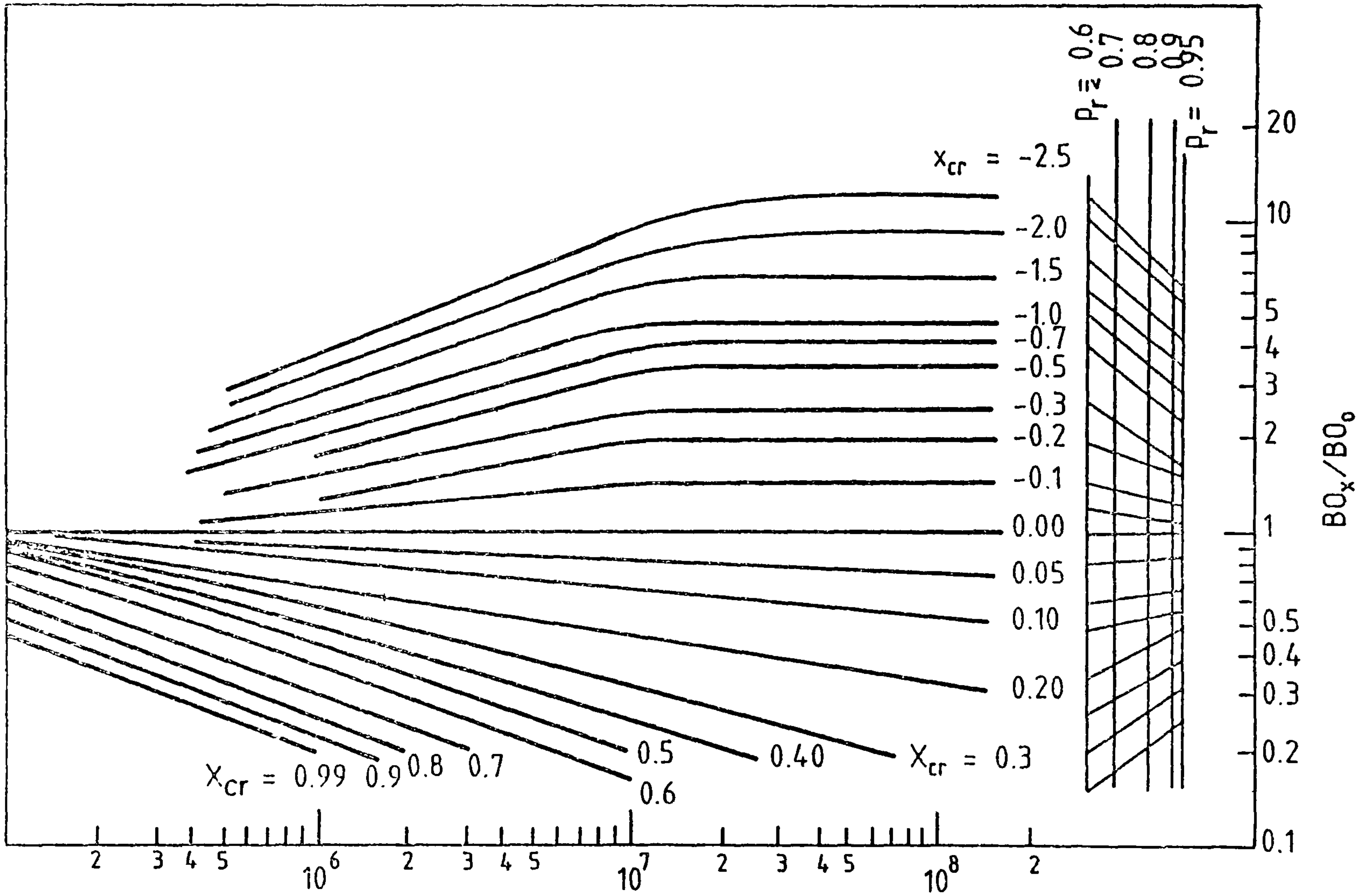


FIGURE 2.15 PART 3 OF SHAH'S CORRELATION. RATIO OF BOILING NUMBER AT x_{cr} = x TO THE BOILING NUMBR AT x_{cr} = 0. SHAH (1979)

2.3.6 Katto's Semi-Empirical Correlation

Katto (1978; 1979(a),(b); 1980(a),(b),(c); 1982; 1983) proposed a generalized correlation for predicting CHF in various fluids in forced convection boiling in vertical uniformly heated round tubes. Katto applied dimensional analysis to generate dimensionless CHF correlations based on the assumption that the effects of viscous and gravitational forces on CHF are negligibly small in simple boiling systems. Katto's correlations are of the form

$$\frac{q_{co}}{G\,\lambda} = F\left(\frac{\rho_g}{\rho_f}, \frac{\sigma\rho_f}{G^2 L}, \frac{L}{d}\right) \tag{2.19}$$

where q_{co} is the CHF at zero inlet subcooling.

Katto noticed that when ΔH_{in} changes in an experiment, keeping the other parameters constant, the relationship between CHF and ΔH_{in} is frequently linear as illustrated by type A in Fig. 2.16. Occasionally it has a curvature such as illustrated by type B or C in Fig. 2.16. The slope of the CHF vs. ΔH_{in} relationship depends on the conditions of CHF and geometry. If the liquid at the entrance of the tube is subcooled and the linear relationship between the CHF and ΔH_{in} holds (type A in Fig. 2.16) the CHF is given by

$$q_c = q_{co}(1 + K_k \Delta H_{in}/\lambda) \tag{2.20}$$

where K_k is a non-dimensional parameter independent of $\Delta H_{in}/\lambda$. K_k depends only on the regimes described below. It can be determined from the gradient of the straight line A in Fig. 2.16. Therefore

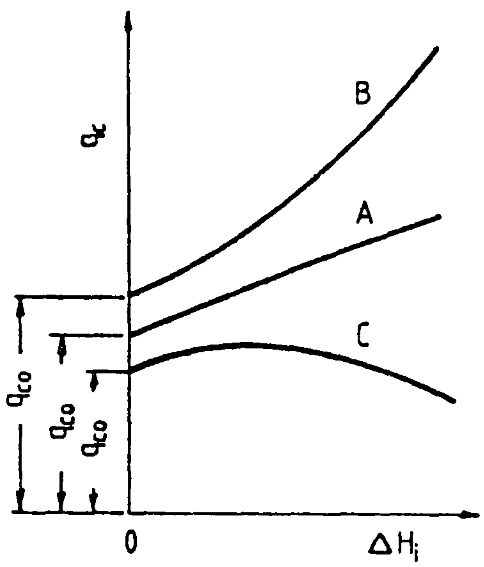


FIGURE 2.16 RELATIONSHIP BETWEEN q_c AND ΔH_{in} (TYPE A FOUND IN L-, H-, AND HP-REGIME; TYPE B IN N-REGIME, AND TYPE C IN V_L-REGIME). KATTO (1979).

$$\frac{q_c}{G\lambda} = F\left(\frac{\rho_f}{\rho_g}, \frac{\sigma\rho_f}{G^2L}, \frac{L}{D}, \frac{\Delta H_{in}}{\lambda}\right) \tag{2.21}$$

In order to analyze the zero subcooling data, the value of $q_{co}/G\lambda$ was divided into five different regimes designated as H, L, VL, N and HP.

In the "H" and "L" regimes (high and low mass velocity respectively), Katto verified that an annular flow pattern exists at the tube outlet and that the CHF in both regimes is caused by dryout of an annular liquid-film flowing over the tube wall. In the "L" regime the net deposition rate ϕ (deposition rate - entrainment rate) was found to be negligible throughout the tube, and the CHF is termed "evaporation controlled", while in the "H" regime, due to high mass velocity there is high entrainment near the tube inlet then the liquid film is supplied by liquid from the core (net deposition) to balance the local evaporation rate, the CHF is termed "deposition controlled".

For the "VL" regime, which has very low mass velocities (inlet liquid velocity is less than 0.2 - 0.3 m/s), Katto suggested that there is a possibility that CHF is in part determined by pool boiling effects. In the "N" regime which is characterized by non-linear relationship between q_c and ΔH_{in}, Katto assumed that the CHF in the regime occurs at low exit quality and is of the DNB type. The "HP" regime replaces the "N" regime when the system pressure is extremely high.

Recently Katto (1983) developed an improved version of his generalized correlation applicable for positive exit qualities and L/d < 600. Also, Katto discarded the characteristic regimes mentioned above in his new correlation. In Katto's improved correlation, the equations of q_{co} are written as follows:

$$\frac{q_{co}}{G\lambda} = C\left(\frac{\sigma\rho_f}{G^2L}\right)^{0.043} \cdot \frac{1}{(L/D)} \tag{2.22}$$

$$\frac{q_{co}}{G\lambda} = 0.10\left(\frac{\rho_g}{\rho_f}\right)^{0.133} \left(\frac{\sigma\rho_f}{G^2L}\right)^{1/3} \frac{1}{1 + 0.0032(L/D)} \tag{2.23}$$

$$\frac{q_{co}}{G\lambda} = 0.098 \left(\frac{\rho_g}{\rho_f}\right)^{0.133} \left(\frac{\sigma\rho_f}{G^2L}\right)^{0.433} \frac{(L/D)^{0.27}}{1 + 0.0031\ (L/D)} \tag{2.24}$$

$$\frac{q_{co}}{G\lambda} = 0.0384 \left(\frac{\rho_g}{\rho_f}\right)^{0.60} \times \left(\frac{\sigma\rho_f}{G^2L}\right)^{0.173} \times \frac{1}{1 + 0.280(\sigma\ \rho_f/G^2L)^{0.233}(L/D)} \tag{2.25}$$

$$\frac{q_{co}}{G\lambda} = 0.234 \left(\frac{\rho_g}{\rho_f}\right)^{0.513} \left(\frac{\sigma\rho_f}{G^2L}\right)^{0.433} \frac{(L/D)^{0.27}}{1 + 0.0031\ \ L/D} \tag{2.26}$$

where the dimensionless parameter C in eq. (2.22) is given by:

$$C = 0.25 \text{ for } L/D < 50,$$
$$C = 0.25 + 0.0009 \{(L/D)-50\} \text{ for } L/D = 50 - 150, \tag{2.27}$$
and
$$C = 0.34 \text{ for } L/D > 150 .$$

$$K_k = \frac{1.043}{4C(\sigma\rho_f/G^2L)^{0.043}} \tag{2.28}$$

$$K_k = \frac{5}{6} \cdot \frac{0.0124 + D/L}{(\rho_g/\rho_f)^{0.133}(\sigma\rho_f/G^2L)^{1/3}} \tag{2.29}$$

$$K_k = 1.12 \cdot \frac{1.52(\sigma\rho_f/G^2L)^{0.283} + D/L}{(\rho_g/\rho_f)^{0.60}(\sigma\rho_f/G^2L)^{0.173}} \tag{2.30}$$

The prediction of CHF will be made by distinguishing two regimes. The first is:

For $\rho_g/\rho_f < 0.15$

When $q_{co}(2.22) < q_{co}(2.23)$, $q_{co} = q_{co}(2.22)$

When $q_{co}(2.22) > q_{co}(2.23)$, then

If $q_{co}(2.23) < q_{co}(2.24)$, $q_{co} = q_{co}(2.23)$

If $q_{co}(2.23) > q_{co}(2.24)$, $q_{co} = q_{co}(2.24)$

When $K_k(2.28) > K_k(2.29)$, $K_k = K_k(2.28)$

When $K_k(2.28) < K_k(2.29)$, $K_k = K_k(2.29)$

For $\rho_g/\rho_f > 0.15$

When $q_{co}(2.22) < q_{co}(2.26)$, $q_{co} = q_{co}(2.26)$

When $q_{co}(2.22) > q_{co}(2.26)$,

If $q_{co}(2.26) > q_{co}(2.25)$, $q_{co} = q_{co}(2.26)$

If $q_{co}(2.26) < q_{co}(2.25)$, $q_{co} = q_{co}(2.25)$

When $K_k(2.26) > K_k(2.29)$, $K_k = K_k(2.28)$

When $K_k(2.28) < K_k(2.29)$,

If $K_k(2.29) > K_k(2.30)$, $K_k = K_k(2.29)$

If $K_k(2.29) < K_k(2.30)$, $K_k = K_k(2.30)$

A computer listing of Katto's correlation is presented in Appendix D.

The accuracy of Katto's correlation was not reported in his papers. The comparisons between the CHF predicted using Katto's correlation a d the experimental results are only shown graphically with $(q''_{co}/G\lambda)$ vs. $(\sigma\rho_f/G^2L)$ for different fluids in different regimes. Based on the e graphs, it appears that the average rms error is less than 20% for a regimes.

2.3.7 Ahmad's Correlation

Ahmad (1973) developed a correlation for predicting CHF in non-aqueous fluids. His correlation was based on the modeling technique developed by the same author in (1973) and summarized in Sec. 2.2.7. Ahmad incorporated the effect of complex geometries in his technique by using the heated equivalent diameter (D_{he}). The general CHF prediction given by eq. (2.6) was rewritten in the following form:

$$\frac{q_c}{G\lambda} = F(\psi_{CHF},\ \Delta H_{in}/\lambda,\ \rho_f/\rho_g,\ L/D,\ D_{he}/D) \tag{2.31}$$

By introducing the dimensionless power number W^+ defined as

$$W^+ = \frac{4q_c L/G\lambda\ D}{1 + \Delta H_{in}/\lambda} \tag{2.32}$$

Equation (2.31) was written in the following form:

$$W^+ = F(\psi_{CHF},\ \Delta H_{in}/\lambda,\ \rho_f/\rho_g,\ L/D,\ D_{he}/D) \tag{2.33}$$

Ahmad proposed a functional form for the term W^+ in the following manner:

$$W^+ = 1 - \exp(-y^+) \tag{2.34}$$

where $\quad y^+ = F(\psi_{CHF},\ \Delta H_{in}/\lambda,\ \rho_f/\rho_g,\ L/D,\ D_{he}/D)$

Then he expressed y^+ as a product of power functions, i.e.

$$y^+ = K\ \psi_{CHF}^a (1 + \Delta H_{in}/\lambda)^b (\rho_f/\rho_g - 1)^c\ (L/D)^d\ (D_{he}/D)^e \tag{2.35}$$

where K and a-e are empirical constants which can be optimized from experimental CHF data.

By using Freon-12 CHF data in round tubes, the constants were optimized. The resulting correlation has the following form:

$$W^{+} = 1 - \exp(-0.522/E^{+})$$
$$E^{+} = E/(1 + \Delta H/\lambda)^{E/2} \qquad (2.36)$$
$$E = \psi_{CHF}/(L/D)^{3/5}$$

The correlation function is shown as the solid line in Fig. 2.17. CHF data for water, Freon-22 and Freon-12 data are also plotted on the same graph. It is observed that the correlation developed from Freon-12 data is in good agreement with water and Freon-22 data.

2.4 Groeneveld's Standard Table for Predicting CHF for Water in Vertical Tubes and Bundles

Groeneveld (1982) & (1986) developed an accurate and simple technique to predict CHF in water over a wide range of conditions. Groeneveld's table look-up technique is based on the local condition assumption i.e.

$$q_c = F(X,\ G,\ P,\ D) \qquad (2.37)$$

The CHF table is presented in table 2.4 for an upward flow in an 8×10^{-3}m I.D. round tube. The table was created using the CHF data bank containing more than 10 000 tube water CHF data and known parametric trends in the regions where data are scarce or unavailable. (For details see Groeneveld (1982)). A comparison between Biasi (1967) correlation, Bowring (1972) correlation and the table method is illustrated in Fig. 2.18. Due to its wide data base the CHF table predicted the most accurate

SYMBOL	FLUID	D (in.)	L/D	G x 10^6 (lb/hr.FT^2)	$\Delta H/\lambda$
○	WATER	0.400	200 TO 480	1.0 TO 7.0	0.04 TO 0.80
△	"	0.393	100 TO 350	0.3 TO 2.6	0.20 TO 0.65
▩	FREON 22	0.400	152	0.4 TO 1.0	0.03 TO 0.29
▲	FREON 12	0.431	119 TO 167	0.4 TO 4.5	0.0 TO 0.24
——	PREDICTION FROM EQUATION (2.38)				

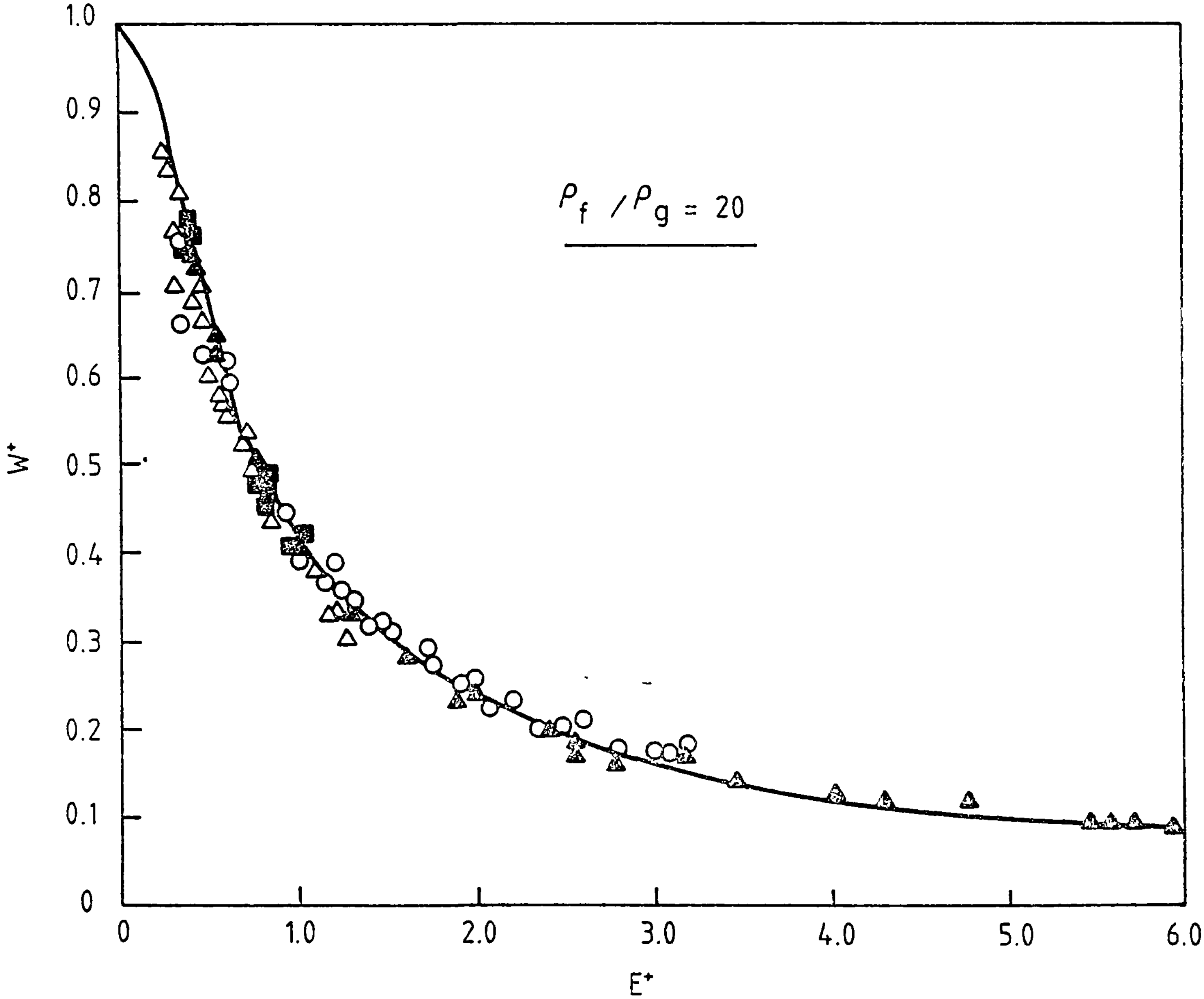


FIGURE 2.17 COMPARISON OF WATER, FREON-22 AND FREON-12 DATA (IN TUBES) WITH PREDICTION FROM AHMAD DIMENSIONLESS CORRELATION BASED ON FREON-12 DATA, AT WATER EQUIVALENT PRESSURE 1000 LB/IN^2 ABS. (ρ_f/ρ_g = 20). AHMAD (1973).

TABLE 2.4: FINAL STANDARD TABLE OF CHF VALUES

G ($kg \cdot m^{-2} \cdot s^{-1}$)	QUALITY -.15	-.10	-.05	0.00	.05	.10	.15	.20	.25	.30	.40	.50	.60	.70	.80	.90	1.00
0	3930	3430	2045	1200	1000	980	833	750	740	733	600	500	450	356	212	99	0
50	4000	3500	2400	1700	1600	1500	1253	1200	1150	1108	873	756	710	506	386	350	0
100	4900	4200	3100	2200	2100	2000	1450	1000	850	820	750	727	700	667	493	330	0
200	5600	4900	3800	2600	2550	2500	1510	1400	1350	1300	1200	1160	1129	863	532	437	0
300	6400	5600	4500	3000	3000	3000	2200	2100	2700	1978	1900	1774	1447	827	627	453	0
500	7200	6300	5200	3600	3550	3500	3450	335	3300	2486	2354	2319	1251	662	633	440	0
750	8000	7000	5900	5500	5000	4700	4572	4105	3186	2986	2887	2394	1378	905	700	430	0
1000	8400	7600	6600	4800	4600	4400	4213	3552	3836	3400	3319	2534	1514	1100	600	320	0
1500	9600	8200	7000	5500	4800	4200	4630	4500	4500	4100	3823	3266	2200	1100	600	300	0
2000	10000	8800	7700	5900	5410	5300	5260	5100	5150	5000	4900	4840	2900	1100	600	300	0
3000	10500	9400	8400	7300	6500	6700	5992	5400	5300	5200	5017	3500	2700	1100	600	330	0
4000	11000	10000	9000	6800	6643	6500	6100	5300	5000	4600	4000	3000	2000	1000	500	300	0
5000	11500	10600	9500	8359	7051	7600	7400	5200	4400	3800	3000	2500	1500	900	500	300	0
7500	12000	11000	10000	9500	9200	9000	7510	5000	4000	3000	2200	2000	1200	860	400	300	0
0	4000	3500	2400	1350	1200	1100	950	947	900	887	680	600	560	377	236	111	0
50	4100	3600	2700	1900	1800	1700	1500	1400	1393	1265	984	793	600	521	423	700	0
100	4800	4200	3200	2400	2200	2000	1930	1800	1410	1372	944	920	900	893	[illegible]	450	0
200	5400	4800	3800	2700	3500	2500	2100	160	1500	1400	1325	1364	1200	1100	1000	500	0
300	6000	5400	4400	3000	3000	3000	2710	2400	2230	1700	1650	1600	1500	1400	800	500	0
500	6600	6000	5300	3700	3600	3500	3130	2700	2227	1800	1668	1500	1700	1147	675	450	0
750	7300	6600	5600	4300	4150	4000	3530	2203	2000	1900	1800	1700	1500	117[illegible]	650	400	0
1000	7800	7200	6200	5000	4700	4400	3770	3400	3100	2901	2700	2300	2200	1100	600	350	0
1500	8400	7600	6800	5500	5200	4800	3803	3600	3400	3100	3000	2500	2500	1100	550	300	0
2000	9000	8200	6000	5500	4988	4529	4135	400	3900	3700	3500	3400	3000	1000	550	300	0
3000	9600	6240	5800	5600	5400	5200	4530	4100	3800	3300	3250	3200	2500	1001	500	300	0
4000	10000	6636	6300	5766	5214	5000	4700	4200	3600	2800	2800	2650	2500	1020	450	300	0
5000	13500	9900	9100	9001	7254	6500	5700	4000	3100	2600	2300	2000	1500	900	450	300	0
7500	11000	10400	9700	9000	8600	8000	6500	500	3000	2200	1800	1600	1000	600	400	300	0
0	4820	3700	2774	1450	277	262	248	233	219	204	175	146	117	87	58	29	0
50	4955	4000	3394	2313	1794	1641	1562	1487	1405	1326	1244	1044	700	600	593	458	0
100	5000	4100	3200	2600	2300	2100	2000	1900	1300	1200	1285	900	751	700	650	315	0
200	5200	4300	3400	2800	2500	2300	2150	1400	1350	1325	1300	1250	1200	1142	600	315	0
300	5400	4450	3500	3000	2700	2400	2200	2150	2100	2000	1810	1461	1000	700	600	350	0
500	5600	4650	3700	3150	2900	2600	2250	2100	2000	1800	1649	1500	1100	800	450	300	0
750	5800	4850	3900	3300	3000	2650	2350	2118	2066	1826	1767	1600	1000	600	450	300	0
1000	6000	5300	4300	3400	3000	2600	2350	2140	1958	1800	1700	1600	1000	600	450	300	0
1500	6200	4600	3800	3300	3000	2600	2350	2284	2119	1800	1700	1500	1000	600	450	300	0
2000	6400	4500	4300	3500	3000	2600	2350	2150	2050	1800	1700	1400	1000	600	450	300	0
3000	7000	5742	4287	3900	3000	2600	2350	2150	2050	1800	1700	1400	1000	600	450	300	0
4000	8500	6411	4800	4500	3000	2600	2350	2150	2050	1800	1700	1400	1000	600	450	300	0
5000	6607	6120	5267	4845	3000	2600	2350	2150	2050	1800	1700	1400	1000	600	450	300	0
7500	6590	6465	5581	5077	3000	2600	2350	2150	2050	1800	1700	1400	1000	600	450	300	0
0	4650	3667	2683	1700	325	308	291	274	257	240	205	171	137	103	68	34	0
50	5063	4292	3296	2975	2681	2327	2248	2168	2014	1860	1551	1067	637	592	549	530	0
100	5200	4500	3500	3400	3200	3000	2930	2800	2600	2400	1212	900	956	825	800	733	0
200	5600	4700	3600	3500	3200	2900	2800	1760	1717	1301	1209	1200	1170	1143	849	600	0
300	4592	3324	3300	3250	3200	2800	2700	2603	2500	2400	2091	1746	1084	511	257	250	0
500	4634	3367	3300	3250	3200	2700	2600	2575	2550	2500	1988	1373	945	400	250	200	0
750	6000	5000	3900	3800	3200	2600	2500	2400	2337	2100	1687	1400	1396	386	281	200	0
1000	6200	5200	4000	3900	3200	2600	2500	2400	2229	2100	1800	1500	1200	700	400	200	0
1500	6400	4154	4100	4000	3200	2600	2500	2456	2301	2100	1800	1500	1200	700	400	200	0
2000	6600	4300	4200	4100	3200	2600	2500	2294	2200	2100	1800	1500	1200	700	400	200	0
3000	7778	5690	4800	4706	3200	2600	2500	2294	2200	2100	1800	1500	1200	700	400	200	0
4000	8443	6302	4518	4400	3200	2600	2500	2294	2200	2100	1800	1500	1200	700	400	200	0
5000	5419	4851	3967	3525	3200	2600	2500	2294	2200	2100	1800	1500	1200	700	400	200	0
7500	5816	5198	4236	3630	3200	2600	2500	2300	2200	2100	1800	1500	1200	700	400	200	0
0	4540	4222	1900	1313	380	360	340	321	300	280	240	200	160	156	93	90	0
50	5035	4627	2330	2250	2195	2115	2035	1993	1550	1873	1860	1625	896	633	567	500	0
100	5200	4100	3400	2900	2800	2700	2650	2550	2200	2000	1500	1234	1217	1095	949	585	0
200	5600	4150	3400	3000	2800	2600	2550	2500	2200	1700	1650	1600	1500	1243	641	572	0
300	4145	2896	2853	2825	2800	2600	2500	2450	2400	2375	2358	1841	1677	744	447	414	0
500	4187	2939	2900	2850	2800	2600	2400	2400	2400	2400	2200	1738	1240	435	275	254	0
750	6300	4300	3400	3100	2800	2600	2300	2151	2000	2785	1439	1024	876	395	300	255	0
1000	6200	4430	3400	3200	2800	2600	2100	1976	1821	1500	1300	1000	564	500	300	200	0
1500	6400	4145	3060	3200	2800	2600	2000	2004	1849	1500	1250	673	450	500	300	200	0
2000	6600	3521	3400	3300	2800	2600	2100	1807	1500	1300	1200	1000	700	500	300	200	0
3000	9216	5752	4146	3716	2800	2600	2200	1800	1500	1300	1200	1000	700	500	300	200	0
4000	9994	6210	4292	4076	2800	2600	2300	1600	1500	1300	1200	1000	700	500	300	200	0
5000	6619	6002	5440	3500	2800	2600	2200	1900	1500	1300	1200	1000	700	500	300	200	0
7500	6878	6271	5707	3600	2800	2600	2200	2000	1600	1300	1200	1000	700	500	300	200	0
0	4482	4264	2359	1488	448	424	401	377	354	330	283	236	189	97	72	47	0
50	5021	4569	2488	1971	2212	2056	1875	1594	1363	1131	971	829	496	363	424	472	0
100	5200	4200	3500	3000	2400	2600	2300	2000	1700	1400	1200	1003	842	764	691	575	0
200	5600	4250	3600	3200	3000	2900	2700	2600	2500	1900	1650	1589	1500	1450	947	647	0
300	5800	4300	3700	3400	3000	2800	2700	2600	2550	2500	2461	2474	1600	1140	662	523	0
500	5900	4400	3800	3500	3000	2900	2800	2700	2650	2600	2500	2396	1376	645	419	359	0
750	6000	4600	3900	3600	3000	2700	2600	2507	2400	2300	2229	1419	717	412	410	376	0
1000	6200	5060	4094	3600	3000	2800	2700	2690	2133	1593	1306	888	484	269	250	200	0
1500	6400	4991	4025	3600	3000	2500	2400	238	1837	1522	1138	722	274	199	175	150	0
2000	6600	5200	4400	3600	3000	2500	2200	1807	1500	1300	1300	900	253	200	200	150	0
3000	6900	5400	4600	3600	3000	2500	2200	1807	1500	1300	1200	900	250	200	200	150	0
4000	7000	5600	4900	3600	3000	2500	2200	1800	1500	1300	1200	900	250	200	200	150	0
5000	720	5800	4900	3600	3000	2500	2200	1900	1500	1300	1200	900	250	200	200	150	0
7500	7400	6000	5000	3600	3000	2500	2200	2000	1600	1300	1200	900	250	200	200	150	0
0	4480	3866	3240	2620	509	483	456	429	402	375	322	268	214	161	107	54	0
50	5620	5092	4560	4195	3427	3271	3114	3032	2801	2569	2330	1942	1174	875	814	476	0
100	6000	5500	5000	4600	4400	4200	4000	390	3600	3300	3000	2500	1400	1113	1050	550	0
200	9300	7500	7000	6000	5800	5600	5400	5100	4700	4400	4300	4200	2327	1697	1139	702	0
300	8000	7500	7000	6500	6300	5600	5400	510	4700	4400	4250	3914	2202	1544	918	683	0
500	8000	7500	7000	6500	6200	5600	5400	5100	4800	4663	4500	3726	2083	1095	609	437	0
750	8000	7500	7000	6500	6100	5600	5400	5000	4900	4785	3936	2297	1174	683	549	500	0
1000	8000	7500	7000	6500	6000	5600	5300	5100	4845	4193	2934	1613	867	575	376	250	0
1500	8000	7500	7000	6500	5900	530	5000	480	4459	3154	2366	1307	624	276	188	150	0
2000	8000	7500	7000	6500	5700	5200	4800	440	3354	3307	3276	2493	860	250	150	130	0
3000	8000	7500	7000	6500	5500	5100	4700	420	3573	3400	3326	1700	750	255	150	130	0
4000	8000	7500	7000	6500	5300	5000	4500	4007	3400	2800	1950	1150	700	250	150	100	0
5000	8000	7500	7000	6600	5400	490	4400	380	310	2601	1650	1003	650	25	150	100	0
7500	8000	7500	7000	6500	5100	4800	4370	3600	3200	2300	1500	900	600	250	150	100	0

TABLE 2.4: FINAL STANDARD TABLE OF CHF VALUES

PRESSURE (kPa)	G ($kg \cdot m^{-2} \cdot s^{-1}$)	QUALITY -.15	-.10	-.05	0.00	.05	.10	.15	.20	.25	.30	.40	.50	.60	.70	.80	.90	1.0
1500	0	4525	4007	3489	2970	584	553	523	497	461	430	369	327	246	184	123	61	0
1500	50	5781	5100	4922	4493	3596	3513	3356	3271	3115	2883	2567	2327	1149	1021	879	-26	0
1500	100	6200	5500	5400	5000	4600	4500	4300	4207	[illegible]	3700	3300	3000	1450	1302	1131	548	0
1500	200	[illegible]	6900	6500	6400	6200	6600	5700	5400	[illegible]	4100	3600	3100	2131	2062	1316	779	0
1500	300	7431	7100	6700	6500	6300	6000	5700	5300	[illegible]	4400	3600	3244	3020	2122	1334	843	0
1500	500	7700	7200	6700	6400	6100	5800	5500	530	5100	4449	4500	4297	3152	1859	997	608	0
1500	750	8300	7200	6700	6300	5900	5600	5400	520	5156	5100	4551	2990	1765	1087	681	443	0
1500	1000	8300	7200	6700	6250	5700	5600	5550	5500	5457	5169	3733	2118	1125	797	450	366	0
1500	1500	8300	7200	6700	6250	5500	5300	5278	5271	4469	4681	2913	1511	873	455	235	200	0
1500	2000	8000	7200	6700	6200	5500	5200	4900	410	4100	3977	2505	1419	1000	[illegible]	400	200	0
1500	3000	7529	6720	6700	6100	5600	5100	4300	4411	4200	3700	2300	2100	1000	[illegible]	400	200	0
1500	4000	7645	6836	6700	6100	5600	5000	4700	3407	3400	3100	1900	1400	1000	[illegible]	400	200	0
1500	5000	8500	7500	6900	6300	5620	4801	4400	360	3500	2600	1700	1500	1000	[illegible]	400	200	0
1500	7500	9000	8000	7100	6300	5530	4700	4100	3600	3300	2350	1600	1200	1000	800	400	200	0
2000	0	4581	4130	3680	3230	647	609	575	541	507	474	406	338	271	203	135	68	0
2000	50	5870	5420	4970	4708	3836	3752	3594	3510	3352	3118	2801	2710	1193	941	927	634	0
2000	100	6300	5850	5400	5200	4900	4800	4600	4500	4300	4000	3600	3500	1500	1287	1131	556	0
2000	200	7000	6900	6800	6700	6600	6300	6300	5600	5300	4800	4400	4000	2151	2023	1311	824	0
2000	300	7600	7350	7200	6900	6600	6600	5900	5700	5500	5200	4950	4181	4313	2749	1550	969	0
2000	500	8200	7800	7600	7200	6600	6600	6200	5964	5514	5191	4750	4457	3680	2222	1274	777	0
2000	750	8400	8000	7800	7200	7000	6981	6361	6200	6120	6036	5129	3590	2314	1281	954	596	0
2000	1000	8700	8400	7800	7762	7061	6718	6311	6347	5573	5581	4274	2769	1713	1029	637	479	0
2000	1500	8830	8400	7800	7144	6467	6459	5469	5000	4900	4870	3239	1919	1041	704	316	330	0
2000	2000	9230	8500	7800	7000	6500	5800	5078	4650	4395	4111	2218	1673	481	415	[illegible]	300	0
2000	3000	8844	8135	7800	7200	6200	5600	5506	4914	4717	4538	3219	1603	1200	105	[illegible]	330	0
2000	4000	9360	8251	7800	6900	5900	5500	5080	4900	4889	4415	2816	1400	1200	903	400	330	0
2000	5000	10000	8500	7300	6500	5800	5500	5200	4600	4550	4202	2400	1450	1200	900	600	530	0
2000	7500	10300	8500	7200	6100	5500	5200	4900	4580	4324	2600	1700	1500	1330	110	800	600	0
3000	0	4653	4293	3930	3570	919	690	551	613	575	536	460	383	306	230	149	147	0
3000	50	6038	5573	5108	4860	4130	3997	3913	3753	3594	3359	3040	2721	2327	882	391	323	0
3000	100	6500	6000	5500	5300	5200	5100	5100	4800	4600	4300	3900	3500	3000	1223	831	726	0
3000	200	8100	7500	7000	6600	7000	6700	6300	6000	5700	5400	4400	4000	3500	2055	1425	837	0
3000	300	9000	8500	7352	7029	7900	7700	7330	6970	6600	6263	5500	4233	4210	2614	1664	894	0
3000	500	9600	9300	7968	7645	8000	7700	6734	6479	6272	5602	5589	4064	3719	2522	1769	1035	0
3000	750	9800	9300	8703	8411	7227	6948	6945	6388	6175	6133	5519	3637	2825	1496	1271	563	0
3000	1000	9900	8000	7187	7679	7010	6648	6530	638	5755	5239	4174	3246	2257	1823	1174	1336	0
3000	1500	9800	7552	7186	7300	6749	6548	5690	5200	4771	4486	3410	2565	1787	1623	1500	1275	0
3000	2000	9900	9000	8500	8000	7500	6975	5878	5125	4374	4137	2745	2099	1288	1000	1300	600	0
3000	3000	10000	9000	7600	8400	7482	5986	5411	4973	4443	3043	1963	2109	1133	1050	1000	630	0
3000	4000	10500	9000	7500	6517	5754	5404	5014	4629	3915	2134	2000	1900	1750	1350	1000	690	0
3000	5000	10800	8362	7171	6320	5367	5164	4695	4117	3566	2160	1900	1900	1750	1350	1000	630	0
3000	7500	11200	8608	7200	5504	4590	4117	3779	360	3424	2200	2150	2000	1809	1500	1200	703	0
4500	0	4676	4400	4125	3850	1362	793	730	687	644	601	515	429	344	260	134	130	0
4500	50	5669	5300	5006	4713	3941	3573	3442	3247	2711	2179	1629	1212	836	372	338	300	0
4500	100	6009	5600	5300	5000	4800	4500	4400	410	3400	2700	2000	1500	1300	860	746	666	0
4500	200	7900	7300	6700	6000	5800	4900	4700	4600	4200	3700	3200	2800	2500	1600	1419	954	0
4500	300	8100	7600	6490	6367	6300	5400	5300	5200	4700	4600	4440	3727	3480	2240	1620	1149	0
4500	500	8200	7300	7106	6783	5900	5516	5115	4550	4181	3652	3480	3067	2500	3350	1691	1123	0
4500	750	8300	7000	7500	6600	5593	5121	4432	4500	4300	4200	3923	2734	2602	2301	1631	965	0
4500	1000	8700	6500	6244	6067	5803	4800	4622	4345	4350	4336	3731	3032	2554	2552	1400	875	0
4500	1500	8900	6138	5774	5600	5600	5407	4846	4510	4083	3674	3178	2663	1975	1713	1231	922	0
4500	2000	6239	6454	5422	5422	5400	5233	4754	4274	3966	3421	2762	2054	1415	1100	1000	900	0
4500	3000	658	6177	5453	5109	5054	4818	4636	4161	3743	2166	2113	1324	639	391	330	224	0
4500	4000	8901	6682	6334	5248	4849	4506	4249	3849	3251	2466	1700	1603	1500	393	309	200	0
4500	5000	9200	7836	6453	4917	4528	4273	4118	3671	2975	2253	1700	1603	1500	1300	1100	900	0
4500	7500	9400	8354	6900	4923	4375	3915	3613	3600	3214	2776	2400	2200	1800	1500	1300	1100	0
7000	0	4538	4348	4160	3973	1921	1221	858	741	713	466	570	475	380	195	121	130	0
7000	50	5485	5137	4790	4443	3786	3380	3142	2965	2579	1966	1495	1169	970	525	298	230	0
7000	100	5802	5400	5200	4600	4420	4100	3910	3730	3700	2600	1800	1401	1120	900	668	563	0
7000	200	6500	6000	5800	5393	4800	4600	4510	4400	4000	350	3500	2300	1612	1450	1300	1155	0
7000	300	7300	6300	5600	5122	5000	4800	4710	4407	4100	417	3500	2630	2568	1914	1521	1236	0
7000	500	7250	6500	5800	5500	5300	5200	5010	4414	4293	3026	3462	2438	2215	2069	1587	1133	0
7000	750	7500	7000	6200	5700	5600	5557	5044	3937	3692	3272	2819	2619	2292	1937	1497	1045	0
7000	1000	7700	5802	5626	5122	5100	4416	4170	3575	3400	3215	2053	2557	2243	1431	1029	800	0
7000	1500	7900	5453	4966	4900	4747	4392	3915	3469	3208	3126	2505	1534	1482	721	600	400	0
7000	2000	5966	5889	4956	4639	4349	3880	3170	3167	2878	2151	1727	1013	634	313	176	115	0
7000	3000	6395	5858	5138	4213	3787	3705	3128	3078	2823	2179	1788	465	212	213	171	124	0
7000	4000	8217	6382	5757	4606	3717	2942	2687	2437	2175	1453	1168	600	255	234	175	113	0
7000	5000	8600	7814	6157	4465	3603	2857	2453	2424	2298	1770	1136	600	400	300	250	150	0
7000	7500	9100	8400	6903	4957	4046	3169	2478	2300	2200	1557	1700	700	500	400	300	200	0
10000	0	4144	4019	3896	3770	2282	1584	1191	918	748	698	598	495	399	300	256	200	0
10000	50	4486	4230	4000	4018	3495	2946	2549	2191	1837	1524	1250	903	700	450	400	537	0
10000	100	4630	4300	4200	4100	3500	2731	2690	2636	2469	1697	1716	1053	1590	1017	500	756	0
10000	200	5000	4600	4453	4400	2961	2700	2670	2538	2194	[illegible]	1400	1650	1550	1327	1280	1150	0
10000	300	5100	4311	4300	4197	3938	3600	3575	3233	3139	[illegible]	2796	1399	1598	1391	1120	844	0
10000	500	5873	5089	4460	4300	3730	3682	3476	2956	2403	2513	2259	1949	1371	1027	775	538	0
10000	750	5074	4815	4465	3635	3500	3475	3255	2917	2681	[illegible]	1897	1443	1023	685	443	331	0
10000	1000	4500	4630	4195	4035	3671	3188	3129	[illegible]	2731	[illegible]	1546	1164	800	600	550	400	0
10000	1500	4859	4606	4445	3910	3652	3393	3097	2536	2424	1178	1150	679	623	500	400	300	0
10000	2000	5900	5023	4733	4070	3602	2962	2733	1899	1570	1146	761	330	362	275	200	175	0
10000	3000	6400	5472	5174	3650	3256	2561	2224	1857	1521	1408	866	777	229	220	209	158	0
10000	4000	7100	6120	5330	3659	3061	2539	1976	1692	1564	1191	768	700	500	400	177	165	0
10000	5000	8322	7155	5532	4380	3113	2586	1967	1872	1709	[illegible]	1262	800	500	400	177	153	0
10000	7500	8835	7855	6052	4555	3681	2872	2262	2200	2100	1800	1554	1007	500	400	170	163	0
15000	0	3103	3046	2987	2930	2236	1731	1395	1145	952	[illegible]	577	601	580	70	250	133	[illegible]
15000	50	3176	3087	2997	2978	2501	2158	1319	1795	1663	1160	1519	795	696	50	47	454	[illegible]
15000	100	3200	3100	3000	2900	2400	2200	1910	153	1700	1115	1513	1309	1173	772	578	550	[illegible]
15000	200	3200	3200	3000	2500	1801	1600	1530	1417	1400	135	1300	1700	1125	863	654	550	[illegible]
15000	300	3301	2726	2700	2612	2573	2300	2146	201	1879	1600	1500	1083	735	548	17	374	[illegible]
15000	500	3300	3200	2946	2405	2200	2126	2097	1706	1578	1434	1103	706	465	289	311	173	[illegible]
15000	750	3434	3400	3014	2447	2149	2216	2041	1562	1362	1127	744	661	312	222	[illegible]	173	[illegible]
15000	1000	3100	3000	2978	2576	2257	1893	1646	142	1299	1037	521	311	250	225	[illegible]	173	[illegible]
15000	1500	3272	3059	2855	2340	2009	1666	1414	1131	893	769	595	283	250	225	[illegible]	173	[illegible]
15000	2000	3419	3595	3107	2421	2171	1816	1439	1329	726	544	565	546	510	225	[illegible]	173	[illegible]
15000	3000	4400	3867	3573	2651	2241	1813	1457	1176	1150	956	885	[illegible]	510	225	[illegible]	173	[illegible]
15000	4000	5100	4200	3156	2460	2437	2031	1431	1363	1502	1100	1333	[illegible]	720	225	[illegible]	173	[illegible]
15000	5000	5581	4658	4156	3606	2976	2438	2133	1985	1500	1495	1291	1003	750	710	[illegible]	200	[illegible]
15000	7500	5791	5301	4387	4440	3771	2422	2400	2274	2110	1877	1669	1103	950	910	400	200	[illegible]
20000	0	1107	1087	1066	1045	907	791	692	607	533	467	357	289	250	150	105	53	[illegible]
20000	50	1133	1131	1069	1077	922	813	762	697	642	598	544	359	264	199	175	146	[illegible]
20000	100	1142	1106	1070	1034	927	820	795	713	679	642	606	321	295	563	153	147	[illegible]
20000	200	1147	1162	1073	1034	927	829	795	730	640	606	571	561	476	488	67	454	[illegible]
20000	300	1177	1150	1100	1300	907	85	795	713	546	571	535	441	394	26	46	152	[illegible]
20000	500	1177	1162	1113	1297	903	820	813	727	612	547	415	241	211	112	100	69	[illegible]
20000	750	1217	1213	[illegible]	961	907	805	750	636	475	431	361	201	178	110	100	34	[illegible]
20000	1000	1382	1268	1361	989	901	825	801	635	519	530	350	201	161	110	100	33	[illegible]
20000	1500	1296	1260	1100	1050	1000	938	969	647	[illegible]	664	412	361	195	110	100	38	[illegible]
20000	2000	1562	1408	1200	1190	1144	1143	1161	857	767	679	595	507	189	110	100	38	[illegible]
20000	3000	1887	1792	1606	1550	1650	1637	1412	1267	1211	996	833	611	189	115	100	94	[illegible]
20000	4000	2500	2400	2100	2700	2101	2032	1312	1517	1449	1248	983	643	189	143	178	153	[illegible]
20000	5000	3005	2831	2771	2661	2373	2350	1190	1977	1449	1405	942	701	210	153	250	214	[illegible]
20000	7500	3268	2969	2409	2430	2754	2570	[illegible]	2164	1331	1557	1136	703	[illegible]	175	371	56	[illegible]

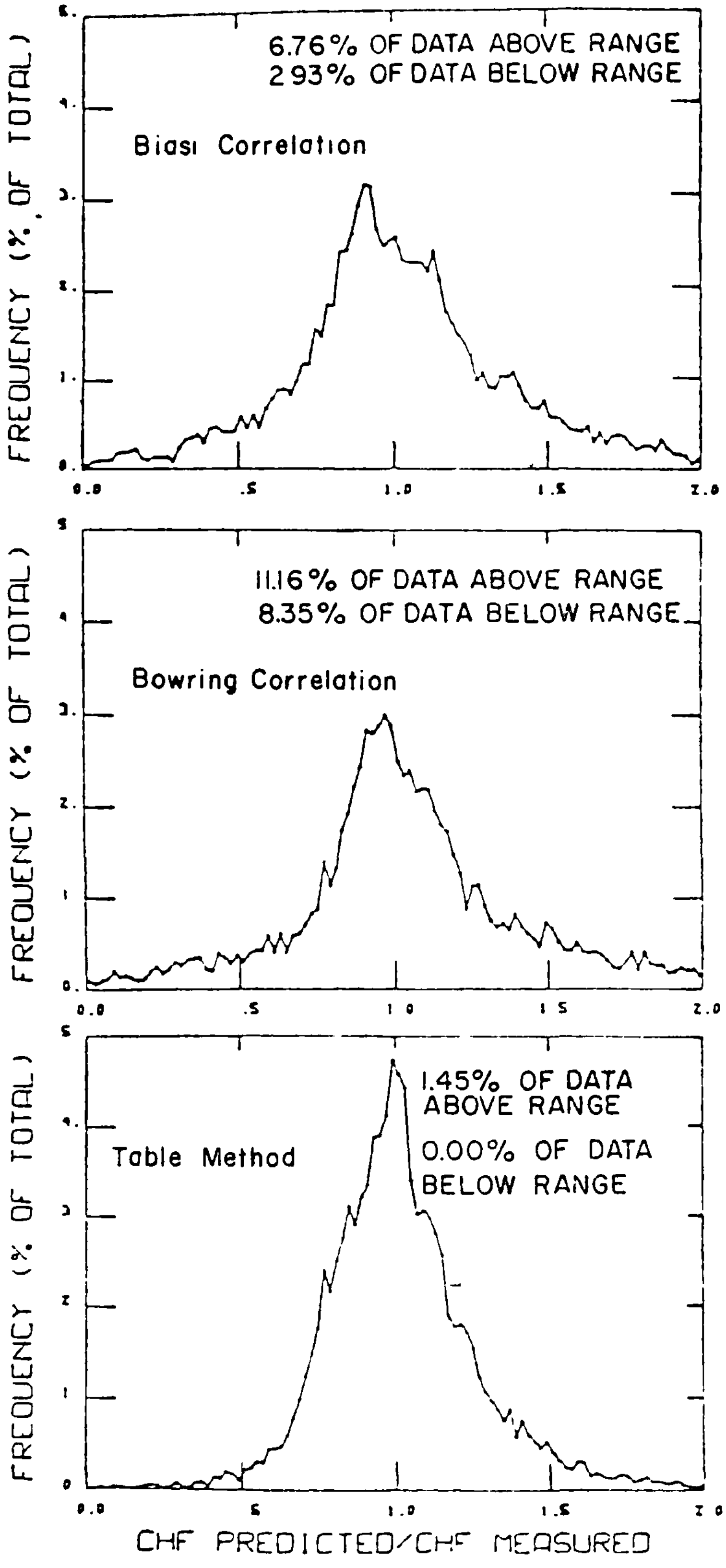


FIGURE 2.18 COMPARISON OF CHF ERROR HISTOGRAMS, GROENVELD (1984)

results among the existing correlations over a wide range of conditions, Groeneveld (1986). The range of the table method is:

$$\begin{aligned} \text{pressure:} &\quad 100 - 20\,000 \text{ kPa} \\ \text{Mass flux:} &\quad 0 - 7500 \text{ kg/m}^2\text{/s} \\ \text{Quality:} &\quad -15 \text{ to } 100\% \end{aligned} \tag{2.38}$$

The predicted CHF using the standard CHF table may require the use of several correction factors as shown:

$$CHF_{actual} = CHF_8(P,G,X)\cdot K_1 \cdot K_2 \tag{2.39}$$

Where $CHF_8(P,G,X)$ represents the CHF obtained by interpolating in the table and K_1-K_2 are corrections factors listed in table 2.5; their derivation is discussed by Groeneveld (1982).

Groeneveld's table look-up technique is not dimensionless. However, it will be shown in Chapter 4 that the table can be transformed to a dimensionless form that can be used in predicting CHF in non-aqueous fluids.

2.5 Theoretical Models

The theoretical models are usually based on a specific CHF mechanism. They may require a few empirical constants that can be optimized from experimental CHF data. The models predict the CHF in a system within a range of conditions regardless of the fluid type.

2.5.1 Whalley's Theoretical Model For Predicting CHF in Annular Flow

Whalley et al. (1973) developed a theoretical model for predicting CHF in forced convection boiling in vertical up-flow in round tubes.

Table 2.5. CHF Correction Factors

Correction Factor	Equation	Comments
K_1, Subchannel or Tube Cross Section Factor	For $0.002 < D < 0.016$: $K_1 = \left(\frac{0.008}{D}\right)^{1/3}$	Includes the observed diameter effect on CHF. This effect is quality dependent and could be included by replacing the exponent 1/3 by (2-X)/4 (requires verification)
K_2, Heated Length Factor	$L/D \geq 5$: $K_2 = \exp\left[\frac{D}{L} \cdot e^{2\alpha}\right]$ α evaluated from homogeneous model	Inclusion of α correctly predicts the diminishing length effect at subcooled conditions. The length effect is particularly noticeable if $L/D < 10$ for subcooled burnout and $L/D < 100$ for two-phase dryout.

The heat flux was assumed to be uniform. The model predicts the CHF in the annular flow regime. In this regime, CHF occurs due to a reduction of liquid film flow on the channel wall to zero. The annular flow was arbitrarily assumed to start at 1% quality with 99% of the liquid entrained at this condition. This assumption does not represent the true situation near the start of annular flow, but Whalley found that the predicted CHF results were relatively insensitive to the assumed inlet condition. By writing a mass balance on the liquid film Whalley obtained

$$\frac{d\ G_{LF}}{dz} = \frac{4}{D}\left(\text{Dep} - \text{Ent} - \frac{q_{co}}{\lambda}\right) \tag{2.40}$$

where Dep and Ent are the local rate of droplet deposition and entrainment per unit area of the tube wall, respectively, and q_{co}/λ is the evaporation rate of liquid per unit area of the tube wall. G_{LF} is the mass flow of the liquid film (per unit of cross section area of the channel), z is the distance along the channel and D is the tube diameter. By introducing the deposition mass transfer coefficient K_w, Dep and Ent are written as follows: Dep = $K_w C$ and Ent = $K_w\ C_{eq}$ where C is the droplet concentration in the gas core, and C_{eq} is the value of C for hydrodynamic equilibrium. "Hydrodynamic equilibrium" is approximated in a very long channel with adiabatic flow where the deposition rate becomes close to the entrainment rate. Empirical values of K_w were given by Whalley et al. for water, Freon-12 and liquid nitrogen as a function of surface tension. The variation of K_w with σ is shown in Fig. 2.19. Based on the assumption of a homogeneous mixed condition of the gas core, C was given theoretically as a function of liquid and vapor densities, quality and the ratio of the liquid film flow rate to the total flow rate. Also,

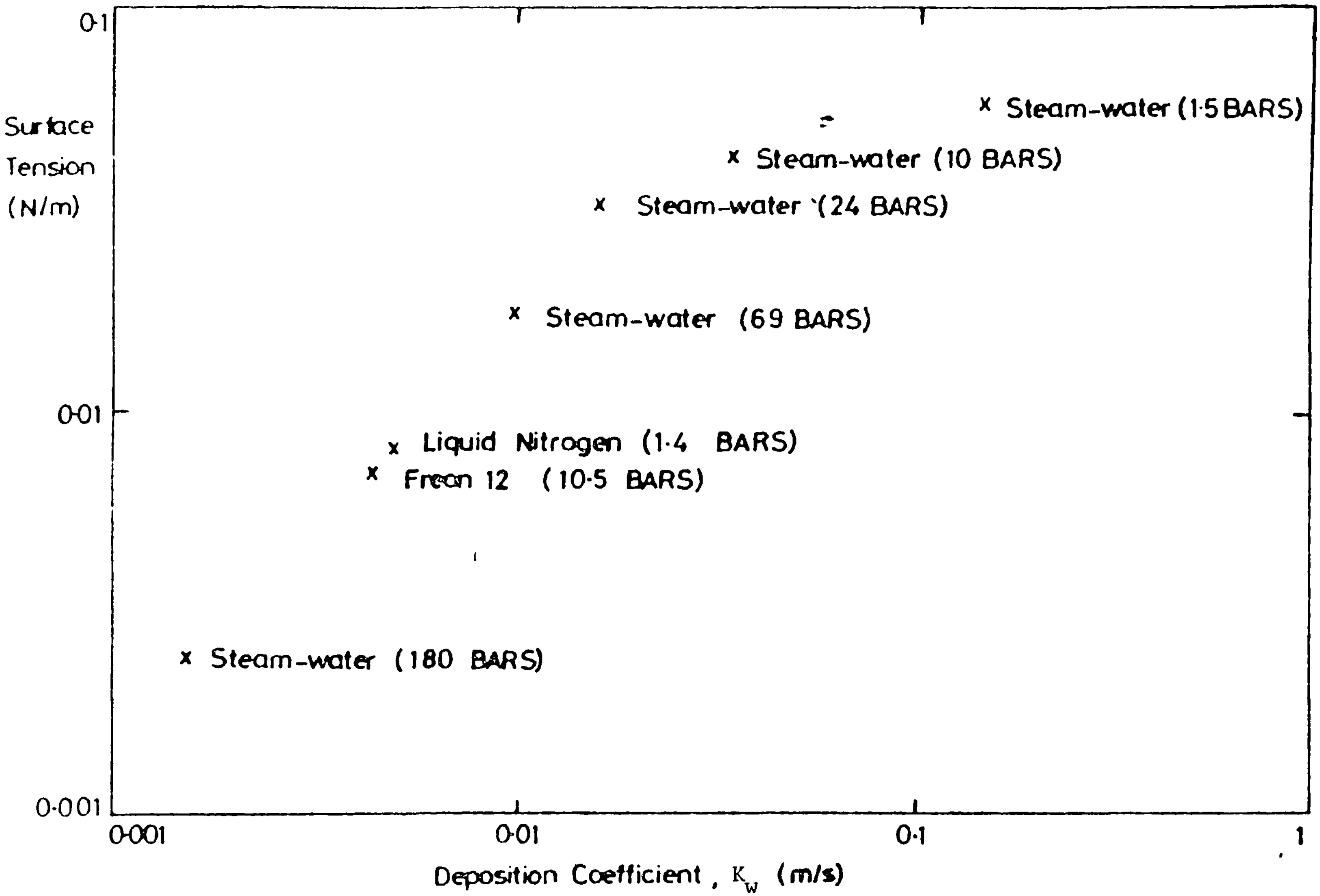


FIG. 2.19 <u>VARIATION OF DEPOSITION COEFFICIENT WITH SURFACE TENSION</u>, WHALLEY ET AL. (1973)

Whalley et al. gave empirical values of C_{eq} as a function of τ_i m/σ where τ_i is the interfacial shear stress, m the film thickness, and σ the surface tension.

The parameter τ_i and m can be calculated provided the film flow rate at a particular point along the channel is known and by using a combination of the following relationships:

(1) the "triangular relationship" given by Hewitt (1961). This relates the liquid film flow, liquid film thickness and pressure drop such that any of these parameters can be calculated if the other two are known.

(2) the "geometrical similarity" relationship which relates the thickness of the liquid film to the effective roughness presented by the film interface to the gas core. The final form of the relationship was given by Wallis (1970) who suggested that the interfacial friction factor (defined in terms of a homogeneous core, could be expressed as (1 + 360 m/d) times the friction factor for the gas core flowing in the absence of the liquid film.

Using these relationships, equation (2.40) was integrated from the point of onset of annular flow (defined arbitrarily as above). The integration was continued along the uniformly heated tube until G_{LF} became zero. This is the location where the CHF is assumed to take place.

If the tube length (L) calculated from the quality relation $\left(x = \frac{4q_{co}}{G\lambda} \cdot \frac{L}{d}\right)$ at $G_{LF} = 0$ agrees with the real tube length, then the value of q_{co} is regarded as the solution. Otherwise, the calculations must be performed iteratively until L predicted agrees with the tube length. For details see Whalley (1973).

Encouraging agreement was obtained between the experimental data of Becker (1965) for water at 91 bars and Behar et al. (1973) for Freon-12 at 23.3 bars and Whalley's model. The comparisons are illustrated in Figs. 2.20 and 2.21. The highest errors are found in the low quality range (5 - 20%) where the assumption of annular flow is not valid.

2.5.2 Levy's Theoretical Model for Predicting CHF in Annular Flow

Levy (November, 1980) developed a theoretical model for predicting CHF in the annular flow regime. He based his model upon the Whalley et al. (1973) model with the following exceptions:

1. Levy's model employs a semi-empirical adiabatic model for liquid film-flow and entrainment (Levy (August, 1980)).
2. The annular flow is assumed to start at a vapor void fraction of 80%.
3. It uses an integral form of the mass balance equation in terms of steam quality.

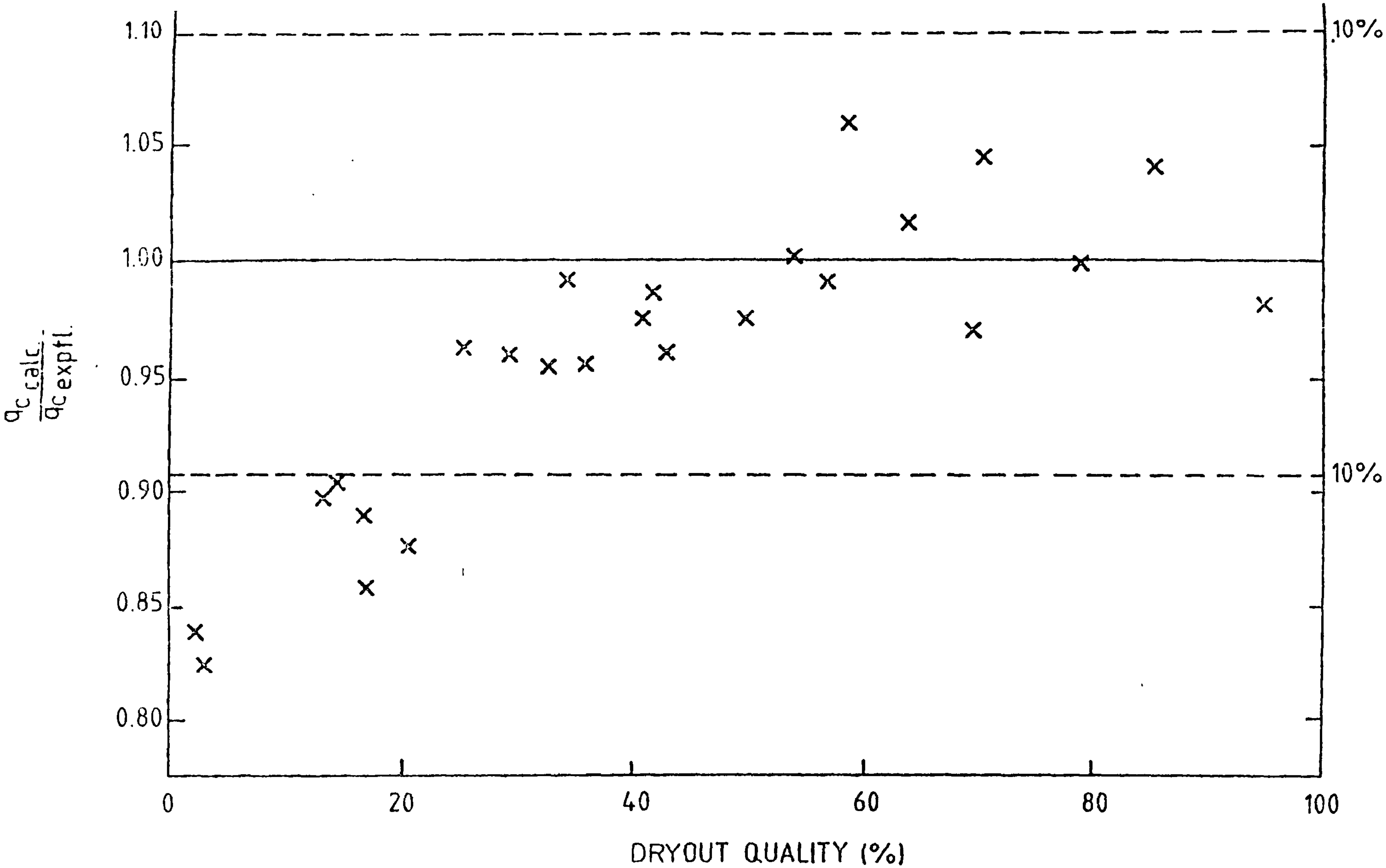


FIGURE 2.20 COMPARISON OF CALCULATED AND EXPERIMENTAL BURNOUT HEAT FLUXES FOR STEAM-WATER FLOW AT 91×10^2 kPa, $D = 9.98 \times 10^{-3}$ M, K = 0.008 M/s. DATA FROM BECKER (1965), WHALLEY ET AL. (1973)

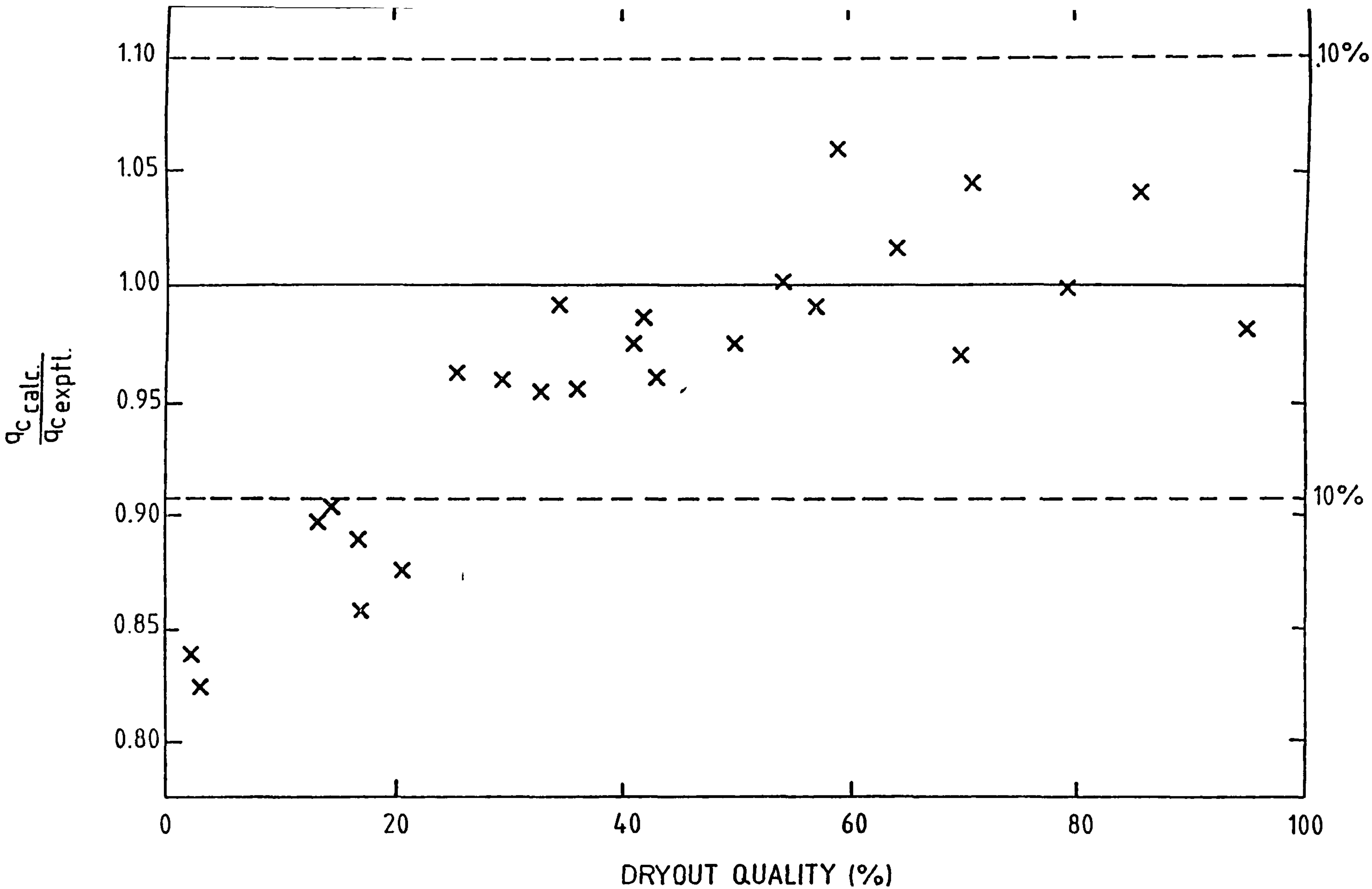


FIGURE 2.21 COMPARISON OF CALCULATED AND EXPERIMENTAL BURNOUT HEAT FLUXES FOR FREON-12 AT 23.3×10^{2} kPa, $D = 10^{-2}$ M, $K = 0.0015$ m/s. DATA FROM BEHAR ET AL. (1969), WHALLEY ET AL. (1973).

The model shows two distinct regions of CHF versus steam quality at the CHF location. At low steam qualities, the CHF is independent of heat flux distribution, and it is controlled by vaporization of the liquid film. At high steam qualities, the CHF depends upon the net deposition into the liquid film, and the heat flux distribution. Levy's model was not tested with fluids other than water.

2.5.3 Weisman & Pei Theoretical Model for Predicting CHF in Flow Boiling at Low Qualities

Weisman & Pei (1983) developed a theoretical model to predict CHF for high velocity flow in tubes at low exit qualities. The model is based on the following assumptions:

- The CHF in the subcooled and low quality region is caused by limited enthalpy transport between the bubbly layer adjacent to the wall and core.
- Under subcooled and low quality conditions, CHF is a local phenomenon.
- The CHF occurs when the volume fraction of vapor in the bubbly layer exceeds the critical void fraction. The critical void fraction is the void fraction obtained when an array of ellipsoidal bubbles can be maintained without significant contact between the bubbles, and was found to be 82%.
- The volume fraction of vapor in the bubbly layer is determined by a balance between the outward flow of vapor and the inward flow of liquid at the bubbly-layer core interface.

Fig. 2.22 shows the bubbly layer at the CHF location Z_{CHF}. The quality in the bubbly layer is assumed to be a constant at the average value, x_2. A total mass balance on the bubbly layer control volume is written as follows:

$$\dot{m}_3 = \Delta\dot{m}_2 + \dot{m}_4 \tag{2.41}$$

where $\Delta\dot{m}_2$ is the difference between the axial flow in and out of the bubbly layer control volume. Also, there is a radial interchange between the bubbly layer and the core region. $\dot{m}_3$ represents the total flow rate from core to bubbly layer and $\dot{m}_4$ the total flow rate from bubbly layer to core. Writing a mass balance on the liquid in the bubbly layer and simplifying it leads to

$$\frac{q_c}{G_3\lambda} \frac{(h_L - h_{Ld})}{(h_f - h_{Ld})} = x_2 - x_1 \tag{2.42}$$

where

$$G_3 = \dot{m}_3/(2\pi\ (r_0 - s)\ \Delta L)$$

s = bubbly layer thickness

q_c, the heat flux evaluated from eq. (2.42), becomes the CHF when x_2 corresponds to the critical void fraction.

The critical void fraction was determined based on the assumption that bubbles are approximately ellipsoidal with the ratio of major to minor ellipse axes being 3:1. The maximum void fraction was obtained when the bubbly layer was filled with such bubbles which were just touching,

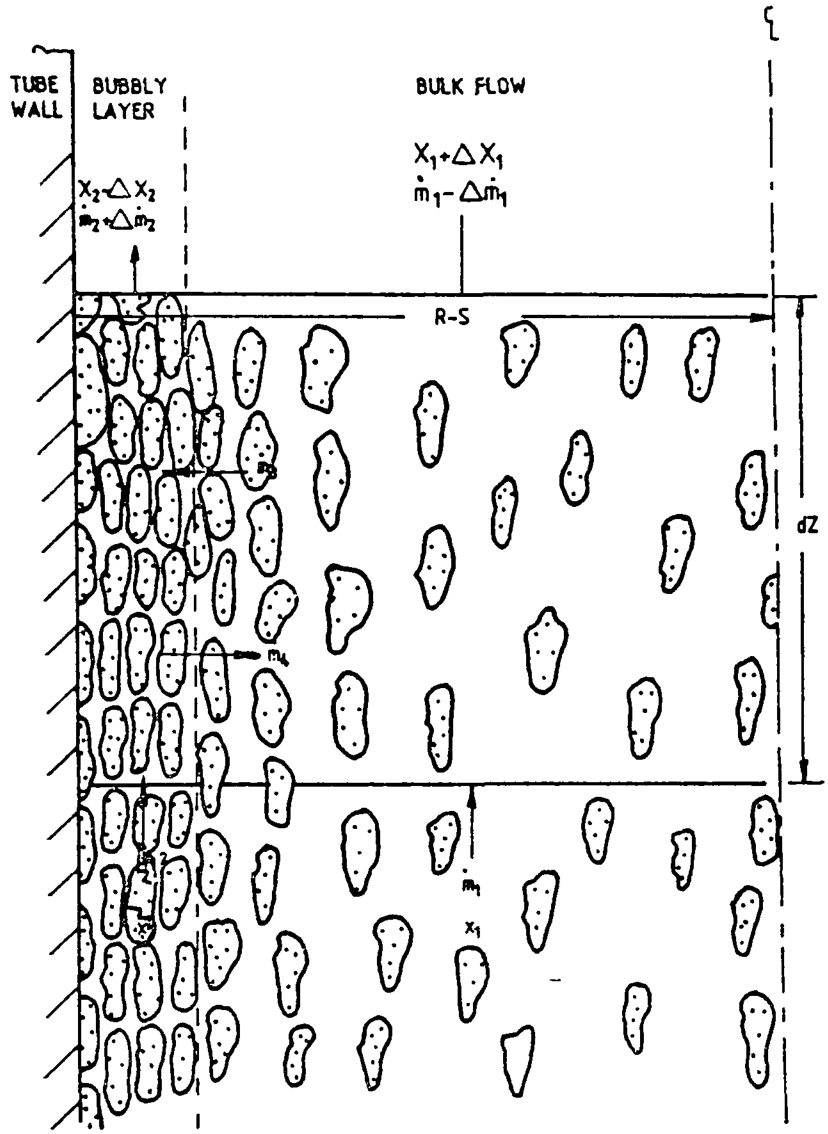


FIGURE 2.22 TWO-PHASE MASS TRANSFER AT CONTROL VOLUME SEGMENT LOCATED AT Z_{CHF}, PEI (1981).

$\alpha_c = 0.82$. The corresponding value of x_{2c} was computed based on the assumption that vapor slip was negligible. This assumption holds only at high mass velocities (for water, $G \geq 875$ Kg $m^{-2}s^{-1}$). To evaluate the mass flow between the core and the bubbly layer, a value of the turbulent interchange at the bubbly layer - core interface is required. The turbulent intensity at the bubbly layer core interface was found to be:

$$i_b = 0.462 \; Re^{-0.1} \; (K)^{0.6} \; (\frac{Dp}{D})^{0.6} \; [1 + a \; (\frac{\rho_f - \rho_g}{\rho_g})] \qquad (2.43)$$

The values of both a and K were determined by an empirical fit of experimental CHF data, and Dp is the average bubble diameter. For details see Pei (1981). The bubble diameter was evaluated using Levy's (1966) model which balances buoyancy and drag forces against surface tension. At high velocities, buoyancy forces are negligible and

$$Dp = 0.015 \; (\frac{8 \; \bar{\rho} \; \sigma \; D_h}{f' \; G^2}) \qquad (2.44)$$

where f' is a friction factor. Finally,

$$q = \lambda G(x_2 - X_1) \; i_b \psi \; (\frac{h_f - h_{Ld}}{h_L - h_{Ld}}) \qquad (2.45)$$

where

$$\psi = \{\frac{1}{2\pi} \exp-[-\frac{1}{2}(\frac{v_{11}}{\sigma_{v'}})^2 - \frac{1}{2}(\frac{v_{11}}{\sigma_{v'}}) \; \mathrm{erfc}(\frac{1}{\sqrt{2}} \; \frac{v_{11}}{\sigma_{v'}})\}$$

v': radial fluctuating velocity (m/s)

$\sigma_{v'}$: standard deviation of v'

v_{11}: radial velocity created by vapor generation (m/s)

The calculation procedure may be summarized as follows: A value of q is assumed, then Levy's model is used to calculate Z_d and h_{Ld}.

An iterative method to calculate X_{avg} (which is calculated using Lahey's (1977) mechanistic subcooled-quality model) and h_L at Z_{CHF} (the CHF location) is used. The values of i_b and ψ are then calculated. Based on $\alpha_2 = 0.82$ at Z_{CHF} x_l and ρ_l at Z_{CHF} are calculated. The RHS of eq. (2.52) can now be calculated. If the assumed heat flux equals the value predicted by the RHS within a preassigned tolerance the CHF is equal to the RHS. Otherwise, another CHF value is assigned to the LHS of eq. (2.52) and the process is repeated. The flow chart illustrating the calculations scheme is shown in Fig. 2.23. A computer listing of the model is presented in Appendix E.

Weisman and Pei proposed a range of parameters for their model. The range of parameters for water is:

Pressure:	2 - 20.5	MPa	
Mass flux:	972 - 13 600	kg $m^{-2}s^{-1}$	
Tube Length:	0.35×10^{-2} - 3.6	m	(2.46)
Tube diameter:	0.115×10^{-2} - 3.75×10^{-2}	m	

$\alpha_{CHF} \leq 0.6$

Weisman & Pei evaluated the accuracy of their model by testing it with the W-3 (Tong (1967)) and the CISE (Bertolleti et al. (1964)) correlations. The upper half of table 2.6 compares the three correlations for data that belong to the W-3 correlation range. The lower half of table 2.6 compares the correlations for more than 1500 data points obtained with water in uniformly heated round tubes at low qualities. It is seen that Weisman & Pei's model is more accurate than the CISE or the W-3 correlations for the data based used. Fig. 2.24 shows a comparison between CHF values predicted by Weisman & Pei's model and experimental

FIGURE 2.23 PROGRAM FOR UNIFORM HEAT FLUX DNB PREDICTION PEI (1981)

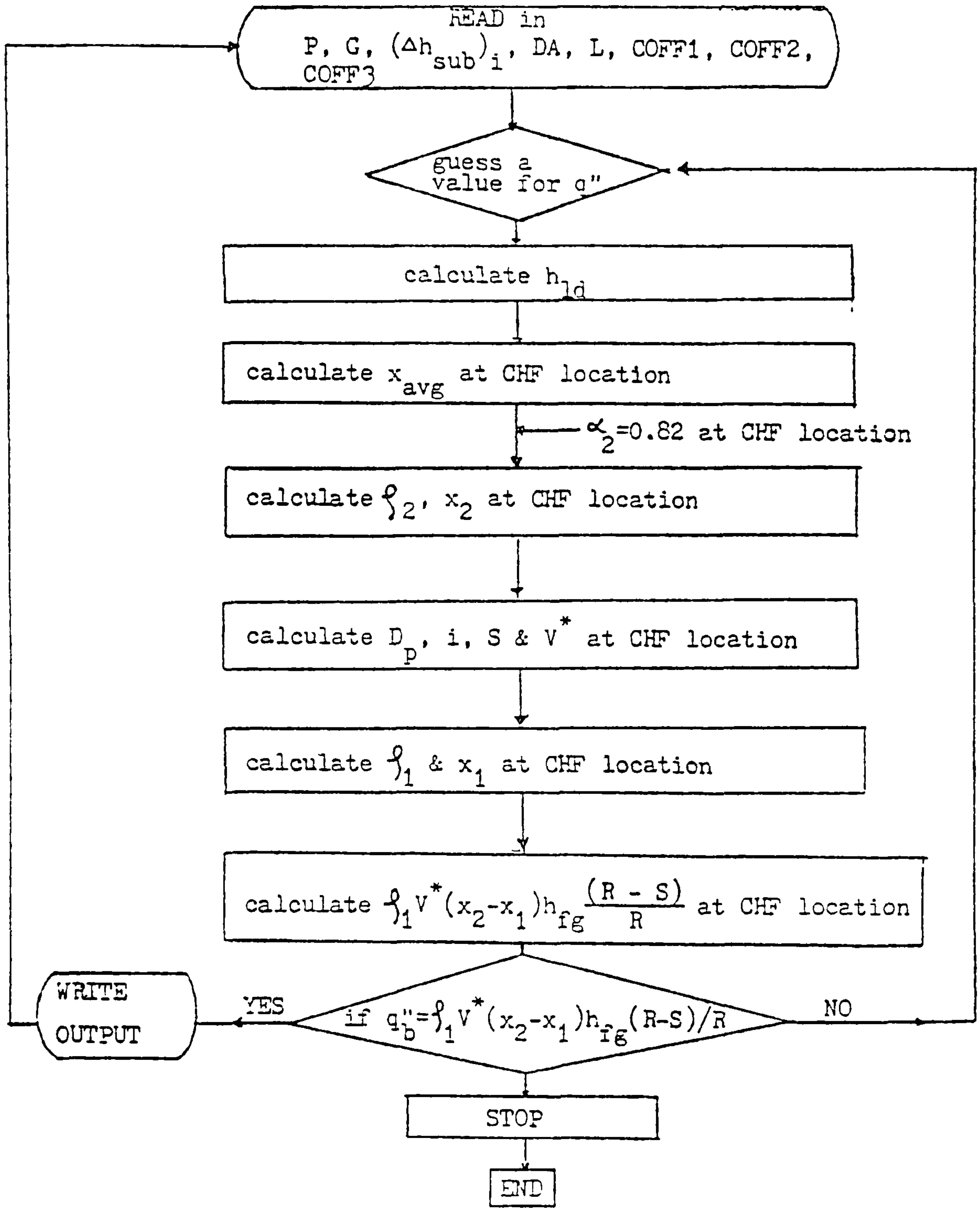


Table 2.6. Comparison of predictions and experimental data water in uniformly heated round tube, Weisman & Pei (1983)

Prediction	Number of data points	$\mu(R)$*	$\sigma(R)$*
W-3 correlation	406 (W-3 range)	0.989	0.059
CISE correlation	406 (W-3 range)	1.012	0.118
Weisman & Pei	406 (W-3 range)	0.994	0.065
W-3 correlation	1516	1.131	0.570
CISE correlation	1516	0.946	0.178
Weisman & Pei	1516	0.9995	0.099

R: $\dfrac{CHF_{predicted}}{CHF_{measured}}$

$\mu(R)$: mean value of R

$\sigma(R)$: standard deviation of R

ones in uniformly heated round tubes using water as a coolant. The test was done with 1500 data points; however, only one point out of each ten was randomly plotted in Fig. 2.24. Also, Weisman & Pei extended the application of their model to fluids other than water, without any change in the empirical constants. Fig. 2.25 illustrates the comparison of CHF values for several fluids and table 2.7 lists the statistical comparison.

2.6 Discussion

2.6.1 Scaling Techniques

As for fluid to fluid modeling of CHF, there are two approaches: the Stevens & Kirby (1964) empirical approach and the dimensional analysis initiated by Barnett (1963). Both approaches showed only limited success because they dealt with one fluid (Freon-12) at one pressure. However, both approaches laid the ground work for more techniques that followed.

Most of the scaling techniques mentioned earlier are simply an extension or a modification of the above mentioned approaches. The modification to the Stevens and Kirby's approach proposed by Staub lacks in generality since it applies only to two fluids (Freon-12 and Freon-22) within a narrow pressure range. The extension of Barnett's scaling law to subcooled liquid conditions was made by Coffield. Also, Coffield found that the scaling factor K (used in the Stevens & Kirby technique) varies with the pressure. Coffield's extension lacks in generality since it applies only to one fluid (Freon-113) with a limited pressure range. Dix suggested that the mass flux scaling factor varies with mass flux, length to diameter ratio, pressure and Freon type. However, his suggestion has a

Table 2.7. Comparison of uniformly heated round tube data for several fluids with predictions of Weisman & Pei (1983)

Fluid	Number of data points	$\mu(R)^*$	$\sigma(R)^*$
Freon 11	20	1.071	0.048
Freon 113	40	1.054	0.094
Liquid N_2	50	1.302	0.098
Anhydrous ammonia	7	1.168	0.285
All non-water data	117	1.169	0.159
Water	1516	0.9995	0.099

R: $\frac{CHF_{predicted}}{CHF_{measured}}$

$\mu(R)$: mean value of R

$\sigma(R)$: standard deviation of R

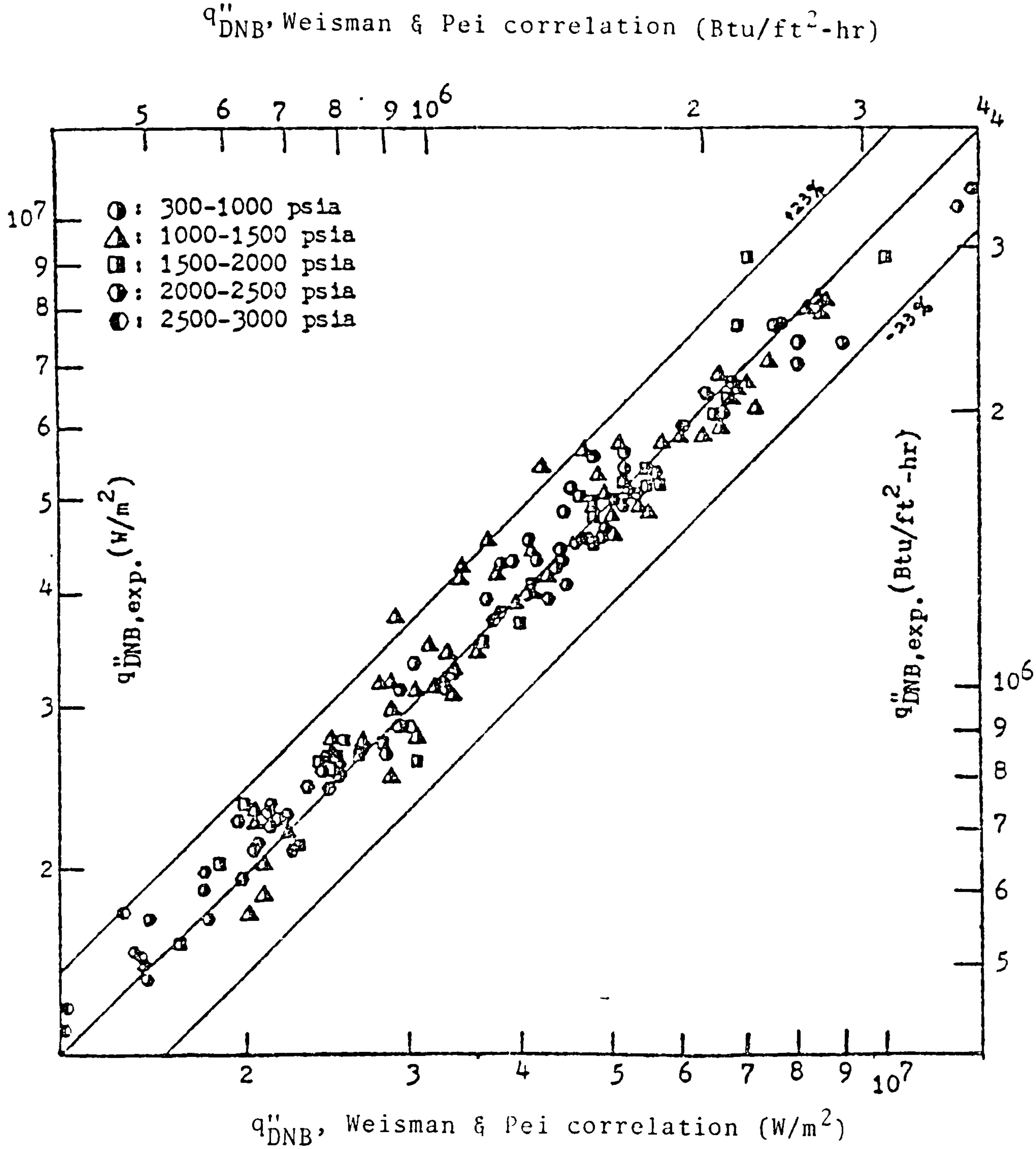


FIGURE 2.24 "DNB, WEISMAN & PEI CORRELATION vs. EXPERIMENTAL DNB" FOR 150 RANDOMLY SELECTED UNIFORM HEAT FLUX LOW QUALITY WATER DNB DATA. WEISMAN & PEI (1983)

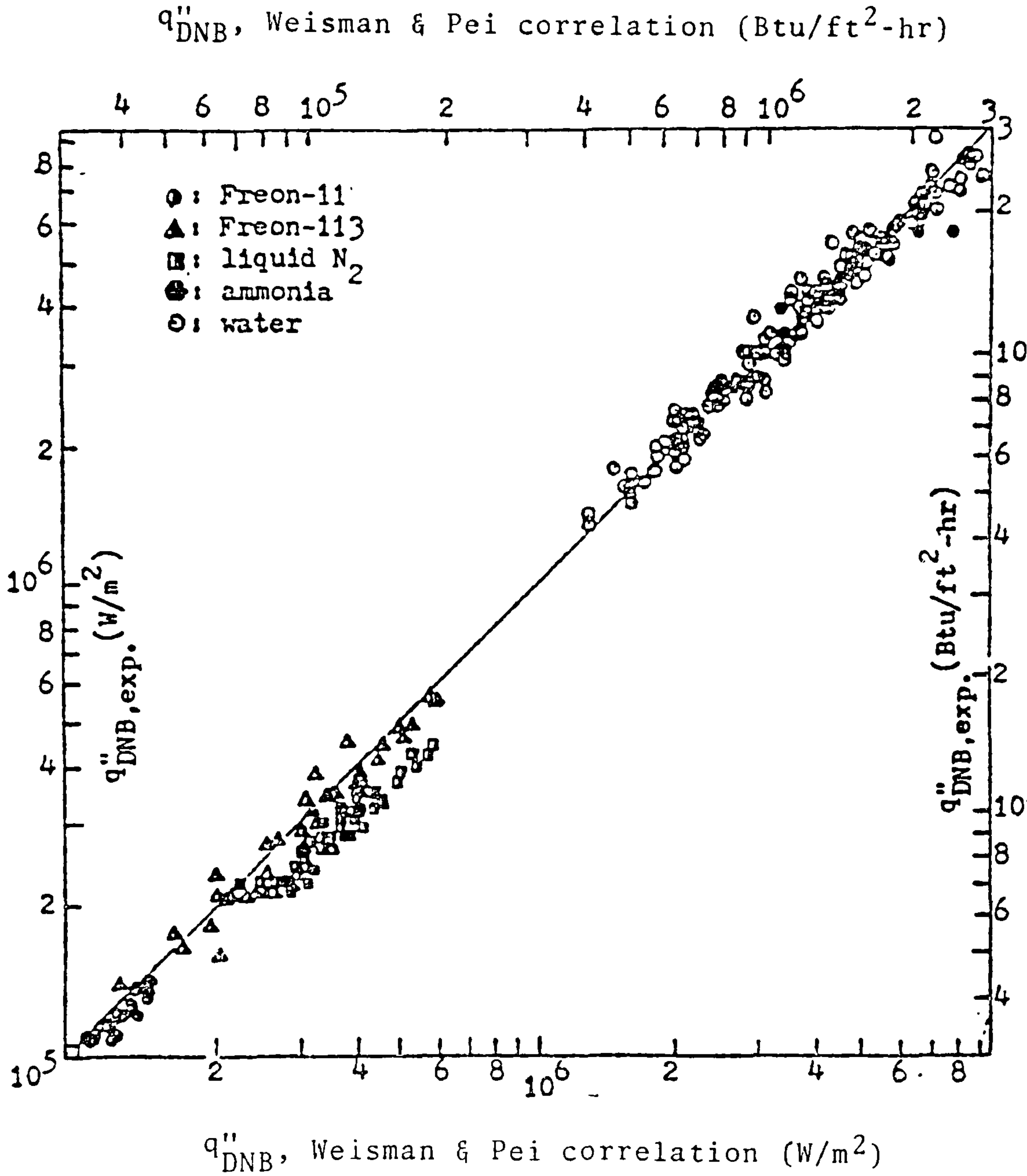


FIGURE 2.25 "DNB, WEISMAN & PEI'S CORRELATION vs. EXPERIMENTAL "DNB FOR UNIFORM HEAT FLUX LOW-QUALITY DNB DATA FOR WATER, FREON-11, FREON-113, LIQUID N2 AND AMONIA. (WEISMAN & PEI (1983)

limited range of application since it applies only to a limited number of Freon types and a narrow range of pressure.

Hauptmann's technique requires additional fluid properties such as P_c, T_c and M. Also, the value of the equilibrium boiling length (L_B) is required to scale CHF. This presents a major disadvantage if only the inlet conditions are known.

Ahmad's technique for modeling CHF in flow boiling was applied for a number of fluids (Freons, water, potassium and carbon dioxide). The technique was applied over a wide range of pressure, mass flux, and inlet subcooling in both subcooled and high quality regions. The difference between Ahmad's technique and Steven's and Kirby empirical approach is the mass flux scaling parameter: Ahmad's dimensionless groups used to scale the mass flux are independent of fluid type.

2.6.2 Empirical Correlations

Kutateladze and Zuber's correlations for predicting CHF in pool boiling are similar. Kutateladze's correlation for predicting CHF in forced convective boiling was not tested with any fluid. Hauptmann's correlation lacks in generality, since it was applied only to three fluids within a limited range of geometry and exit quality. Also, in some cases, the value of the equilibrium boiling length (L_B) is required to predict CHF. If the value of L_B is not known, the CHF can be calculated by using an iterative procedure. Hauptmann's correlation has incorrect parametric trends at low flows and high pressure. As the mass flux approaches zero, the CHF should approach its pool boiling value. Instead, Hauptmann's correlation (eq. (2.16)) predicts a zero CHF value. Also, as the pressure approaches the critical pressure, the CHF value should approach zero. Instead, the CHF predicted by eq. (2.16) is a positive constant value at the critical pressure. Shah's correlation for predicting CHF is applicable over a wide range of conditions. However, in some cases, the value of dryout quality x_c is required to predict the CHF using Shah's correlation. If the value of x_c is not known, an iterative procedure should be used to calculate the CHF. Katto's correlation gave adequate CHF predictions when tested with more than 14 fluids. However, Katto's correlation is restricted to the positive dryout quality range. Katto's correlation has the correct parametric trends at low flows and high pressures. Eq. (1.3) indicates that in the "low mass velocity region", q_{co} tends towards $(GD\lambda/4L)$. Katto (1983) indicates that at low mass flux eq. (2.22) should be used. The term $\left(\frac{\sigma \rho_f}{G^2 L}\right)^{0.043}$ in eq. (2.22) approaches 1. The value of C is around 0.25. Therefore q_{co} tends towards $\left(G \cdot \lambda \cdot \frac{D}{4\ L}\right)$, which is the same value predicted by (1.3). Also, as the pressure approaches the critical pressure, the CHF value tends towards zero. This is obtained from eqs. (2.22), (2.25) and (2.26). Ahmad's correlation was only tested with three fluids at one liquid to vapor density ratio.

2.6.3 Theoretical Models

Whalley's theoretical model for predicting CHF was tested with water and Freon-12. The model lacks in generality since empirical values of the deposition mass transfer K were not determined for other fluids. Also, the model is only applicable in the annular flow regime, which occurs at qualities above 10-15%. Weisman & Pei's model for predicting CHF in the subcooled and low quality region is restricted to high pressure (above 2 MPa) and high mass flux (above 970 $kg/m^2/s$). Also, the model is more complex than any of the previously mentioned techniques.

2.6.4 Discussion of Dimensionless Parameters

Table 2.8 lists the dimensionless groups used by different authors for CHF modeling. The dimensionless groups used to scale pressure, geometry, inlet subcooling and CHF are similar. The main difference between the various scaling techniques lies in the mass flux scaling parameter. Table 2.9 lists the mass flux scaling factors applicable to a specific Freon type and pressure. Ahmad's mass flux scaling parameters are applicable over a wide range of conditions and fluid types. The dimensionless term involving the mass flux in Katto's correlation requires two variable fluid properties; the surface tension and the liquid density. The dimensionless parameters used in Katto's correlation may be used to scale CHF results between various fluids.

Katto (1978) compared the mass flux scaling factors $F_G(G_W/G_F)$ proposed by himself and Ahmad. The mass flux scaling factors proposed by Katto and Ahmad are respectively

$$F_G = \frac{G_W}{G_F} = \left[\frac{(\sigma\ \rho_L)_W}{(\sigma\ \rho_L)_F}\right]^{1/2} \tag{2.55}$$

$$F_G = \frac{G_W}{G_F} = \left[\frac{(\gamma/\rho_f\ \mu_f)_F}{(\gamma/\rho_f\ \mu_f)_W}\right]^{1/3} \left[\frac{(\mu_f/\mu_g)_F}{(\mu_f/\mu_g)_W}\right]^{1/8} \tag{2.56}$$

Table 2.10 lists F_G proposed by Katto in the case of ρ_f/ρ_g = 20 (except for water-potassium where ρ_f/ρ_g = 590) with the empirical values of F_G

Table 2.8. Dimensionless Groups used for CHF Modelling

Author/Fluid	Pressure	Flow	Geometry	Inlet Subcooling	CHF
Ahmad[1] (1973)	ρ_f/ρ_g	$\left(\frac{G^2 D}{\rho_f \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-0.133} \times \left(\frac{GD}{\mu_g}\right)^{-0.2}$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$
Ahmad[2] (1973)	ρ_f/ρ_g	$\left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2} \mu_f}{D \rho_f^{1/2}}\right)^{2/3} \left(\frac{\mu_f}{\mu_g}\right)^{1/8}$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$
Barnett (1964)	ρ_f/ρ_g	$\frac{G \gamma^{1/2}}{\rho_f^{1/2}}$	L/D, $\frac{D\, C_{p_L} \rho_f^{1/2}}{K_L \gamma^{1/2}}$	$\Delta H_{in}/\lambda$	$\frac{q_c \gamma^{1/2}}{\lambda \rho_L^{1/2}}$
Stevens et al.*	ρ_f/ρ_g	$K \cdot GD^{1/4} \left(\frac{D}{L}\right)^{0.59}$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$
Staub (1969)*	ρ_f/ρ_g	$K \cdot GD^{1/4} \left(\frac{D}{L_b}\right)^{0.59}$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$
Dix (1970)*	ρ_f/ρ_g	$K \cdot G$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$
Hauptmann**(1983)	P/P_c	GD/μ_f	L_B/D		$\frac{q_c}{(RT_c P_c^2/M)^{1/2}}$
Shah (1979)	P/P_c	$G^{1.8} D^{0.6} \left(\frac{c_p}{K \rho_f^{0.8} g^{0.4}}\right)\left(\frac{\mu_f}{\mu_g}\right)$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$, x_{cr}
Katto (1983)	ρ_f/ρ_g	$\frac{\sigma \rho_f}{G^2 L}$	L/D	$\Delta H_{in}/\lambda$	$\frac{q_c}{\lambda G}$

** Hauptmann also used Z_c which is the critical compressibility factor $\left(\frac{P_c V_c}{RT_c}\right)$ in his modeling technique.

* K value depends on fluid type K = 1 for water; for other fluids K is defined in table 2.9.

Table 2.9. The Scaling Factor $K = G_{Freon}/G_{water}$.

Author	K
Stevens et al. (1964) F-12	0.658
Staub (1969)	0.658
Coffield (1969)	0.684, 0.690 and 0.715 for ρ_f/ρ_g = 20.6, 11.8 and and 7.2 respectively
Dix (1970)	$C_T\ (1.0 - 0.09\ G_W \times 10^{-6})(1.04 - 0.05\ \frac{L}{D} \times 10^{-2})$ $(1.41 - 0.02\ \rho_f/\rho_g)$ C_T depends on the freon type - see table 2.2.

obtained by Stevens et al. (1970) for water-Freon-12, Staub (1969) for water-freon-22 and water-potassium, Coffield (1969) for water-Freon-113 and Hauptmann (1983) for water-carbon dioxide. Table 2.10 also lists Ahmad's scaling factor for all the mentioned fluids. Note that Katto's scaling factor predicted a value lower than the empirical one for Freons. On the contrary, Ahmad's scaling factor given by eq. (2.56) predicted values much closer to the empirical ones for all fluids. Katto concluded that the viscosity of the fluid has a secondary effect on the occurrence of CHF.

Table 2.11 lists the various dimensionless correlations derived to predict CHF. Their range of applicability and the number of fluids tested are also presented. Their dimensionless groups were listed in table 2.8.

Table 2.10. Comparison of the value of F_G at density ratio ρ_f/ρ_g = 20 except ρ_f/ρ_g = 590 for water-potassium

System W	H_2O	H_2O	H_2O	H_2O	H_2O
System F	Freon-12	Freon-22	Freon-113	CO_2	K
Katto	1.28	1.34	1.21	1.19	1.24
Empirical	1.40	1.40	1.46	1.13	1.0
Ahmad	1.38	1.38	1.34	1.2	1.1*

* The value for ρ_f/ρ_g = 590

Table 2.11. Dimensionless Correlations

Author	Correlation	Comment
Kutateladze (1963)	$\dfrac{q_{co}}{\lambda\ \overline{g^2\rho_g(1+\frac{\rho_f}{\rho_g})}^{4}\sqrt{\sigma_g(\rho_f-\rho_g)}} = K_1 = \text{const.}$ $K_1 = 0.13 + 4\ Ar^{-0.4}$	- Pool boiling correlation - tested with many fluids (Fig. 2.11) - subcooled and saturated boiling
Zuber (1959)	$\dfrac{q_c}{\rho_g\lambda} = 0.18[\dfrac{\sigma(\rho_f-\rho_g)g}{\rho_g^2}]^{1/4} \times [\dfrac{\rho_f}{\rho_f+\rho_g}]^{1/2}$, m/s	- pool boiling correlation
Hauptmann (1983)	$\dfrac{q_c}{(RT_cP_c^2/M)^{1/2}} = a\ Pr(\dfrac{GD}{\mu_f})^c\ (\dfrac{L_B}{D})^d\ (Z_c)^e$	- tested with CO_2, water Freon-12 - use only one variable fluid property μ_L - range: $L_B/D > 35$; $5\% < X_c < 75\%$
Shah (1979)	Graphical correlation	- shown Figs. 36-38 - range $0.0012 < P_r < 0.94$, $6 < G < 24{,}300\ \frac{Kg}{m^2s}$ - $2.6 < X_c < 0.96$, $-3.0 < X_{in} <$ positive - tested with more than 11 different fluids
Katto (1983)	Eqs. (2.24) to (2.32)	- Range: only positive dryout quality - tested with more than 14 different fluids

3. Data Base

3.1 Experimental CHF Data for Fluids other than Water

The CHF data base used in this study was limited to data obtained in uniformly heated round tubes in heat flux controlled systems. A summary of experimental CHF data for non-aqueous fluids is listed in table 3.1. The data are listed along with the range of all parameters affecting the CHF. The actual experimental CHF data are presented in Appendix A. The helium CHF data given by Katto (1983) could not be used in this study. The physical properties* could not be found at the given pressure which is near the critical pressure. Also, the potassium CHF data given by Hoffmann & Krakoviak (1964) could not be used due to lack of given information. This investigation used only the data listed in appendix A. Additional experimental CHF data for fluids other than water may be found in the literature. Their range of conditions is presented in table 3.2.

3.2 Experimental Water CHF Data

The experimental water CHF data were randomly selected from the AECL-CHF data bank. This data bank contains more than 10 000 CHF data points in round tubes obtained from different sources. The selection procedure was done in the following manner.

1. An energy balance, relating inlet subcooling and critical quality was applied to each CHF point. The points that did not satisfy the energy balance within two percent were rejected.

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* The physical properties were obtained by using a heat transfer and fluid flow services (HTFS) subroutine. The subroutine is available on the CRNL computer system.

Table 3.1. Summary of Experimental CHF Data for non-aqueous fluids

Reference	Fluid Type	No of Data	Ranges						
			D(m)	L(m)	G(kg/m^2/s)	P(kPa)	ΔH_{in}(kJ/kg)	Quality (%)	CHF (kW/m^2)
Coffield (1969)	Freon-113	40	1.02×10^{-2}	$76.2\ 10^{-2}$	1292-5617	910-2186	11.6-104	-54→2.5	136-55
Papellov (1966)	Liquid Nitrogen	49	1.28×10^{-2}	$30.48\ 10^{-2}$	1442-2532	345-1655	12.8-66.7	-40→1	221-597
Leung (1980)	Freon-11	20	1.17×10^{-2}	2.74	1396-2802	1988-2897	19.14-57.2	8→18	103-137
Groeneveld (1969)	Freon-12	268	0.78×10^{-2} 1.61×10^{-2}	$60.2\ 10^{-2}$-1.83	509-3264	1062-1089	0.23-28	-6.2→8.0	62.8-283
Katto (1983)	Liquid Helium (I)	138	10^{-3}	$25\ 10^{-3}$ $200\ 10^{-3}$	10.47-107.6	199	3.646→6.25	-16→94	0.1176-2.15
Dix (1980)	Freon-114	441	10^{-2}-1.41×10^{-2}	0.635 - 1.93	449-3944	841-1434	3.63-53.5	2-75	69.-252.
Barnett & Wood (1965)	Freon-21	504	0.67×10^{-2} 1.61×10^{-3}	0.53-3.3	470-2370	731-1380	5.35-70	-3→96	85.-473
Rotem & Hauptmann (1970)	CO_2	172	0.006	1.056	680.-5848	1923-5219	0.08-5219*	0.-74	236-573
Hoffmann & Krakoviak (1964)	Potassium	41	0.83×10^{-2}	1.12	122.4-287	-	-	10-87	189-490

* subcooling ratio $\Delta H_{in}/\lambda$

Table 3.2. Summary of Available Experimental CHF Data for Fluids other than Water

Reference	Fluid Type	No of Data	Ranges						
			D(m)	L(m)	G(kg/m^2/s)	P(kPa)	ΔH_{in}(kJ/kg)	Quality (%)	CHF (kW/m^2)
Merilo (1976)	Freon-12	178	1.26×10^{-2}	1.22–4.88	1680–5410	1050–1520	0–35*	10–80	20–220
Pokhalov (1971)	Benzene	39	0.5×10^{-3}	0.08–0.16	69–10,000	153–4500	0.02–1.68*	0.	350–1100
Alad'yev (1969)	Potassium	59	0.4×10^{-3} 0.6×10^{-3}	0.12–0.60	38–270	15–41	19.14–57.2 0.03–0.19*	46–96	270–1400
Keilin (1974)	Helium-1	230	2×10^{-3}	0.1	18–96	110–150	–	33–60	.1–10
Katto (1983)	Freon-12	–	0.01	1.	120–2100	1960–3440	0.4–40	–	20–200
Girratuno (1974)	Helium-1	–	0.213×10^{-2}	0.01–0.076	45–630	110–200	0. – 0.3	–	1.63–7.55
Povarnin (1964)	Ethyl alcohol	163	2×10^{-3} 3.5×10^{-3}	0.04–0.21	0.49–50†	207–6200	0–210††	–	567–21,600
Lewis (1962)	Hydrogen	44	1.4×10^{-2}	0.28–0.46	0.1†	345	0–3.3††	–	19–66
Lewis (1962)	Nitrogen	11	1.4×10^{-2}	0.46	0.027†	345	1.6††	–	50–177
Ogata (1973)	Helium-1	–	0.109×10^{-2}	0.028–0.056	–	110–200	–	−20→100	0–6
Gambill (1962)	Ethyl	16	0.64×10^{-2}	0.183	5.3–2.7†	138–610	86–147††	–	6500–19,700

* inlet subcooling ratio $\Delta H_{in}/\lambda$

† velocity m/s

†† °C

Table 3.3. Summary of CHF Water Data

Technique	No. of Data	Ranges						
		D(m)	L(m)	G(Kg/m^2/s)	P(KPa)	ΔH_{in}(KJ/Kg)	Quality %	CHF (KW/m^2)
Weisman & Pei's model	68	0.001-0.0128	0.04-4.96	300.-13800	2900-21000	0.-1000	-50.→35.	500-9000
Katto's correlation	219	0.001-0.0924	0.04-4.966	13.-9500	103.-18000	-1200.→* 1600	-13.→100	379-1500
Non-dimensional table	236	0.001-0.0924	0.04-4.966	57.2-14,500	758.-17,000	-1280.→* 2400	-15.→100	128.-14500

* Negative inlet subcooling means that two phase flow exist at the tube inlet.

2. The ranges of quality, mass flux, and pressure and the number of intervals within each range were provided.
3. The first point in the new CHF data bank was assigned to the corresponding intervals of quality, mass flux and pressure.
4. To avoid selecting most of the points from one set of experimental results, a random number of points were skipped. The random number was equal to the integer absolute value of the quality times 100.
5. Only one point belonging to one set of intervals of quality, mass flux and pressure was selected.
6. If the end of the file containing the new CHF data bank was encountered, the file was rewound.

The listing of the computer programs used in the selection procedure is presented in Appendix B. Three runs were made to select water CHF data for Weisman & Pei's model, Katto's correlation and the non-dimensional table. The summary of the water CHF data selected is listed in table 3.3 and the actual experimental water CHF data is presented in appendix C.

4. RESULTS

4.1 General

The CHF prediction methods which appear to be the most promising for non-aqueous fluids, are Weisman & Pei's model and Katto's correlation. A new method, which uses a scaling technique in conjunction with a reliable method for predicting CHF in a single fluid (e.g. water) is developed. The CHF prediction methods were tested with different fluids such as carbon dioxide, nitrogen, freons and water. The results were plotted versus the various parameters that were known to influence CHF (such as dryout quality, length to diameter ratio etc.).

4.2 Weisman & Pei's model

4.2.1 General

Weisman & Pei's model was tested with nitrogen, Freon-11, Freon-12, Freon-113 and water. A summary of the experimental CHF data for non-aqueous fluids and water is presented in Chapter 3. The results are presented in graphical form in Appendix G. A summary of average and rms errors for all the fluids tested is listed in Table 4.1.

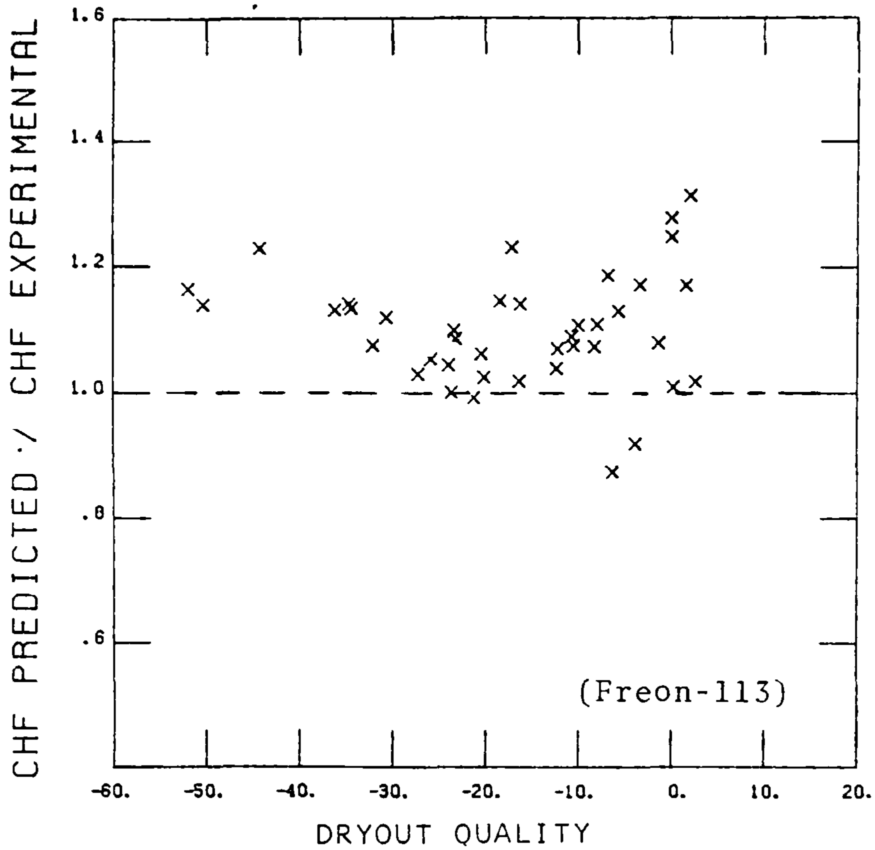
4.2.2 Parametric and Asymptotic Trends

One can observe the following parametric and asymptotic trends from Weisman & Pei's model predictions.

- An increase in error with increasing dryout quality. This is illustrated in Fig. 4.1 for Freon-113 and water.
- A decrease in error with increasing mass flux. This is illustrated in Fig. 4.2 for water.
- A decrease in error with increasing pressure. This is illustrated in Fig. 4.3 for Freon-113 and water.

Table 4.1. Summary of Average and RMS Errors for Weisman & Pei's Model

Fluid	No. of Data	Rms Error %	Average Error %
Freon-12	20	12.26	11.11
Freon-11	20	25.28	25.90
Nitrogen	49	34.34	32.78
Freon-113	40	13.47	10.12
Water	68	16.34	-7.09



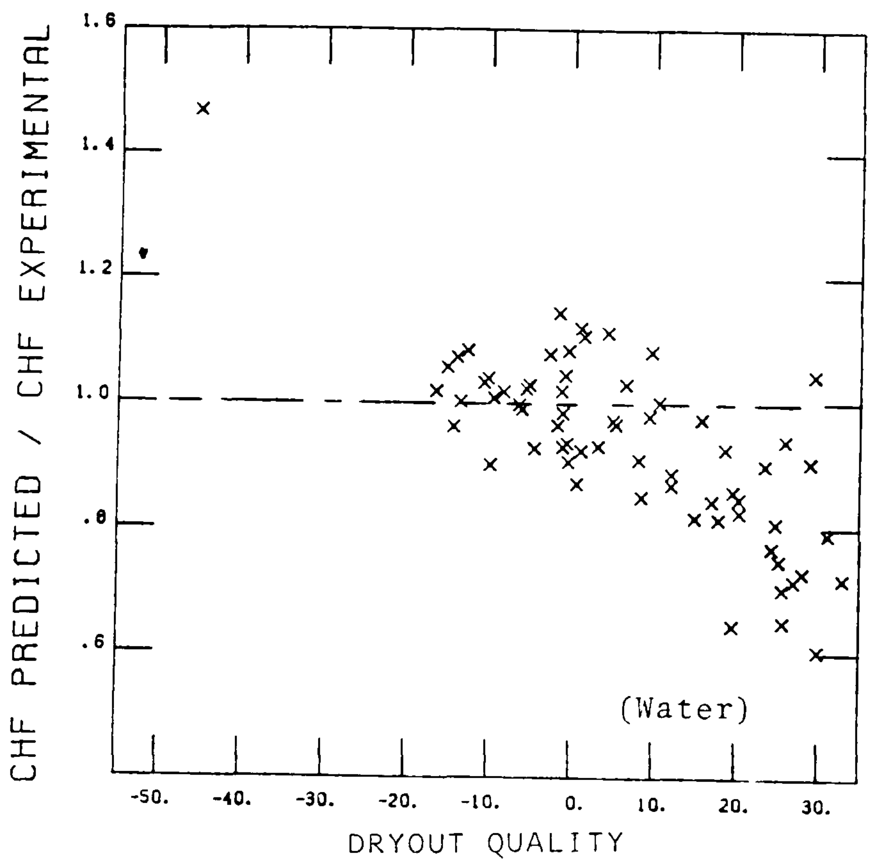


FIGURE 4.1 WEISMAN & PEI'S MODEL CHF PREDICTIONS VERSUS DRYOUT QUALITY

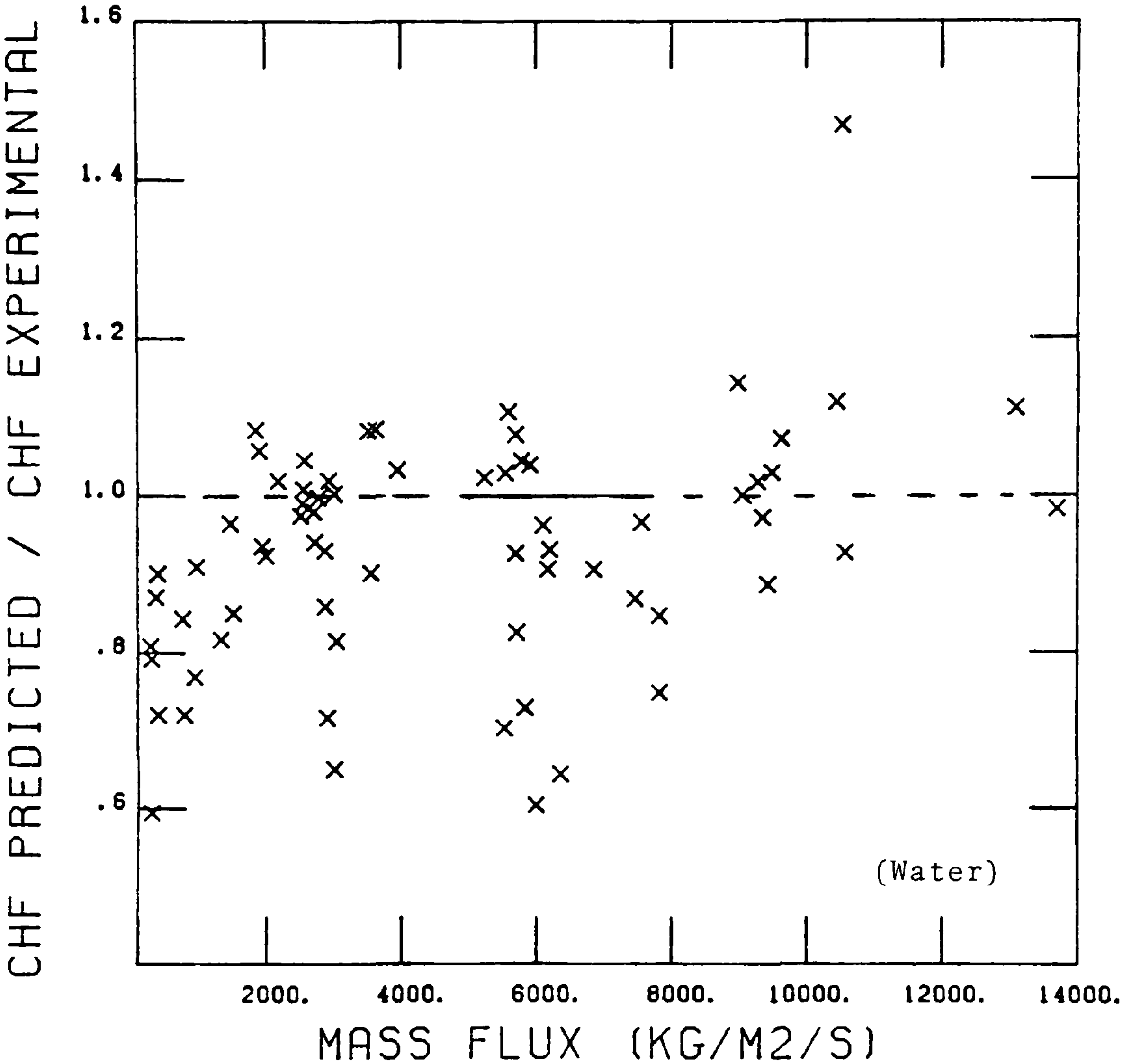
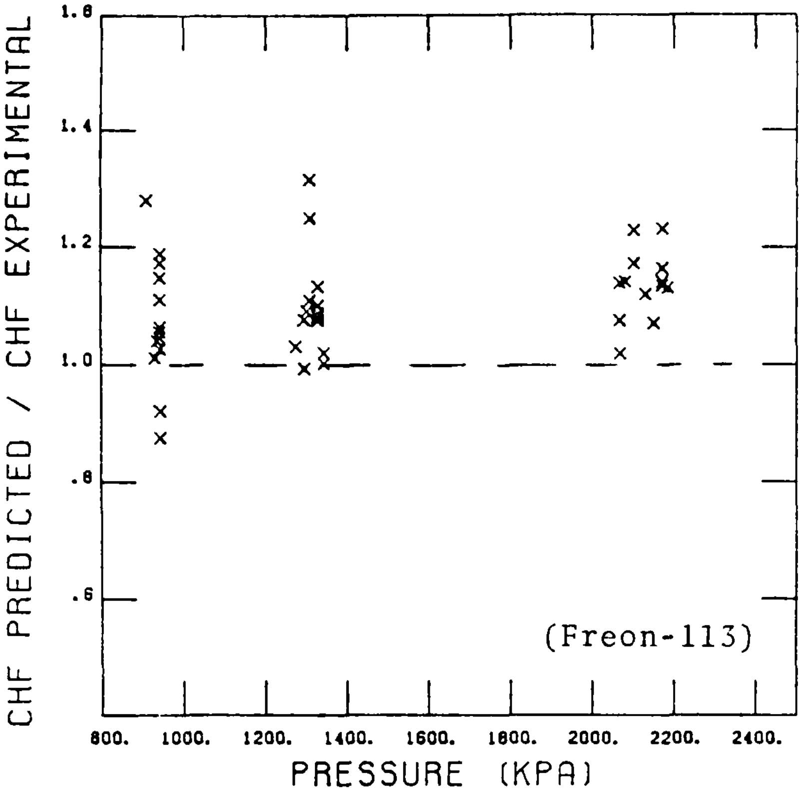


FIGURE 4.2 WEISMAN & PEI'S MODEL CHF PREDICTIONS VERSUS MASS FLUX



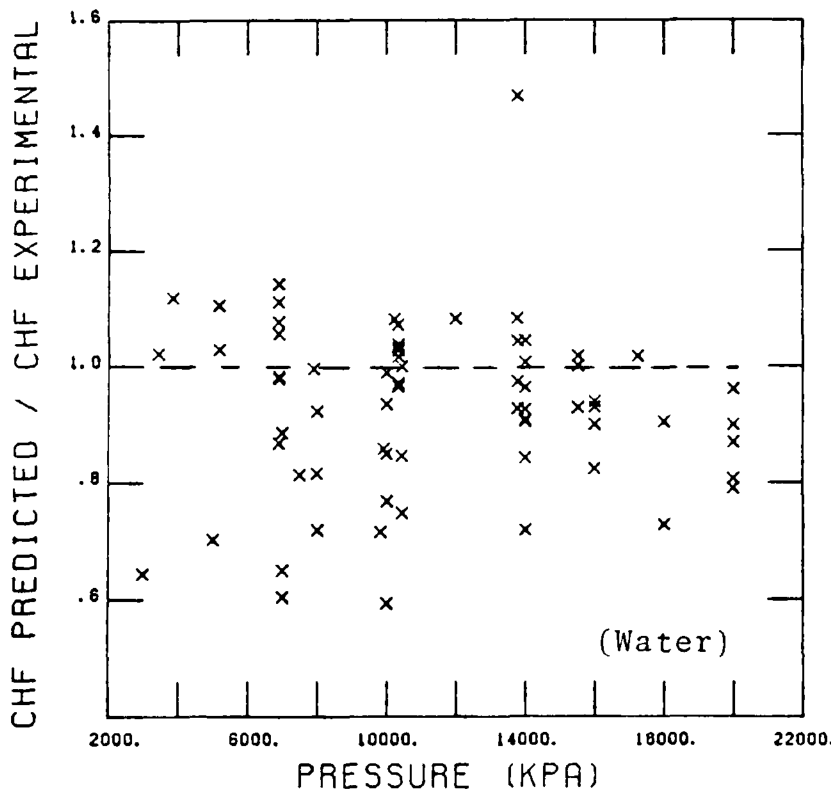


FIGURE 4.3 WEISMAN & PEI'S MODEL CHF PREDICTION VERSUS PRESSURE

- A decrease in error with increasing CHF. This is illustrated in Fig. 4.4 for Freon-113, Freon-12 and water.

4.2.3 Discussion

Weisman & Pei's model is applicable in the bubbly flow regime, which corresponds roughly to void fractions less than 60% and qualities less than 20%. This is illustrated in Fig. 4.1 for the water case. At higher values of dryout quality and void fraction, the annular flow regime exists. In this region, the CHF is caused by liquid film depletion rather than near-wall bubble crowding and vapor blanketing. The model performed adequately at highly subcooled conditions: as low as -55% dryout quality. This is illustrated in Fig. 4.1 for Freon-113. This suggests that the model is also applicable to situations where CHF occurs before bubbles can detach from the wall. Weisman & Pei's model is applicable only at high mass fluxes; higher than 1000 $kg/m^2/s$ for water. This is illustrated in Fig. 4.2. At low mass fluxes, vapor bubbles coalesce into slugs. This results in two effects: (i) Due to buoyancy forces, the slugs travel upward towards the top of the tube. This causes slip between liquid and vapor phases. The homogeneous model used to predict the vapor void fraction from quality cannot be used in this case and (ii) the presence of slugs makes the assumption of bubbly flow near the wall invalid. Weisman & Pei's model is applicable at high pressures only; above 2 MPa for water. This is illustrated in Fig. 4.3. At low pressures, there is considerably more slip between liquid and vapor phases. Therefore, the homogeneous model used to predict vapor void fraction from quality cannot be used. Also, for pressures lower than 2 MPa for water, the model has convergence problems. As the pressure approaches the critical pressure, the model gave better predictions. This is illustrated in Fig. 4.3.

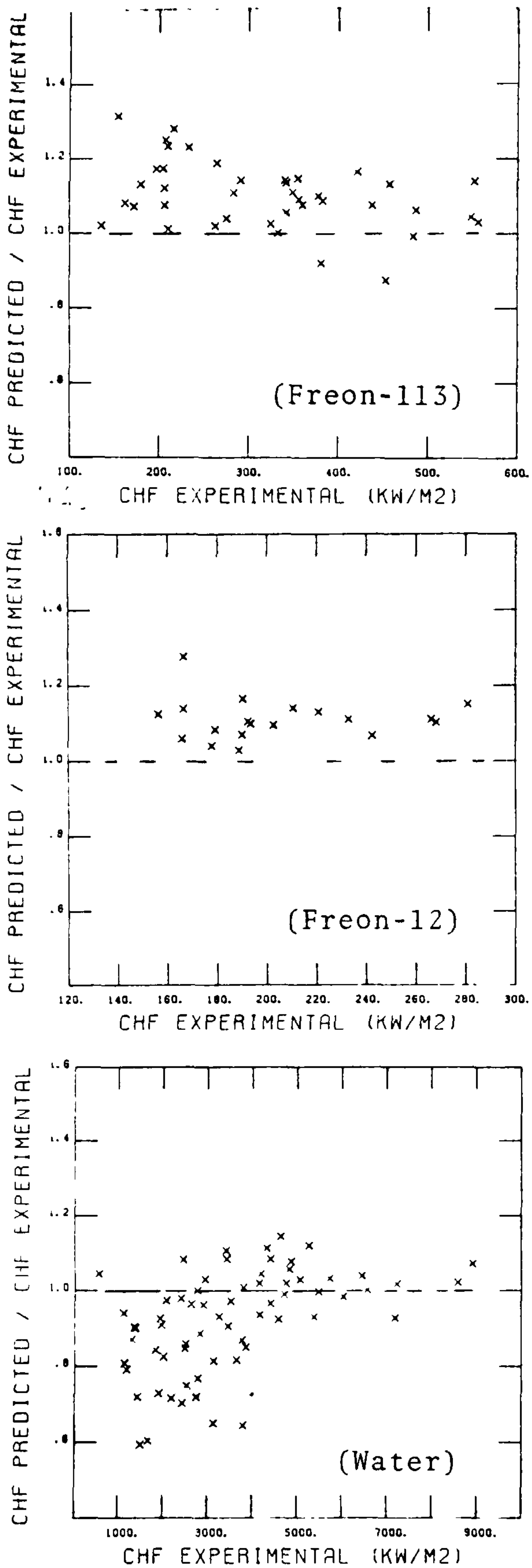


FIGURE 4.4 WEISMAN & PEI'S MODEL CHF PREDICTIONS VERSUS EXPERIMENTAL CHF

In summary, the model performed adequately in predicting CHF in non-aqueous fluids without changing the empirical constants. The main limitations of the model are the ones suggested by Weisman & Pei. That is, the model is applicable at dryout qualities less than 20%. This is the region where CHF is caused by near-wall bubble crowding and vapor blanketing. Also, the model is limited to high mass fluxes and pressures; higher than 1000 $kg/m^2/s$ and 2 MPa, respectively, for water. That is, the model is limited to bubbly flow pattern in which negligible slip between liquid and vapor phase exists.

4.3 Katto's Correlation

4.3.1 General

Katto's correlation was tested with Freon-114, Freon-21, Freon-12, carbon dioxide and water. A summary of the experimental CHF data for non-aqueous fluids and water is presented in tables 3.1 and 3.3. The results are listed in appendix H. A summary of average and rms errors for all tested fluids is presented in table 4.2.

4.3.2 Parametric and Assymptotic Trends

One can observe the following parametric and asymptotic trends from Katto's correlation predictions.

- A decrease in error with increasing dryout quality. This is shown in Fig. 4.5 for carbon dioxide, Freon-21, Freon-114 and water.
- A decrease in error with increasing length to diameter ratio. This is shown in Fig. 4.6 for Freon-21, Freon-114, Freon-12 and water.
- A decrease in error with increasing mass flux. This is shown in Fig. 4.7, for water.

Table 4.2. Summary of Average and RMS Errors for Katto's Correlation

Fluid	No. of Data	Rms Error %	Average Error %
Carbon Dioxide	172	14.65	2.17
Freon-12	268	7.43	2.1
Freon-114	441	13.29	09.06
Freon-21	504	10.86	-1.1
Water	219	37.30	5.16

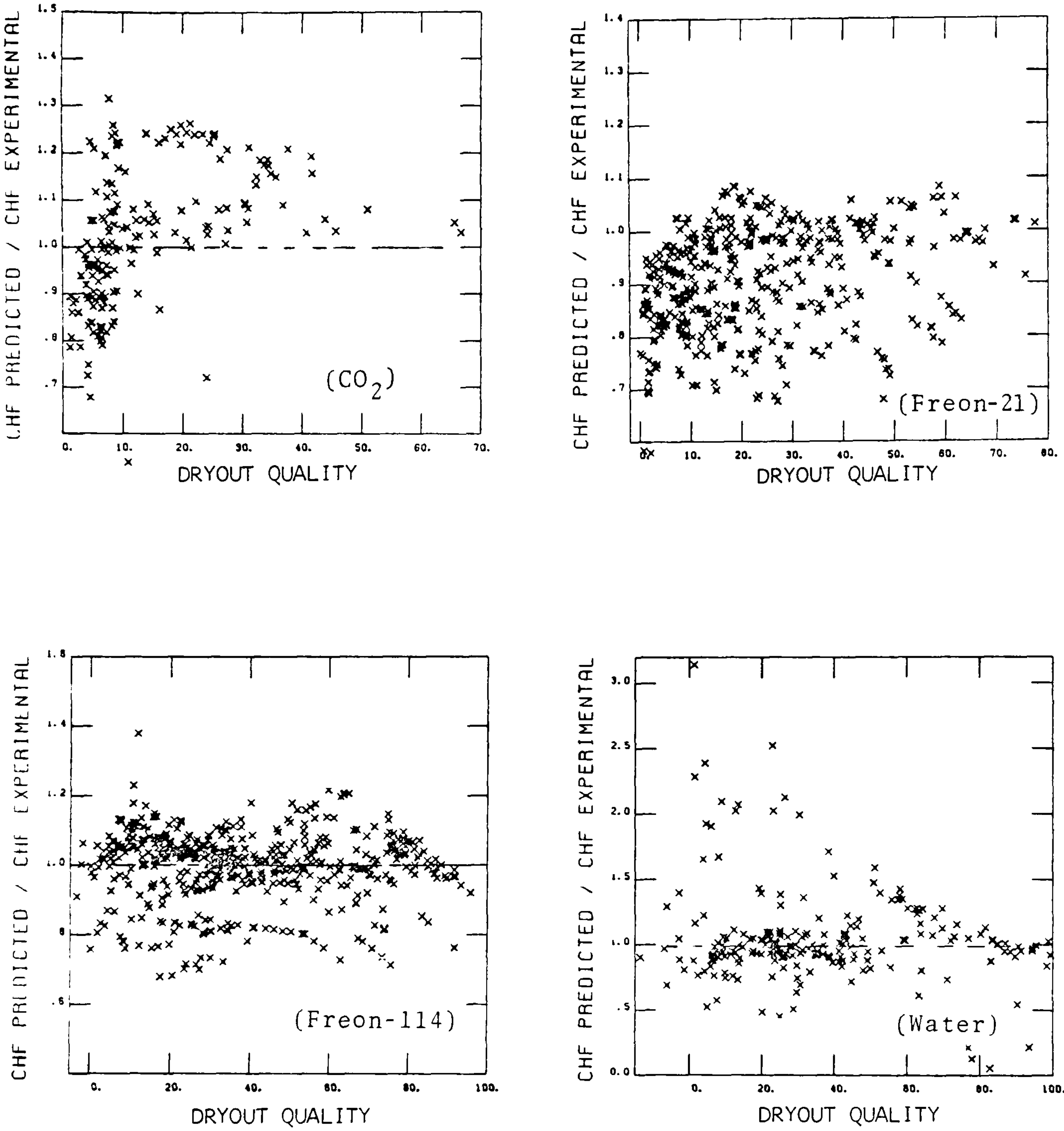


FIGURE 4.5 KATTO'S CORRELATION CHF PREDICTIONS VERSUS DRYOUT QUALITY

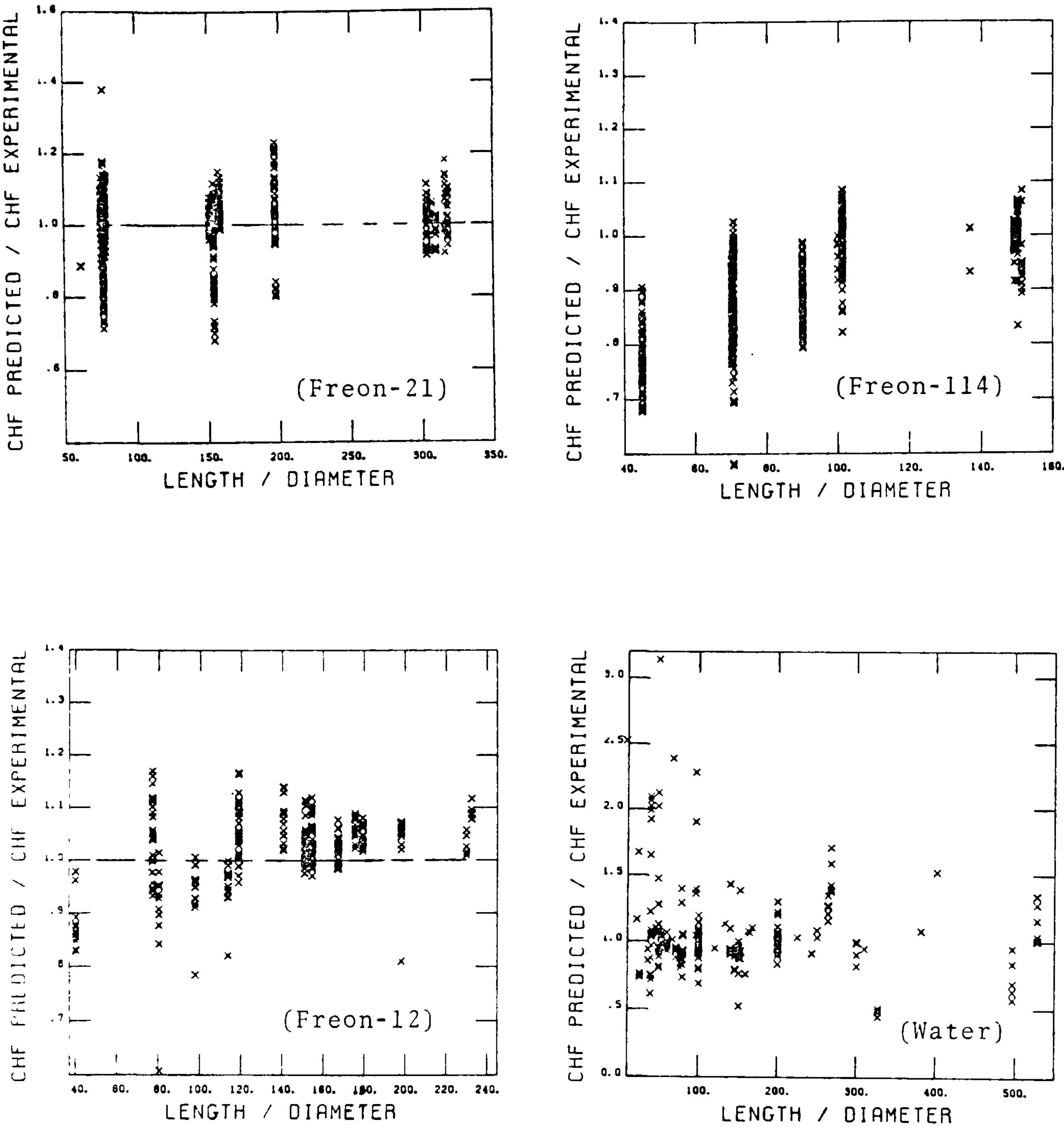


FIGURE 4.6 KATTO'S CORRELATION CHF PREDICTIONS VERSUS L/D

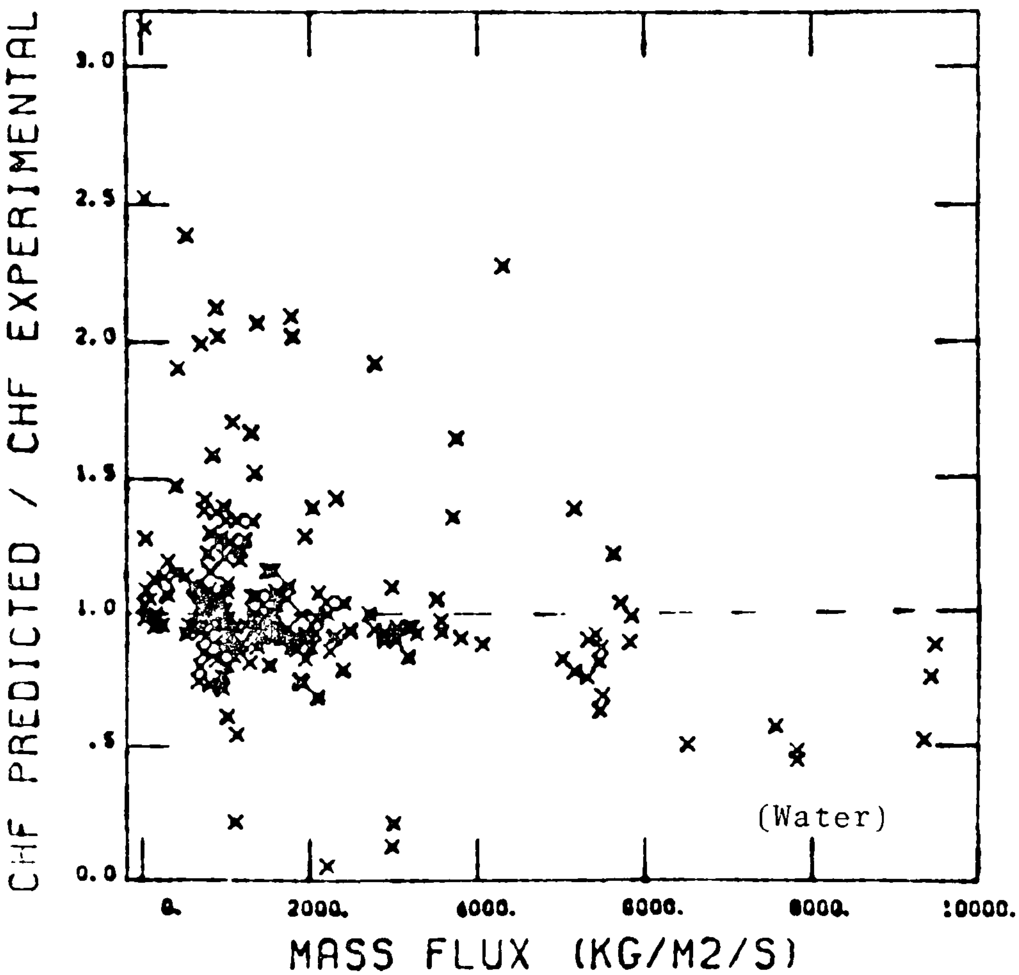


FIGURE 4.7 KATTO'S CORRELATION CHF PREDICTIONS VERSUS MASS FLUX

- A decrease in error with increasing boiling number (CHF/λ/G). This is shown in Figs. 4.8. The figures are for carbon dioxide, Freon-21, Freon-12 and water.
- A decrease in error with increasing inlet subcooling ratio. This is illustrated in Fig. 4.9 for water.

4.3.3 Discussion

Katto's correlation is limited to the positive dryout quality range. This is illustrated in Fig. 4.5. The correlation performed best at dryout qualities higher than 40%. The largest errors were encountered in the lowest quality range (0-30%). Fig. 4.6 shows that the correlation performed best at high length to diameter ratio ($L/D \geq 150$). It performed relatively poorly at low length to diameter ratio ($L/D < 100$). Fig. 4.7 shows that the correlation performed best at high mass fluxes ($G > 2000$ kg/m^2/s for water). Finally, the correlation performed best at large values of inlet subcoolings ($\Delta H_{in}/\lambda > 0.4$ for water). The worst performance of the correlation was encountered with two-phase flow at the tube inlet. This is illustrated in Fig. 4.9.

In summary, the correlation performed adequately in predicting CHF in non-aqueous fluids. The correlation is recommended for use in the high dryout quality range (above 20%), large values of length to diameter ratio (in excess of 50). The correlation is not recommended at low mass fluxes; lower than 2 000 kg/m^2/s for water. Finally, the correlation is definitely not recommended for situations when two-phase flow is encountered at the tube inlet.

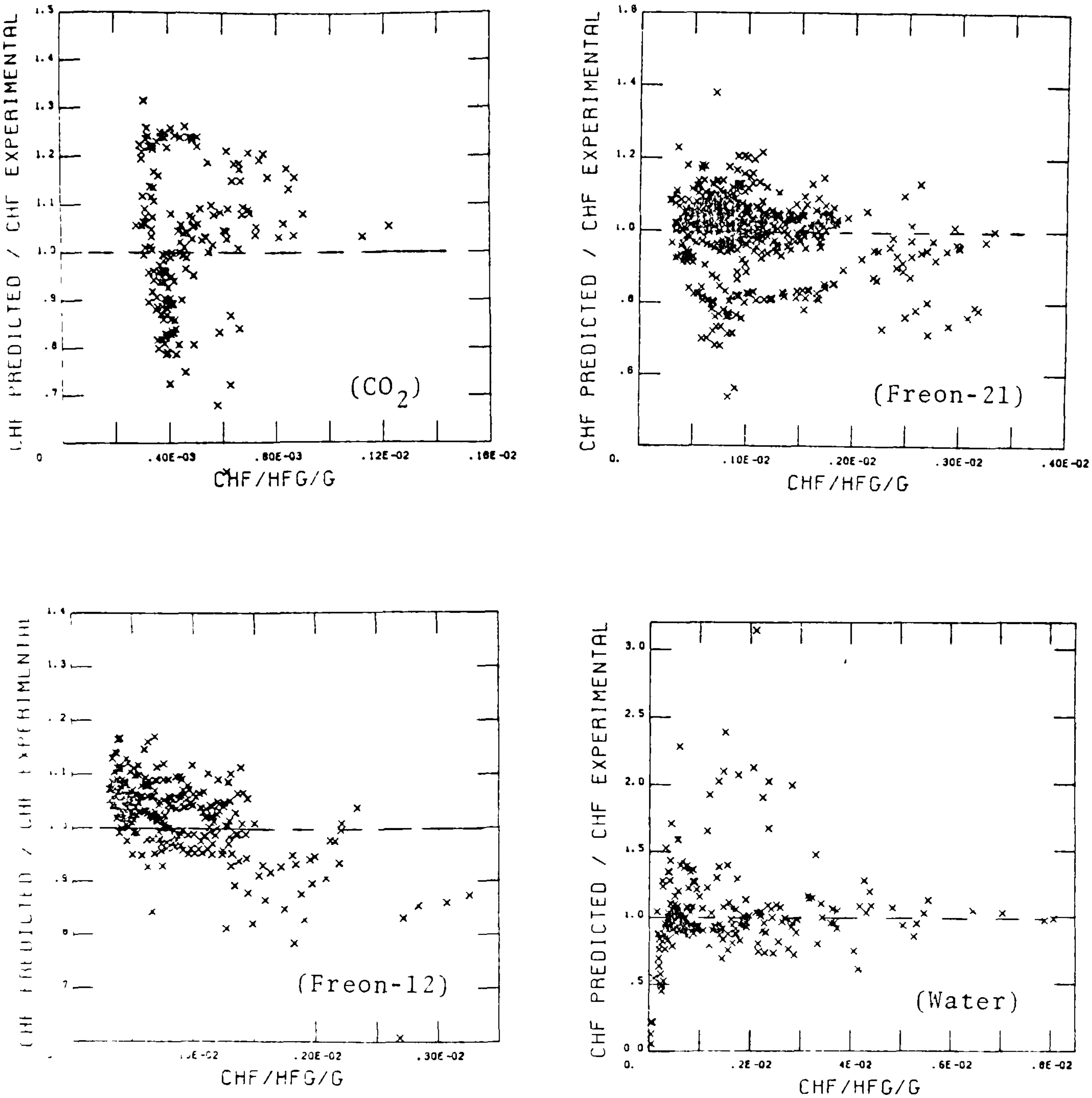


FIGURE 4.8 KATTO'S CORRELATION CHF PREDICTIONS VERSUS BOILING NUMBER

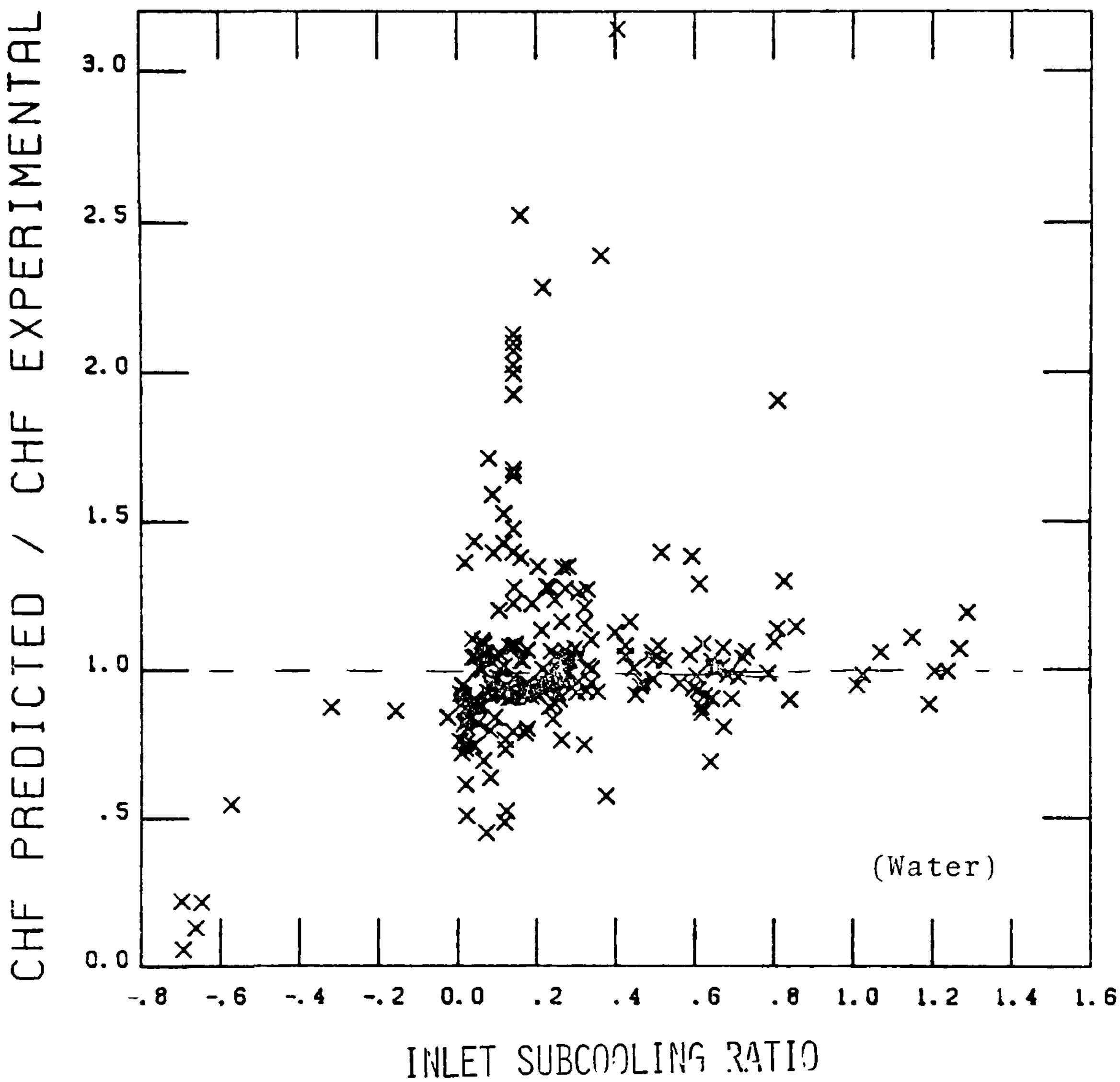


FIGURE 4.9 KATTO'S CORRELATION CHF PREDICTIONS VERSUS INLET SUBCOOLING RATIO

4.4 Non-Dimenional CHF Table

4.4.1 General

A summary of the dimensionless groups used for CHF modeling was presented in table 2.8. Some of the modelling techniques require different empirical constants for each fluid type. Others use P/P_c which requires the knowledge of an additional fluid property (P_c). Barnett's scaling method put on additional restraint on the diameter. Only Ahmad's and Katto's modeling techniques are applicable for multiple fluids without any restrictions. Both techniques can be used in conjunction with a reliable method for predicting CHF in a single fluid (e.g. water). The resulting method can be used to predict CHF in any fluid. Groeneveld's standard table for predicting CHF in water is considered to be the most reliable. The dimensional table is presented in table 2.4. It covers a wider range than any other CHF prediction method for water. The dimensional table is converted into dimensionless form by replacing P by ρ_f/ρ_g, CHF by CHF/(λG) and G by $\Psi_K = \frac{GD^{0.5}}{\sigma^{0.5}\rho_f^{0.5}}$ * for Katto's technique, by $\Psi_\sigma = \left(\frac{G^2 D}{\rho_f \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-.133} \times \left(\frac{\mu_f}{\mu_g}\right)^{-.2}$ for Ahmad's first scaling method and by $\Psi_\gamma = \left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2}\ \mu_f}{D\ \rho^{1/2}}\right)^{2/3} \times \left(\frac{\mu_f}{\mu_g}\right)^{1/8}$ for Ahmad's second scaling method.

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* Since identical geometries were used (identical L and D), the results of using $\Psi_K = \frac{GD^{0.5}}{\sigma^{0.5}\rho_f^{0.5}}$ or $\frac{\sigma\ \rho_f}{G^2 L}$ are the same.

Since the dimensional table was presented for an inside tube diameter of 0.008 m and since the most accurate way to scale CHF was found to be for identical geometries (L and D identical). The same D = 0.008 m was used in calculating the dimensional mass fluxes ϕ_K, ϕ_γ and ϕ_σ. The non-dimensional table is presented in table 4.3. Its application is described in appendix J.

The non-dimensional table was tested with carbon dioxide, Freon-21, Freon-114, Freon-12, Freon-11, nitrogen, Freon-113 and water. Three different tests were conducted for each fluid using Ψ_K, Ψ_σ and Ψ_γ. The results for Ψ_K and Ψ_γ are listed in appendix F. A summary of average and rms errors for all tested fluids is presented in tables 4.4 and 4.5 for constant exit conditions and inlet conditions, respectively. Fig. 4.10 illustrates the errors based on constant exit and inlet conditions.

4.4.2 Parametric and Asymptotic Trends

One can observe the following parametric and asymptotic trends from the non-dimensional table using Ψ_K.

- A decrease in error with increasing dryout quality. This is illustrated in Fig. 4.11 for carbon dioxide, Freon-21, Freon-114 and water.
- A decrease in error with increasing inlet subcooling ratio. This is illustrated in Fig. 4.12 for carbon dioxide, Freon-21, Freon-114 and water.
- A decrease in error with increasing Ψ_K. This is illustrated in Fig. 4.13 for carbon dioxide, Freon-21, Freon-12 and water.

Table 4.3 Non-Dimensional CHF Table

$$\frac{Q}{\lambda G} \times 10^6$$

Quality

ρ_f/ρ_g	ψ_γ	ψ_k	-.15	-.10	-.05	0.0	.05	.10	.15	.20	.25	.30	.40	.50	.60	.70	.80	.90	1.0
1123.3	5.72	.13	15438.	31889.	22241.	15361.	14179.	13709.	11975.	10632.	10189.	9814.	7734.	6698.	6298.	4483.	3823.	3181.	0.
1123.3	11.43	1.19	21283.	18839.	13712.	9766.	9303.	8860.	6423.	4430.	3765.	3532.	3322.	3220.	3101.	2955.	2184.	1462.	0.
1123.3	22.97	2.28	12683.	10851.	6417.	5759.	5648.	5537.	3322.	3101.	2990.	2679.	2658.	2569.	2454.	1511.	1178.	981.	0.
1123.3	34.32	3.17	9650.	8289.	6645.	4423.	4419.	4430.	3249.	3101.	2953.	2921.	2606.	2619.	2131.	1221.	915.	664.	0.
1123.3	47.19	5.85	6379.	5582.	4647.	3189.	3149.	3101.	3957.	2968.	2924.	2202.	2086.	2054.	1168.	587.	861.	390.	0.
1123.3	65.75	8.03	4729.	4136.	1648.	3243.	2953.	2776.	2700.	2425.	1842.	1764.	1735.	1416.	773.	535.	613.	238.	0.
1123.3	114.13	11.51	3898.	1967.	1878.	2125.	2038.	1949.	1861.	1573.	1566.	1508.	1478.	1123.	671.	447.	266.	133.	0.
1123.3	171.49	17.28	2035.	2422.	2067.	1624.	1418.	1240.	1158.	1329.	1329.	1181.	1129.	965.	650.	325.	177.	69.	0.
1123.3	228.66	23.61	2215.	1969.	1709.	1307.	1196.	1174.	1165.	1130.	1119.	1137.	1085.	1372.	642.	244.	133.	86.	0.
1123.3	342.99	35.12	1558.	1380.	1243.	1375.	980.	866.	945.	797.	781.	768.	741.	517.	399.	162.	89.	44.	0.
1123.3	457.31	47.03	1211.	1187.	997.	753.	740.	720.	578.	587.	554.	509.	443.	332.	221.	111.	55.	33.	0.
1123.3	571.64	55.03	1019.	939.	842.	743.	704.	673.	456.	461.	390.	337.	266.	221.	133.	80.	44.	27.	0.
1123.3	857.47	89.28	739.	650.	541.	561.	543.	532.	443.	295.	236.	177.	138.	118.	71.	67.	24.	18.	0.
1100.7	4.49	.41	38841.	32349.	26261.	17373.	16174.	15376.	13479.	12586.	12493.	11367.	8842.	7126.	5391.	4682.	3621.	2695.	0.
1100.7	8.93	1.12	21568.	18870.	14377.	13763.	9886.	8986.	4536.	4467.	6290.	4416.	4241.	4133.	4844.	3999.	3055.	2022.	0.
1100.7	17.39	2.44	12131.	10703.	9516.	6365.	5087.	5618.	4718.	3594.	3370.	3145.	2977.	2329.	2696.	2471.	2246.	1123.	0.
1100.7	26.39	3.66	8988.	8087.	6593.	4493.	4493.	4493.	4044.	3594.	3295.	2546.	2471.	2396.	2246.	2037.	1198.	749.	0.
1100.7	44.54	6.13	5931.	8191.	4493.	3325.	3235.	3145.	2756.	2628.	2001.	1617.	1499.	1348.	1168.	588.	602.	404.	0.
1100.7	67.41	9.15	6313.	3956.	3359.	2576.	2486.	2396.	2397.	1318.	1198.	1138.	1078.	1018.	899.	701.	389.	240.	0.
1100.7	85.80	12.22	3534.	3235.	2746.	2246.	2112.	1577.	1562.	1528.	1393.	1333.	1213.	1033.	988.	494.	273.	157.	0.
1100.7	134.92	18.28	2516.	2276.	2037.	1647.	1558.	1438.	1138.	1378.	1318.	929.	899.	839.	749.	329.	165.	90.	0.
1100.7	179.76	24.19	2822.	1862.	1348.	1236.	1121.	1017.	929.	899.	876.	831.	786.	764.	674.	225.	124.	67.	0.
1100.7	269.64	36.40	1438.	935.	869.	833.	809.	779.	689.	614.	569.	494.	487.	479.	374.	150.	75.	45.	0.
1100.7	359.51	48.19	1123.	745.	674.	648.	586.	562.	528.	472.	404.	315.	315.	232.	225.	112.	51.	34.	0.
1100.7	449.39	61.40	944.	890.	818.	532.	652.	584.	512.	359.	279.	234.	237.	180.	135.	81.	48.	27.	0.
1100.7	674.39	91.51	659.	623.	591.	333.	519.	479.	189.	336.	180.	132.	108.	96.	60.	36.	24.	18.	0.
934.7	3.79	.12	45323.	36965.	28111.	21317.	16381.	14911.	14193.	13475.	12766.	12048.	11303.	9466.	6360.	5452.	5388.	4252.	0.
934.7	7.58	1.16	22716.	18627.	14518.	11512.	12448.	9561.	9086.	8632.	5906.	5452.	4929.	4089.	3612.	3180.	2953.	1431.	0.
934.7	15.15	2.49	11012.	9769.	7721.	6362.	5679.	5229.	4886.	3180.	3067.	3310.	2953.	2437.	2726.	2594.	1817.	716.	0.
934.7	22.73	3.73	8178.	6739.	8130.	6543.	4089.	3635.	3332.	3256.	3180.	3029.	2741.	2213.	1514.	1060.	909.	530.	0.
934.7	37.39	6.22	5088.	4225.	3342.	2562.	2635.	2272.	2044.	1938.	1817.	1636.	1498.	1363.	999.	727.	489.	273.	0.
934.7	56.42	9.33	3513.	2938.	2362.	1393.	1817.	1605.	1426.	1263.	1251.	1136.	1070.	569.	606.	363.	273.	182.	0.
934.7	75.76	12.16	2726.	2272.	1817.	1545.	1363.	1181.	1168.	972.	898.	818.	772.	727.	454.	273.	234.	136.	0.
934.7	113.63	18.66	1878.	1393.	1151.	333.	909.	787.	712.	892.	642.	549.	515.	456.	363.	182.	136.	91.	0.
934.7	151.51	24.88	1654.	1022.	909.	795.	681.	591.	534.	486.	466.	409.	386.	318.	227.	136.	102.	68.	0.
934.7	227.27	37.32	1060.	879.	649.	591.	454.	394.	356.	326.	310.	273.	257.	212.	151.	91.	68.	45.	0.
934.7	303.03	49.78	965.	729.	545.	511.	341.	295.	267.	244.	233.	204.	193.	159.	114.	68.	51.	34.	0.
934.7	378.79	62.20	633.	556.	479.	443.	271.	236.	216.	155.	186.	164.	154.	127.	91.	55.	41.	27.	0.
934.7	568.19	93.31	423.	392.	318.	308.	182.	157.	142.	130.	124.	109.	103.	85.	61.	36.	27.	18.	0.
564.1	2.38	.64	46820.	39490.	39448.	27511.	22943.	21519.	29728.	20848.	16826.	17200.	14343.	9867.	5891.	5474.	5877.	4624.	0.
564.1	5.95	1.28	24843.	20897.	18193.	15732.	16798.	13871.	13499.	12946.	12022.	11597.	5604.	4161.	3958.	3815.	3699.	3237.	0.
564.1	11.92	2.57	12946.	10865.	8123.	3392.	7398.	6704.	6473.	4069.	3969.	3008.	2795.	2774.	2705.	2436.	1963.	1387.	0.
564.1	17.86	3.89	7077.	5123.	5086.	5309.	4932.	4315.	4161.	4007.	3853.	3699.	3223.	2691.	1671.	788.	442.	385.	0.
564.1	23.76	5.12	4255.	1116.	3052.	3305.	2959.	2497.	2404.	2381.	2358.	2312.	1830.	1278.	874.	378.	231.	185.	0.
564.1	44.66	6.13	3699.	3082.	2404.	2343.	1973.	1603.	1541.	1481.	1441.	1295.	1040.	843.	861.	238.	173.	123.	0.
564.1	59.52	12.83	2867.	2404.	1849.	1543.	1480.	1202.	1156.	1113.	1031.	971.	832.	696.	555.	324.	185.	92.	0.
564.1	69.29	13.29	1973.	1289.	1244.	1233.	986.	801.	771.	757.	703.	647.	555.	462.	378.	216.	123.	62.	0.
564.1	119.75	25.67	1526.	994.	971.	944.	740.	601.	578.	530.	509.	465.	416.	347.	277.	162.	92.	46.	0.
564.1	178.57	38.50	1199.	477.	740.	725.	493.	401.	385.	354.	339.	324.	277.	231.	185.	168.	62.	31.	0.
564.1	238.09	51.33	976.	729.	622.	309.	370.	301.	289.	255.	254.	243.	208.	173.	139.	81.	46.	23.	0.
564.1	297.62	64.17	501.	469.	367.	325.	296.	240.	231.	212.	203.	194.	166.	139.	111.	65.	37.	18.	0.
564.1	446.42	96.25	359.	320.	261.	224.	197.	163.	156.	142.	136.	129.	111.	92.	74.	43.	26.	12.	0.
380.1	2.34	.17	47817.	43664.	21949.	31234.	25715.	19063.	19205.	13858.	18403.	17648.	17553.	15336.	8656.	5976.	6351.	4719.	0.
380.1	4.68	1.33	24537.	19348.	18043.	13526.	13212.	12740.	12288.	12032.	10381.	9437.	7070.	5823.	5743.	5143.	4478.	2760.	0.
380.1	9.35	2.66	13212.	9791.	8022.	7378.	6605.	6134.	6016.	5698.	5190.	4011.	3893.	3775.	3539.	2933.	1984.	1350.	0.
380.1	14.53	3.99	6620.	4555.	4633.	4443.	4404.	4089.	3932.	3854.	3775.	3736.	3709.	2898.	2618.	1170.	733.	651.	0.
380.1	23.39	6.65	3951.	2774.	2737.	2593.	2642.	2454.	2265.	2265.	2265.	2265.	2076.	1640.	1176.	411.	260.	240.	0.
380.1	35.37	9.98	3775.	2709.	2139.	1353.	1762.	1636.	1447.	1353.	1258.	1752.	905.	646.	551.	249.	189.	161.	0.
380.1	46.76	13.31	2926.	2176.	1896.	1510.	1321.	1227.	991.	932.	859.	708.	613.	472.	266.	236.	142.	94.	0.
380.1	70.16	19.56	2013.	1334.	961.	1307.	881.	818.	629.	634.	582.	472.	393.	212.	142.	157.	94.	63.	0.
380.1	93.52	26.62	1557.	831.	892.	773.	561.	613.	495.	425.	354.	337.	283.	236.	165.	118.	71.	67.	0.
380.1	140.27	39.92	1458.	945.	652.	586.	440.	409.	346.	283.	236.	204.	169.	157.	110.	79.	47.	31.	0.
380.1	187.03	52.23	1132.	733.	598.	481.	330.	307.	260.	212.	177.	153.	142.	118.	63.	59.	35.	24.	0.
380.1	233.79	66.54	625.	566.	517.	331.	264.	245.	208.	179.	142.	123.	113.	94.	66.	47.	28.	19.	0.
380.1	350.69	99.81	433.	395.	359.	226.	176.	164.	138.	126.	101.	82.	75.	63.	44.	31.	19.	13.	0.
246.1	1.83	.18	46662.	49232.	24178.	19396.	21429.	19918.	17688.	15442.	13204.	10976.	9407.	7837.	4805.	3517.	4108.	4573.	0.
246.1	3.59	1.29	25188.	20344.	18981.	16532.	13563.	12594.	11141.	7066.	6235.	6781.	5613.	4844.	4079.	3701.	3347.	2771.	0.
246.1	7.19	2.59	13563.	10293.	9719.	7753.	7266.	7024.	5539.	6297.	6055.	4602.	3996.	3846.	3633.	3512.	2294.	1567.	0.
246.1	10.73	4.19	9365.	6943.	5974.	5493.	4844.	4521.	4359.	4198.	4117.	4337.	3974.	3082.	2583.	1841.	1069.	654.	0.
246.1	17.97	6.77	5716.	4263.	3641.	3391.	2974.	2809.	2713.	2616.	2567.	2519.	2422.	2321.	1333.	625.	486.	348.	0.
246.1	26.95	10.46	3875.	2971.	2519.	2325.	1939.	1744.	1679.	1615.	1550.	1485.	1440.	916.	463.	266.	265.	243.	0.
246.1	35.94	13.95	3803.	2451.	1983.	1744.	1453.	1356.	1308.	1303.	1033.	772.	633.	430.	234.	130.	121.	97.	0.
246.1	53.91	20.92	2067.	1612.	1330.	1163.	969.	807.	775.	769.	593.	330.	367.	233.	88.	64.	57.	48.	0.
246.1	71.88	27.91	1590.	1259.	1068.	572.	727.	605.	533.	436.	361.	315.	319.	218.	61.	48.	48.	36.	0.
246.1	107.82	41.85	1078.	872.	743.	581.	484.	404.	355.	291.	242.	210.	194.	145.	40.	32.	32.	24.	0.
246.1	143.76	55.89	848.	678.	551.	435.	363.	333.	286.	218.	182.	157.	145.	109.	30.	24.	24.	18.	0.
246.1	175.69	69.79	638.	582.	475.	343.	291.	242.	213.	184.	145.	126.	116.	87.	24.	19.	19.	15.	0.
246.1	269.54	104.62	478.	388.	323.	233.	194.	161.	142.	129.	103.	84.	78.	58.	16.	13.	13.	10.	0.
172.3	1.40	.73	55833.	50589.	48281.	43782.	34047.	32497.	39937.	30122.	27827.	25522.	23146.	19293.	10986.	8693.	8087.	6232.	0.
172.3	2.91	1.46	29806.	27321.	24837.	22851.	21857.	20863.	19878.	19373.	17881.	16392.	14992.	12418.	6954.	5529.	5218.	2732.	0.
172.3	5.81	2.92	19078.	16628.	17356.	14302.	14405.	13909.	13412.	12667.	11673.	10928.	11668.	10432.	5788.	4215.	2829.	1744.	0.
172.3	8.72	4.38	13246.	12418.	11991.	10763.	10432.	9272.	9941.	8445.	7782.	7256.	7037.	6481.	3646.	2557.	1523.	1131.	0.
172.3	14.53	7.31	7948.	7451.	6956.	6458.	5160.	5563.	5165.	5067.	4769.	4633.	4471.	3702.	2069.	1088.	665.	634.	0.
172.3	21.79	10.95	5299.	4967.	4636.	4395.	4049.	3709.	3577.	3312.	3245.	3169.	2607.	1521.	751.	452.	364.	331.	0.
172.3	29.06	14.62	3974.	3726.	3477.	3223.	2980.	2782.	2433.	2533.	2407.	2183.	1457.	861.	431.	286.	187.	124.	0.
172.3	43.59	21.98	2649.	2484.	2318.	2153.	1986.	1759.	1658.	1590.	1477.	1111.	784.	433.	207.	91.	62.	33.	0.
172.3	58.12	29.23	1987.	1863.	1739.	1614.	1416.	1292.	1192.	1093.	833.	820.	601.	419.	199.	62.	37.	25.	0.
172.3	87.18	43.85	1325.	1242.	1159.	1376.	911.	844.	778.	695.	592.	563.	551.	215.	124.	41.	25.	17.	0.
172.3	116.24	58.39	993.	931.	869.	837.	650.	621.	559.	497.	422.	348.	238.	143.	87.	31.	19.	12.	0.
172.3	145.29	73.09	895.	745.	695.	646.	536.	487.	437.	371.	328.	254.	166.	99.	68.	29.	18.	10.	0.
172.3	217.94	109.69	938.	497.	444.	421.	386.	318.	268.	238.	212.	102.	99.	68.	48.	17.	16.	7.	0.

Table 4.3 Non-Dimensional CHF Table (continued)

Quality

ρ_f/ρ_g	ψ_Y	ψ_K	-.15	-.10	-.05	0.0	.05	.10	.15	.20	.25	.30	.40	.50	.60	.70	.80	.90	1.0
[illegible]	[illegible]	[illegible]	59450.	52447.	50617.	[illegible]	36980.	36127.	34512.	33659.	32034.	29548.	26398.	23930.	[illegible]	10503.	9039.	4381.	0.
[illegible]	[illegible]	[illegible]	31930.	29280.	27766.	25749.	23651.	23138.	22110.	21596.	20560.	13025.	16968.	15426.	7456.	6684.	5815.	2616.	0.
[illegible]	[illegible]	[illegible]	18254.	17739.	16964.	15454.	15940.	15426.	14656.	13333.	12855.	10541.	9255.	7970.	5479.	5361.	3378.	2003.	0.
[illegible]	[illegible]	[illegible]	12633.	12169.	11644.	[illegible]	[illegible]	10284.	9770.	9064.	8913.	7941.	6513.	5646.	[illegible]	3637.	2286.	1445.	0.
[illegible]	[illegible]	7.77	7918.	7404.	6839.	6352.	6273.	5965.	5656.	[illegible]	5142.	4781.	4628.	4419.	3241.	[illegible]	1625.	625.	0.
[illegible]	[illegible]	[illegible]	5485.	4936.	4593.	4319.	4045.	3839.	3702.	3565.	3531.	3496.	3123.	2050.	1213.	745.	467.	304.	0.
[illegible]	[illegible]	[illegible]	4114.	3702.	3445.	3216.	2931.	2879.	2356.	2828.	2802.	2598.	1919.	1069.	575.	408.	231.	168.	0.
[illegible]	[illegible]	[illegible]	2742.	2468.	2297.	2462.	2085.	1817.	1608.	1807.	1703.	1576.	959.	519.	293.	156.	81.	69.	0.
[illegible]	[illegible]	31.19	2057.	1851.	1723.	1594.	1414.	1337.	1260.	1354.	1328.	1022.	644.	365.	257.	206.	103.	51.	0.
[illegible]	68.47	[illegible]	1290.	1152.	1148.	1146.	960.	874.	823.	825.	720.	534.	394.	360.	171.	137.	69.	34.	0.
[illegible]	91.29	[illegible]	983.	879.	861.	784.	720.	643.	536.	485.	488.	398.	244.	231.	129.	103.	51.	26.	0.
[illegible]	114.12	77.70	874.	771.	719.	649.	576.	494.	452.	370.	360.	267.	175.	154.	103.	82.	41.	21.	0.
[illegible]	[illegible]	[illegible]	617.	548.	447.	432.	377.	322.	281.	247.	226.	161.	110.	82.	69.	55.	27.	14.	0.
[illegible]	.45	.92	52175.	57409.	52647.	43367.	[illegible]	39741.	38967.	37178.	35504.	33926.	23668.	20704.	12636.	9967.	9813.	4597.	0.
[illegible]	[illegible]	[illegible]	33365.	30981.	28598.	27533.	25950.	25421.	24161.	23832.	22773.	21184.	19065.	18536.	7944.	6816.	6307.	2945.	0.
[illegible]	[illegible]	[illegible]	18536.	18271.	18006.	17741.	17477.	15682.	15488.	14825.	14034.	12710.	11651.	10592.	5696.	5349.	3472.	2182.	0.
[illegible]	[illegible]	[illegible]	13416.	12975.	12710.	12121.	11651.	11651.	10415.	10062.	9709.	9180.	8738.	7381.	7614.	4653.	2648.	1534.	0.
[illegible]	[illegible]	[illegible]	6635.	6262.	7944.	[illegible]	5991.	6591.	6567.	6317.	5840.	5430.	5031.	4721.	3306.	2354.	1349.	823.	0.
[illegible]	[illegible]	[illegible]	5931.	5669.	5367.	5384.	4943.	4929.	4492.	4378.	4307.	4305.	3622.	2535.	1630.	905.	674.	414.	0.
[illegible]	[illegible]	[illegible]	4607.	4449.	4131.	4111.	3739.	3558.	3337.	3262.	2951.	2956.	2242.	1460.	907.	545.	321.	254.	0.
[illegible]	[illegible]	[illegible]	3137.	2966.	2754.	2572.	2424.	2180.	1994.	1765.	1730.	1719.	1144.	674.	368.	249.	112.	106.	0.
[illegible]	[illegible]	[illegible]	2436.	2351.	2065.	1354.	1721.	1536.	1345.	1231.	1164.	1389.	587.	284.	127.	113.	106.	79.	0.
[illegible]	7.63	[illegible]	1679.	1436.	1377.	1236.	1094.	989.	972.	860.	833.	796.	568.	282.	212.	177.	71.	53.	0.
[illegible]	[illegible]	[illegible]	1230.	1092.	1013.	914.	781.	728.	673.	649.	647.	585.	373.	185.	159.	119.	53.	40.	0.
[illegible]	[illegible]	[illegible]	1059.	909.	741.	533.	614.	583.	551.	487.	477.	445.	254.	148.	127.	95.	64.	53.	0.
[illegible]	[illegible]	[illegible]	727.	690.	588.	431.	388.	367.	346.	318.	305.	198.	120.	106.	92.	78.	56.	42.	0.
[illegible]	.76	[illegible]	67333.	62145.	54940.	54243.	46054.	44571.	43534.	41852.	40077.	37456.	32899.	30342.	25949.	9835.	4360.	3602.	0.
[illegible]	[illegible]	[illegible]	36241.	33451.	30645.	[illegible]	28991.	28435.	27878.	26763.	25647.	23375.	21745.	19514.	16727.	6819.	4633.	4048.	0.
[illegible]	[illegible]	[illegible]	22332.	23904.	19514.	15333.	19514.	15678.	17563.	16727.	15890.	15054.	13381.	11151.	9766.	5729.	3973.	2333.	0.
[illegible]	[illegible]	[illegible]	16727.	15797.	13664.	13353.	14682.	14111.	13567.	12954.	12266.	11634.	11222.	7667.	7806.	4658.	3093.	1643.	0.
[illegible]	[illegible]	[illegible]	13735.	13370.	8845.	3325.	5921.	8564.	7509.	7225.	6994.	6581.	6232.	4532.	4147.	2812.	1973.	1154.	0.
[illegible]	11.33	[illegible]	7285.	6916.	6665.	6352.	5373.	5169.	5163.	4749.	4591.	4559.	4103.	2704.	2100.	1464.	952.	493.	0.
[illegible]	[illegible]	[illegible]	5404.	4460.	4017.	4281.	3909.	3707.	3424.	3557.	3209.	2921.	2327.	1810.	1250.	1016.	599.	561.	0.
[illegible]	[illegible]	[illegible]	3643.	3437.	2671.	2600.	509.	2434.	2215.	1933.	1773.	1667.	1268.	946.	664.	603.	558.	474.	0.
[illegible]	[illegible]	[illegible]	2760.	2593.	2370.	2234.	2091.	1944.	1639.	1429.	1219.	1149.	779.	585.	359.	279.	279.	167.	0.
[illegible]	[illegible]	[illegible]	1839.	1677.	1412.	1361.	1391.	1113.	1394.	924.	826.	566.	361.	392.	211.	195.	186.	112.	0.
[illegible]	[illegible]	71.63	1464.	1254.	1045.	930.	802.	754.	699.	645.	540.	297.	279.	265.	244.	188.	139.	84.	0.
[illegible]	[illegible]	[illegible]	1234.	938.	878.	671.	594.	576.	522.	459.	397.	234.	212.	212.	195.	151.	112.	67.	0.
[illegible]	[illegible]	134.39	833.	640.	515.	429.	341.	306.	281.	268.	255.	164.	160.	149.	134.	112.	89.	52.	0.
[illegible]	[illegible]	[illegible]	57031.	63275.	59745.	56257.	47051.	42657.	41571.	38765.	32366.	25967.	19448.	14709.	9981.	4441.	4035.	3582.	0.
[illegible]	[illegible]	[illegible]	35915.	33429.	31634.	29347.	24653.	26462.	26265.	24474.	20236.	16117.	11939.	8554.	5969.	4776.	4453.	3976.	0.
[illegible]	[illegible]	[illegible]	23673.	21789.	19937.	17309.	17311.	14625.	14028.	13730.	12536.	11143.	9531.	8357.	7462.	4776.	4235.	2847.	0.
[illegible]	[illegible]	[illegible]	16117.	15122.	12914.	12309.	12536.	10745.	10546.	10347.	9152.	[illegible]	3835.	7217.	6924.	4457.	3223.	2087.	0.
[illegible]	[illegible]	[illegible]	9793.	9112.	8484.	[illegible]	7044.	6585.	6311.	5372.	4992.	4539.	4155.	3662.	2985.	2415.	2019.	1317.	0.
[illegible]	[illegible]	[illegible]	[illegible]	6167.	5963.	[illegible]	4452.	4076.	3822.	3582.	3422.	3343.	3122.	2152.	2071.	1631.	1293.	768.	0.
[illegible]	[illegible]	[illegible]	5193.	3989.	3727.	[illegible]	3464.	2865.	2759.	2615.	2597.	2588.	2227.	1810.	1525.	[illegible]	836.	522.	0.
[illegible]	[illegible]	32.65	3542.	2443.	2278.	2209.	2189.	2152.	1329.	1795.	1625.	1581.	1265.	1060.	786.	682.	478.	[illegible]	0.
34.7	2.75	[illegible]	1862.	1935.	1618.	[illegible]	1612.	1552.	1419.	1255.	1166.	1140.	824.	616.	422.	388.	298.	60.	0.
[illegible]	[illegible]	[illegible]	1339.	1229.	1085.	1012.	1006.	959.	916.	826.	745.	628.	401.	263.	127.	78.	60.	[illegible]	0.
[illegible]	[illegible]	91.43	1328.	997.	930.	783.	724.	672.	634.	574.	485.	365.	254.	239.	244.	59.	46.	30.	0.
[illegible]	[illegible]	[illegible]	1038.	976.	770.	587.	541.	510.	480.	438.	355.	270.	203.	191.	179.	155.	131.	107.	0.
[illegible]	[illegible]	[illegible]	748.	665.	561.	392.	348.	312.	288.	287.	256.	220.	207.	175.	143.	119.	103.	80.	0.
[illegible]	[illegible]	[illegible]	72856.	68233.	63624.	59015.	57209.	44896.	41734.	39383.	34243.	26114.	19831.	15528.	12223.	6973.	3825.	2657.	0.
[illegible]	[illegible]	[illegible]	38520.	35863.	33217.	33553.	29222.	27230.	25901.	24573.	21252.	15339.	11954.	9296.	7306.	5977.	4436.	4383.	0.
[illegible]	[illegible]	[illegible]	21584.	19924.	18264.	15912.	15939.	15275.	14943.	14611.	13283.	11522.	5962.	7638.	5313.	4815.	4317.	3869.	0.
[illegible]	[illegible]	[illegible]	15497.	13947.	12797.	11339.	11069.	10626.	10405.	9741.	9077.	8855.	7748.	5822.	5625.	4237.	3367.	2736.	0.
[illegible]	[illegible]	[illegible]	9530.	8634.	7704.	7326.	7040.	6507.	5541.	5863.	5702.	4282.	3536.	3238.	2969.	2748.	2108.	1439.	0.
[illegible]	[illegible]	[illegible]	5641.	6199.	5490.	5347.	4959.	4921.	4467.	3460.	3269.	2897.	2514.	2318.	2030.	1715.	1326.	926.	0.
[illegible]	[illegible]	[illegible]	[illegible]	3853.	3736.	3402.	3387.	2933.	2769.	2374.	2258.	2135.	1835.	1698.	1490.	950.	670.	531.	0.
[illegible]	17.74	[illegible]	3498.	2414.	2149.	2235.	2102.	1946.	1733.	1536.	1419.	1335.	1109.	681.	656.	315.	266.	177.	0.
[illegible]	[illegible]	[illegible]	1951.	1956.	1646.	1542.	1444.	1222.	1053.	1052.	956.	683.	569.	336.	211.	104.	58.	38.	0.
[illegible]	27.47	[illegible]	1332.	1297.	1137.	933.	838.	719.	673.	601.	625.	482.	241.	103.	58.	47.	38.	27.	0.
[illegible]	[illegible]	[illegible]	1364.	1063.	956.	764.	620.	438.	446.	405.	345.	277.	177.	106.	42.	39.	29.	18.	0.
[illegible]	[illegible]	[illegible]	1142.	1038.	844.	593.	479.	379.	326.	323.	305.	235.	151.	80.	53.	46.	33.	20.	0.
[illegible]	[illegible]	[illegible]	806.	744.	611.	[illegible]	358.	281.	219.	204.	195.	173.	151.	62.	44.	35.	27.	18.	0.
[illegible]	.37	[illegible]	58033.	64128.	60633.	[illegible]	[illegible]	44656.	38578.	33345.	27846.	[illegible]	18193.	14400.	10611.	6821.	6063.	6018.	0.
[illegible]	[illegible]	[illegible]	34854.	32590.	31833.	31375.	26527.	20699.	20312.	19979.	16713.	13696.	13006.	12574.	12051.	8087.	6653.	5715.	0.
[illegible]	[illegible]	[illegible]	18343.	17432.	16864.	15574.	10842.	10232.	9853.	9618.	9087.	7458.	6821.	6253.	5874.	5069.	4851.	4358.	0.
[illegible]	[illegible]	[illegible]	12835.	10891.	10863.	10503.	9949.	9095.	9032.	8335.	7930.	7071.	6053.	5025.	4290.	3514.	2830.	2132.	0.
[illegible]	7.73	[illegible]	8992.	7714.	6761.	6353.	5609.	5581.	5193.	4491.	4249.	3909.	3424.	2803.	2078.	1557.	1114.	966.	0.
[illegible]	[illegible]	[illegible]	5130.	4866.	4512.	3573.	3537.	3512.	3299.	2941.	2708.	2251.	[illegible]	1458.	1034.	687.	448.	304.	0.
[illegible]	7.45	[illegible]	[illegible]	3135.	3323.	3353.	2787.	2568.	2523.	2387.	2370.	1629.	1179.	882.	609.	455.	417.	303.	0.
[illegible]	[illegible]	[illegible]	2455.	2327.	2246.	1363.	1845.	1714.	1513.	1312.	1069.	848.	531.	343.	315.	253.	202.	152.	0.
[illegible]	[illegible]	[illegible]	2236.	1994.	1813.	1542.	1365.	1122.	846.	720.	673.	510.	298.	148.	137.	134.	87.	63.	0.
[illegible]	22.36	[illegible]	1617.	1382.	1107.	[illegible]	823.	647.	511.	464.	458.	361.	219.	70.	56.	56.	53.	42.	0.
[illegible]	[illegible]	[illegible]	1345.	1160.	985.	593.	580.	481.	346.	303.	296.	224.	146.	133.	95.	76.	34.	30.	0.
[illegible]	17.45	[illegible]	1261.	1085.	839.	513.	472.	392.	298.	285.	258.	234.	191.	121.	76.	61.	27.	24.	0.
[illegible]	[illegible]	[illegible]	893.	794.	612.	[illegible]	372.	298.	229.	222.	212.	182.	157.	101.	51.	40.	17.	16.	0.
[illegible]	[illegible]	[illegible]	63279.	61506.	59713.	57960.	49831.	42537.	39829.	35585.	33134.	30563.	28273.	15840.	13867.	9962.	6965.	8049.	0.
[illegible]	[illegible]	[illegible]	31879.	30883.	29986.	23393.	23909.	21917.	18328.	17532.	16936.	16089.	15073.	13030.	11686.	7691.	5758.	5479.	0.
[illegible]	[illegible]	[illegible]	15939.	15939.	14941.	12453.	8966.	7570.	7472.	7058.	6973.	6724.	6475.	5977.	5604.	4293.	3258.	3238.	0.
[illegible]	[illegible]	[illegible]	10358.	9859.	8664.	3743.	9544.	7638.	7584.	6641.	6236.	5313.	4981.	3596.	2644.	1824.	1229.	1259.	0.
[illegible]	[illegible]	24.97	6575.	6376.	5870.	4782.	4383.	4232.	4164.	3395.	3146.	2357.	2317.	1586.	926.	576.	420.	345.	0.
[illegible]	4.51	17.45	4516.	4516.	3990.	3253.	2854.	2941.	2711.	2072.	1803.	1497.	988.	611.	414.	295.	266.	230.	0.
[illegible]	[illegible]	49.63	3088.	2989.	2967.	2536.	2248.	1886.	1640.	1415.	1294.	1033.	521.	310.	243.	224.	199.	172.	0.
[illegible]	[illegible]	74.60	2173.	2052.	1896.	1554.	1334.	1101.	939.	752.	593.	437.	262.	188.	166.	149.	133.	115.	0.
[illegible]	[illegible]	[illegible]	1982.	1791.	1548.	1206.	1081.	905.	717.	503.	362.	346.	281.	292.	264.	112.	100.	86.	0.
[illegible]	[illegible]	[illegible]	1461.	1277.	1196.	584.	744.	602.	484.	391.	382.	317.	294.	266.	176.	75.	66.	57.	0.
[illegible]	24.75	[illegible]	1270.	1046.	786.	712.	607.	506.	371.	335.	396.	274.	257.	224.	174.	56.	50.	43.	0.
[illegible]	32.96	249.67	1112.	926.	838.	736.	593.	486.	418.	395.	359.	298.	257.	199.	149.	141.	80.	40.	0.
[illegible]	[illegible]	274.11	769.	704.	583.	595.	581.	375.	319.	302.	279.	249.	222.	146.	126.	121.	53.	27.	0.
2.3	.28	5.33	38233.	37212.	36130.	35349.	31162.	27478.	25754.	[illegible]	21698.	20711.	18386.	10410.	8923.	6726.	5746.	4935.	0.
[illegible]	.56	21.49	19239.	18690.	18042.	[illegible]	15665.	13857.	13266.	12049.	11458.	10849.	10241.	5425.	4816.	9514.	6213.	6743.	0.
[illegible]	[illegible]	22.37	3643.	9649.	9041.	8737.	7873.	6929.	6533.	5315.	5408.	5120.	4825.	4732.	4191.	[illegible]	3549.	3414.	0.
[illegible]	1.57	[illegible]	6630.	6478.	6196.	5633.	5070.	4708.	4422.	4016.	3661.	3716.	3014.	2479.	1881.	1465.	1036.	845.	0.
[illegible]	2.78	59.64	3975.	3863.	3424.	3728.	3052.	2771.	2748.	2444.	2204.	1843.	1403.	980.	713.	412.	330.	331.	0.
[illegible]	4.18	93.53	2733.	2733.	2253.	2173.	2044.	2017.	1701.	1433.	1070.	704.	813.	563.	356.	248.	225.	221.	0.
[illegible]	5.57	119.17	2163.	2143.	2114.	1683.	1523.	1479.	1441.	1071.	862.	845.	531.	423.	272.	106.	169.	166.	0.
[illegible]	8.35	179.8.	1460.	1420.	1239.	1287.	1127.	1124.	1091.	768.	665.	635.	464.	383.	213.	124.	113.	110.	0.
[illegible]	[illegible]	239.14	1318.	1190.	1014.	1305.	967.	966.	964.	724.	631.	574.	503.	428.	160.	93.	84.	83.	0.
[illegible]	[illegible]	359.61	1360.	958.	905.	573.	817.	789.	757.	714.	637.	555.	469.	360.	106.	62.	56.	55.	0.
[illegible]	22.77	479.48	1356.	1014.	972.	323.	887.	845.	760.	641.	596.	527.	415.	274.	80.	77.	75.	60.	0.
2.3	27.54	539.75	1843.	957.	937.	856.	882.	734.	737.	[illegible]	571.	475.	318.	237.	91.	86.	84.	72.	0.
2.3	41.76	839.53	736.	669.	653.	531.	621.	563.	543.	486.	439.	351.	229.	169.	76.	73.	72.	56.	0.

Table 4.4. RMS and Average Errors in CHF Based on Constant Exit Conditions Using Non-Dimensional Table and various non-dimensional mass fluxes

Fluid	No. of data	ϕ_γ RMS(%)	ϕ_γ AVG(%)	ϕ_σ RMS(%)	ϕ_σ AVG(%)	ϕ_κ RMS(%)	ϕ_κ AVG(%)
Nitrogen	26	8.1	-3.5	7.6	-0.4	9.5	2.7
Carbon Dioxide	172	39.9	35.4	31.9	23.2	34.7	26.6
Freon-21	504	34.5	12.6	30.	7.	42.5	23.3
Freon-12	268	17.76	10.8	16.5	9.2	29.6	24.4
Freon-11	20	20.6	17.1	27.3	-25.6	17.3	-13.7
Freon-114	441	21.1	-8.5	22.	-14.5	20.3	0.3
Freon-113	19	18.8	10.3	18.4	-14.2	13.5	-2.7
Water	212	182.9	12.9	182.9	12.9	182.9	12.9

$$\Psi_\gamma = \left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2} \times \mu_f}{D \times \rho_f}\right)^{2/3} \times \left(\frac{\mu_f}{\mu_g}\right)^{1/8}$$

$$\Psi_\sigma = \left(\frac{G^2 D}{\rho_f \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-.133} \times \left(\frac{GD}{\mu_g}\right)^{-.2}$$

$$\Psi_k = \frac{\sigma\ \rho_f}{G^2 L} \quad \text{or} \quad \frac{GD^{0.5}}{\sigma^{0.5}\ \rho_f^{0.5}}$$

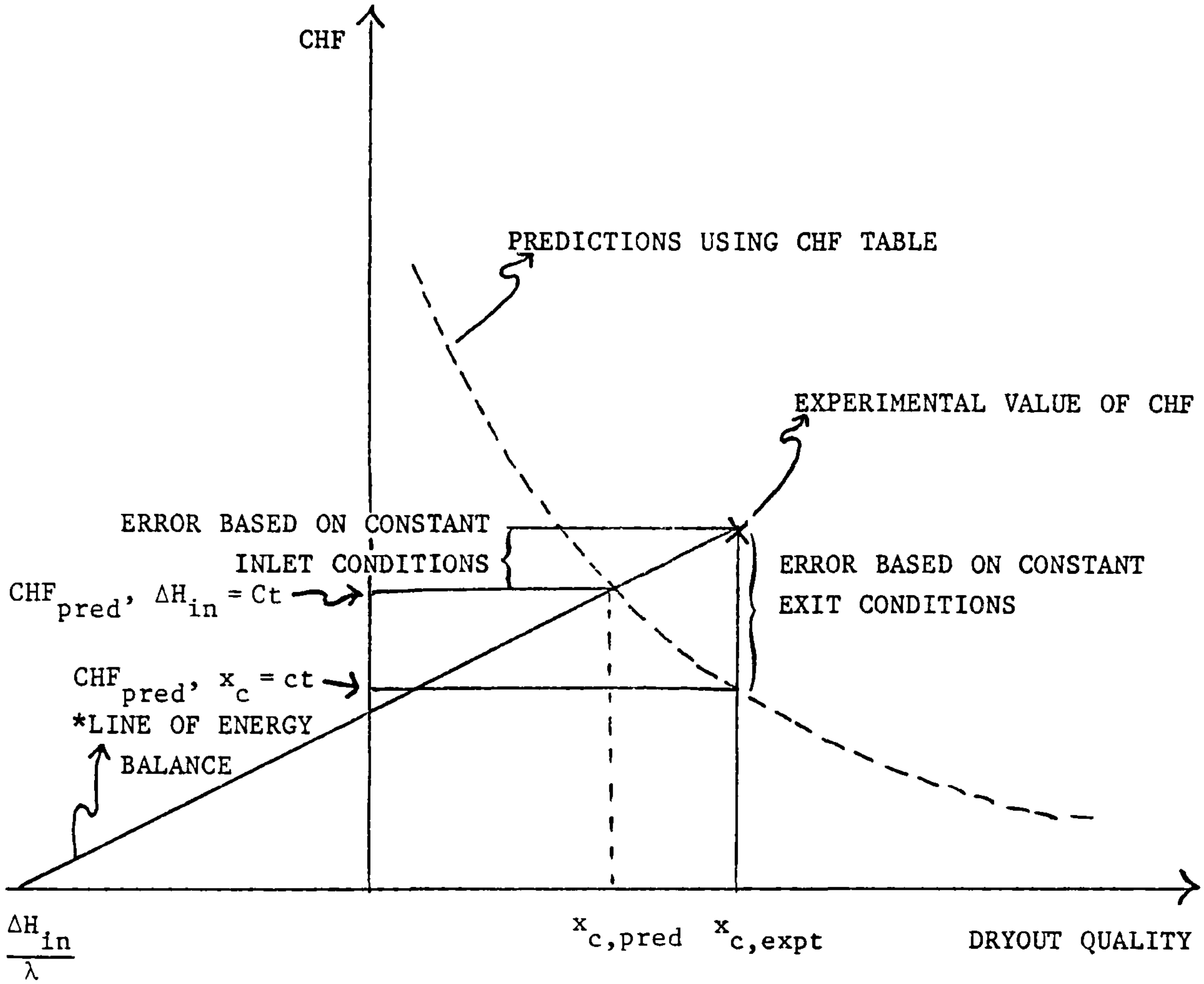
Table 4.5. RMS and Average Errors in CHF Based on Constant Inlet Conditions Using Non-Dimensional Table and various non-dimensional mass fluxes

Fluid	No. of Data	Ψ_γ RMS(%)	Ψ_γ AVG(%)	Ψ_σ RMS(%)	Ψ_σ AVG(%)	Ψ_κ RMS(%)	Ψ_κ AVG(%)
Nitrogen	26	6.5	-2.8	6.1	-0.3	7.7	2.2
Carbon Dioxide	172	17.2	15.	13.8	9.9	15.	11.3
Freon-21	504	12.3	3.4	11.3	1.3	14.2	7.4
Freon-12	268	7.28	4.4	6.8	3.7	12.5	10.6
Freon-11	20	9.5	6.8	9.8	-9.3	5.7	-4.5
Freon-114	441	11.1	-4.4	11.7	-7.6	10.5	0.1
Freon-113	19	10.6	6.	10.6	-8.4	7.3	-1.6
Water	212	27.0	- .23	27.0	- .23	27.0	-.23

$$\Psi_\gamma = \left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2} \times \mu_f}{D \times \rho_f}\right)^{2/3} \times \left(\frac{\mu_f}{\mu_g}\right)^{1/8}$$

$$\Psi_\sigma = \left(\frac{G^2 D}{\rho_f \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-.133} \times \left(\frac{GD}{\mu_g}\right)^{-.2}$$

$$\Psi_k = \frac{\sigma\ \rho_f}{G^2 L} \quad \text{or} \quad \frac{GD^{0.5}}{\sigma^{0.5}\ \rho_f^{0.5}}$$



* Energy balance is calculated from the following equation

$$x = \frac{4q}{\lambda G} \times \frac{L}{D} - \frac{\Delta H_{in}}{\lambda}$$

FIGURE 4.10 ERRORS BASED ON CONSTANT EXIT AND INLET CONDITIONS

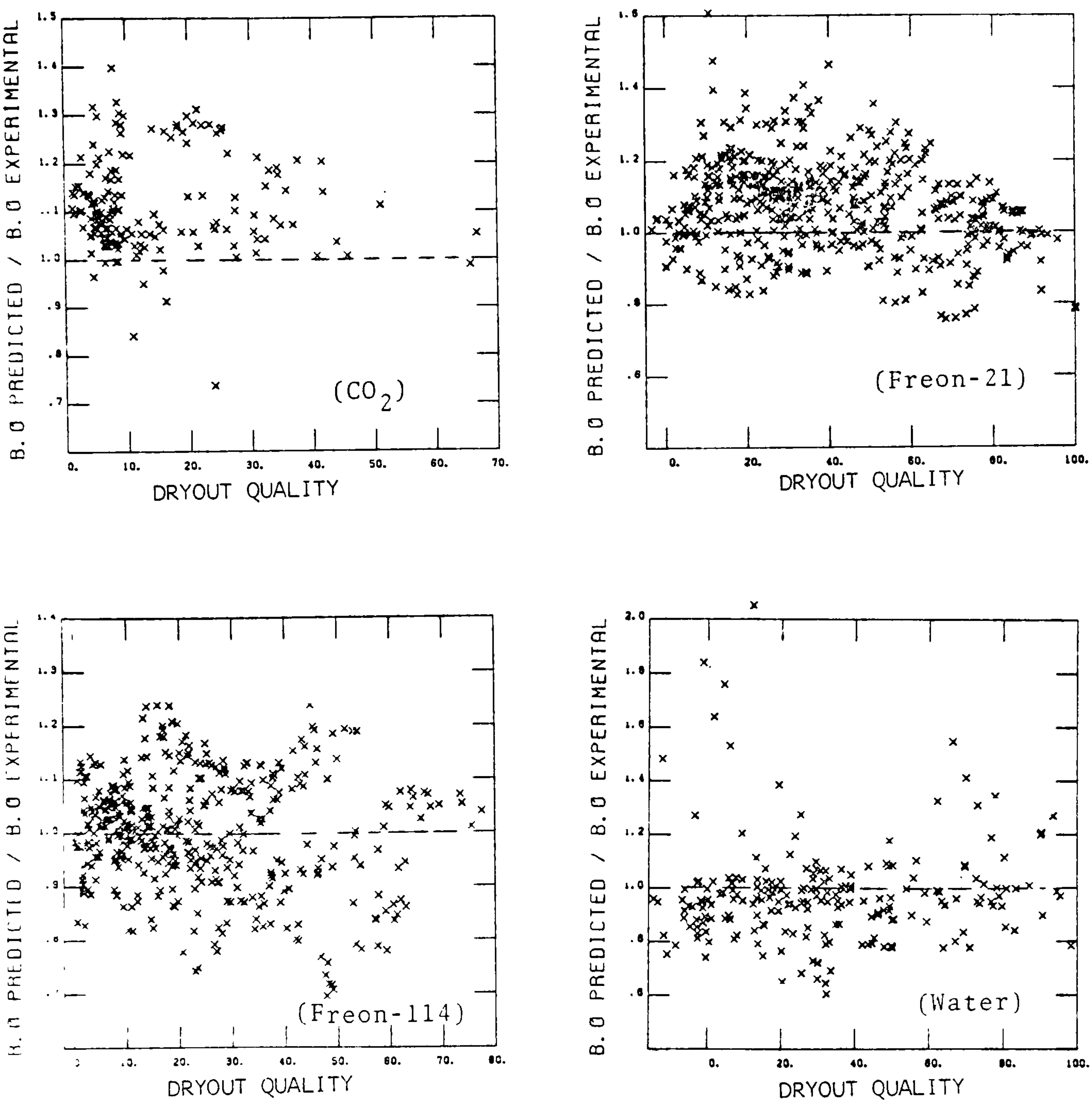


FIGURE 4.11 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_K VERSUS DRYOUT QUALITY

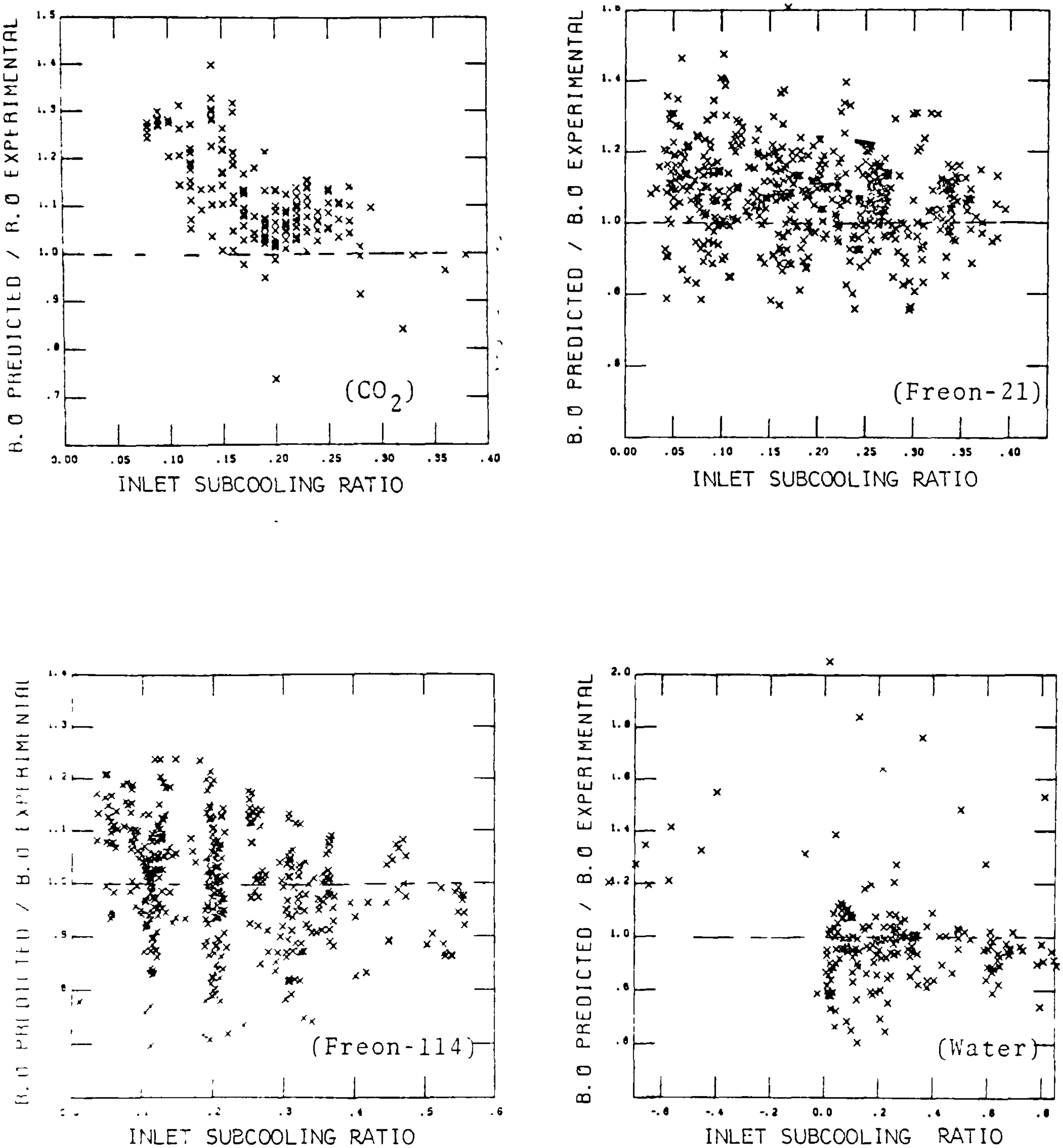


FIGURE 4.12 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_K VERSUS INLET SUBCOOLING RATIO

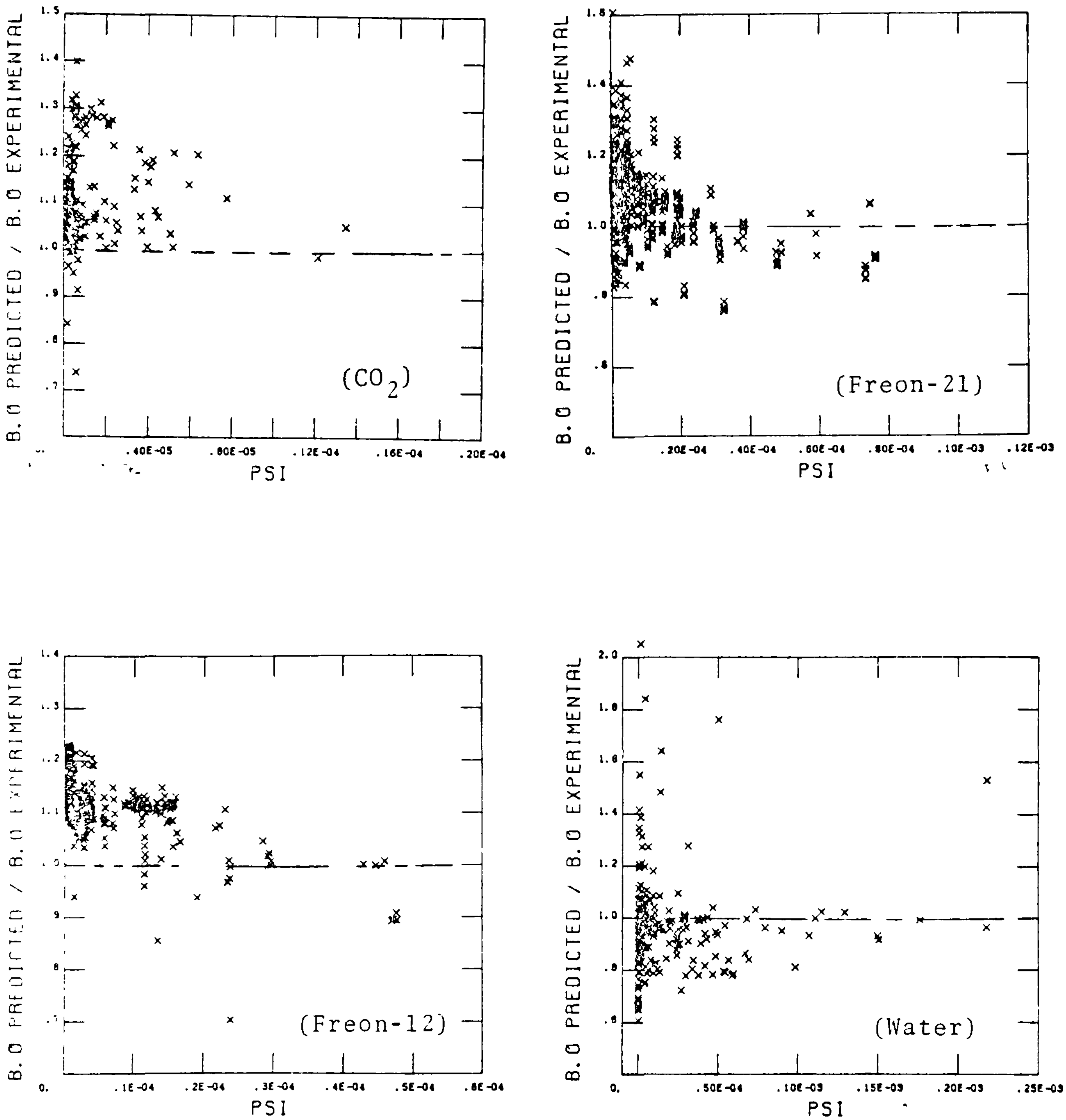


FIGURE 4.13 NON-DIMENSIONAL TABLE CHF PREDICTIONS VERSUS EXPERIMENTAL Ψ_K

- A decrease in error with increasing B.O. This is illustrated in Fig. 4.14 for carbon dioxide, Freon-21, Freon-12 and water.

Also, one can observe the following parametric and assymptotic trends for the non-dimensional table using Ψ_γ.

- A decrease in error with increasing dryout quality. This is illustrated in Fig. 4.15 for carbon dioxide and Freon-21.
- A decrease in error with increasing inlet subcooling ratio. This is illustrated in Fig. 4.16 for carbon dioxide, Freon-114, Freon-11 and Freon-21.
- An increase in error with increasing Ψ_γ. This is illustrated in Fig. 4.17 for carbon dioxide, Freon-11, Freon-21 and Freon-12.
- A decrease in error with increasing B.O. This is illustrated in Fig. 4.18 for Carbon dioxide, Freon-11, Freon-21 and Freon-12.

4.4.3 Discussion

Table 4.5 shows that the non-dimensional table RMS and average errors in CHF using the three dimensionless parameters are approximately equal. The dimensionless parameters Ψ_k and Ψ_σ are the only ones using surface tension. Ψ_σ was not selected due to the complexity of its expression. The non-dimensional table predictions using Ψ_κ and Ψ_γ were adequate in the negative dryout quality range. This is illustrated in Fig. 4.19 for nitrogen and Freon-113. The non-dimensional table predictions using Ψ_κ and Ψ_γ are most accurate in the high dryout quality range (20 - 100%). This is illustrated in Fig. 4.11 for Ψ_κ and Fig. 4.15 for Ψ_γ. The non-dimensional table predictions using Ψ_κ and

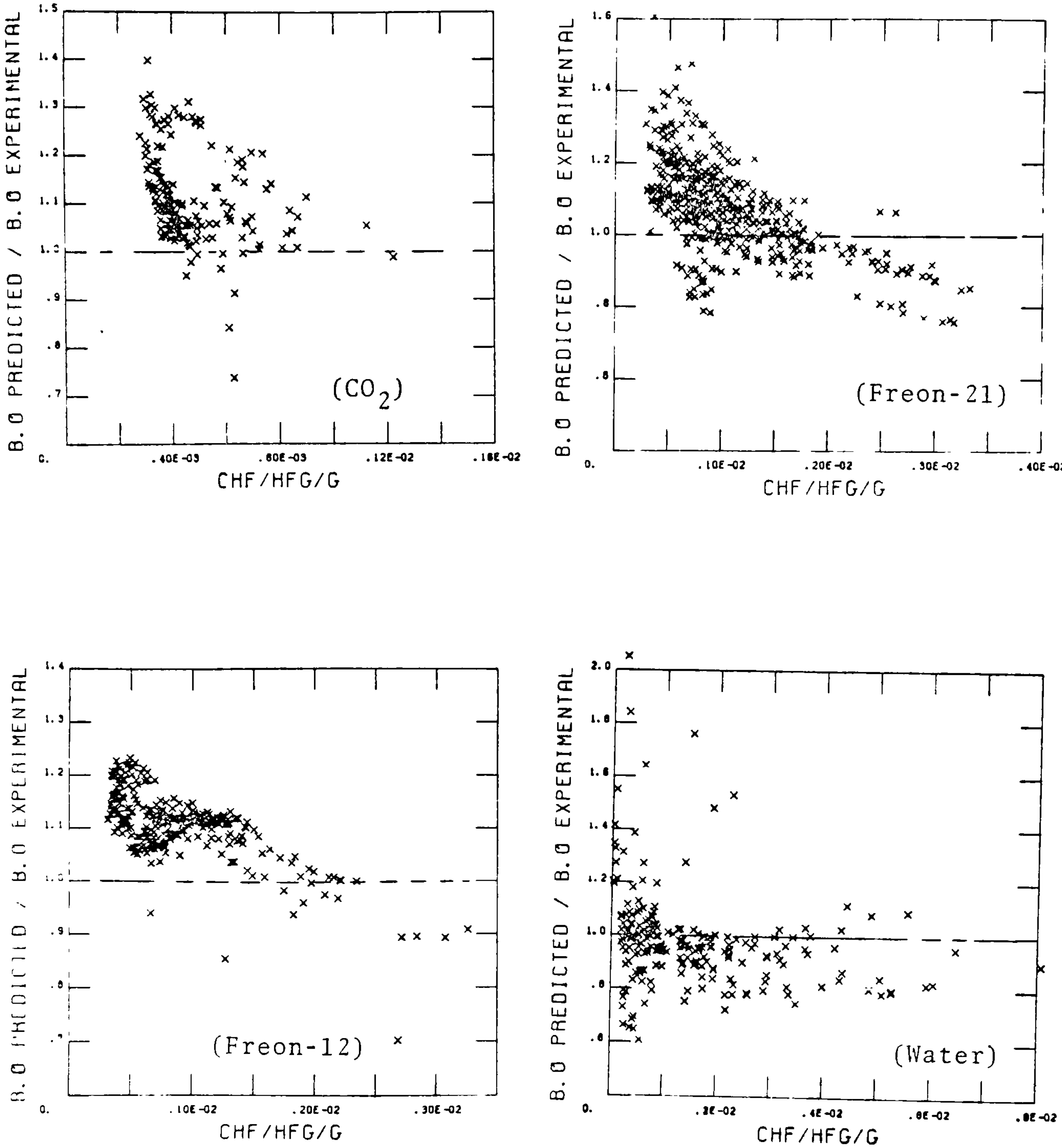
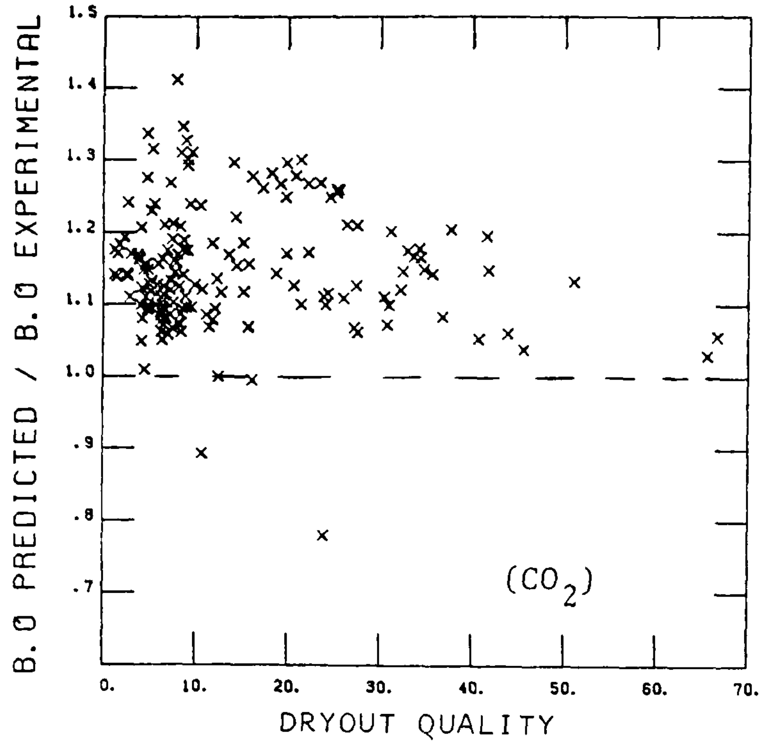


FIGURE 4.14 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_K VERSUS BOILING NUMBER



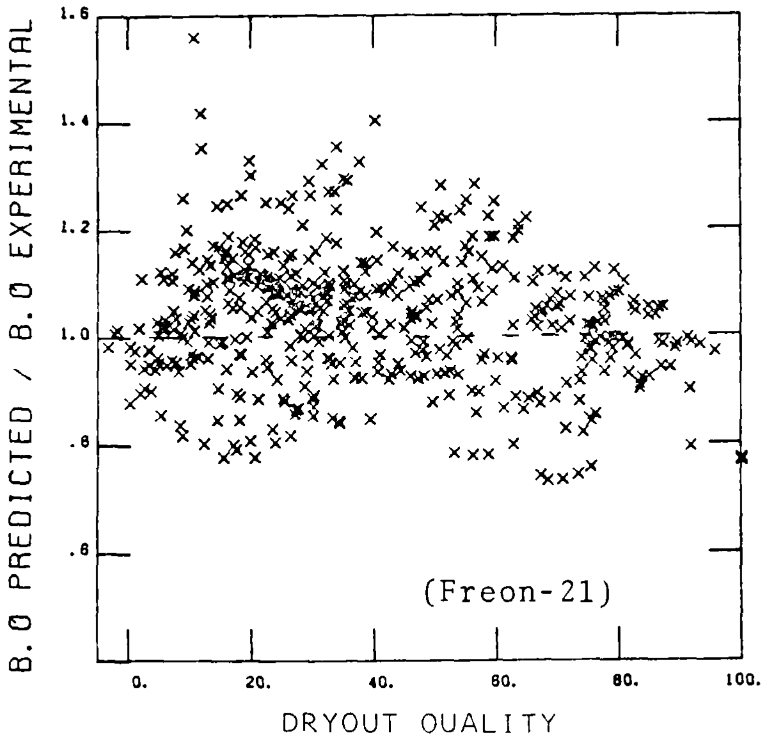


FIGURE 4.15 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_γ VERSUS DRYOUT QUALITY

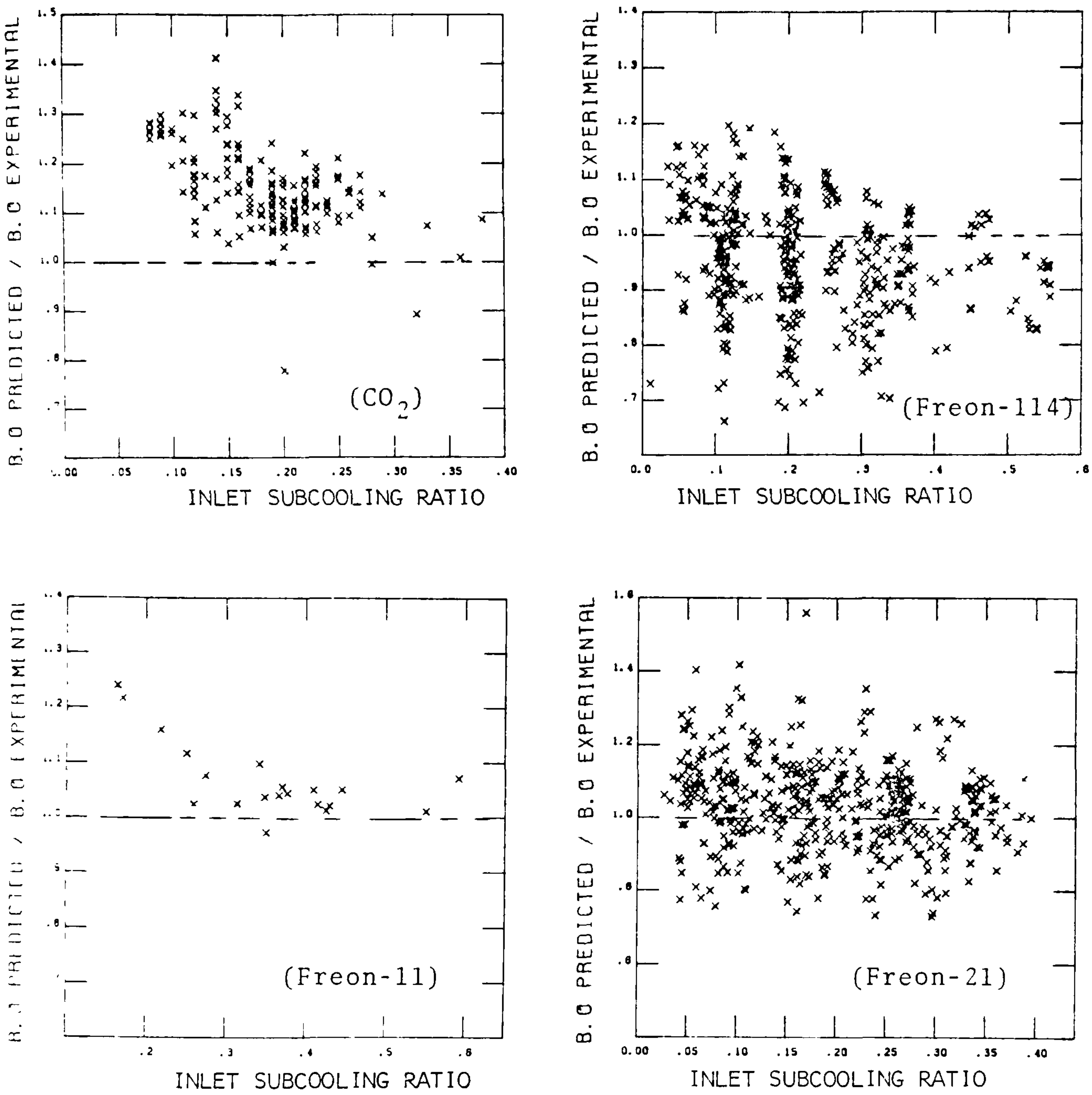


FIGURE 4.16 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_{γ} VERSUS SUBCOOLING RATIO

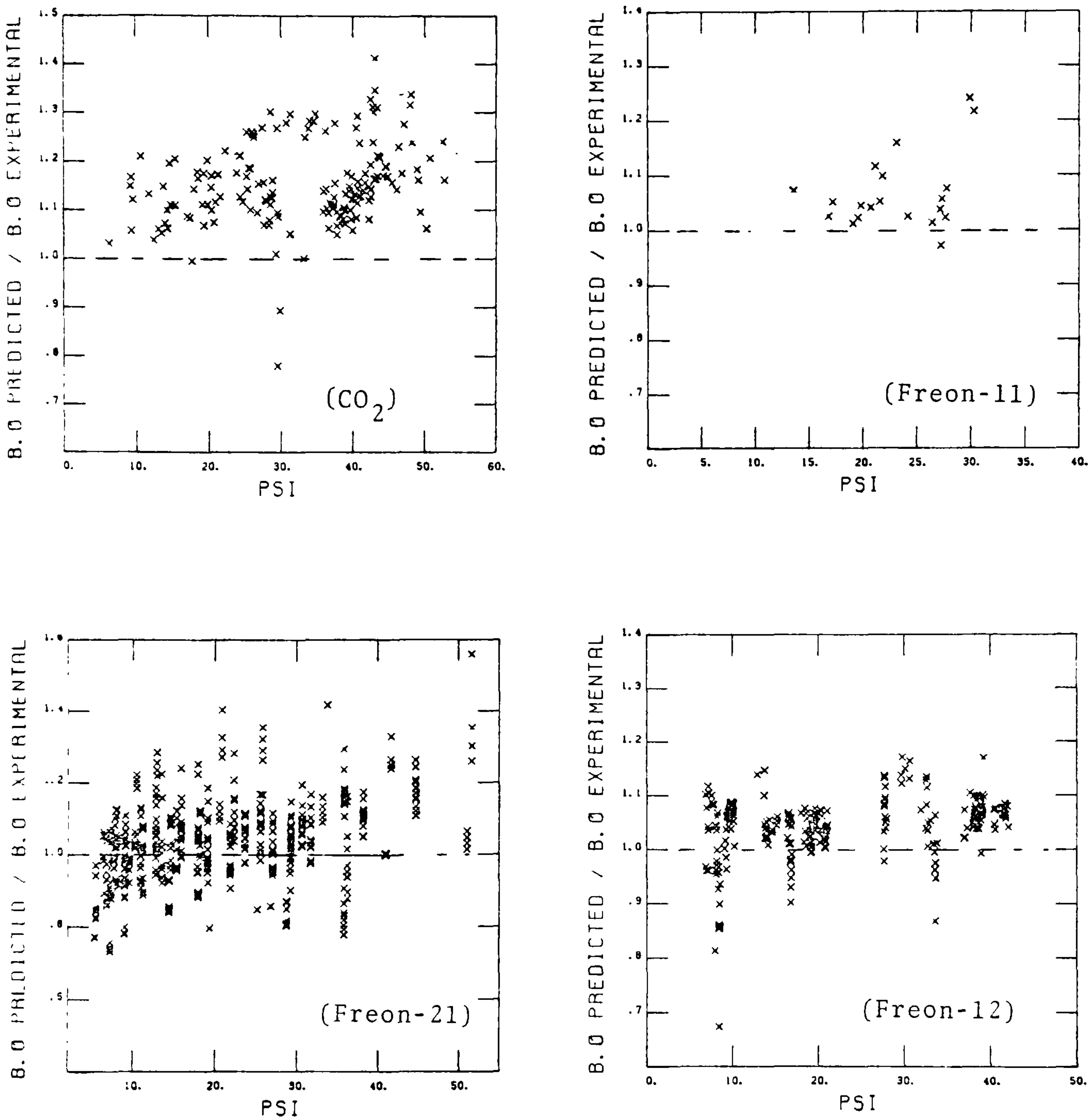


FIGURE 4.17 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_γ VERSUS EXPERIMENTAL Ψ_γ

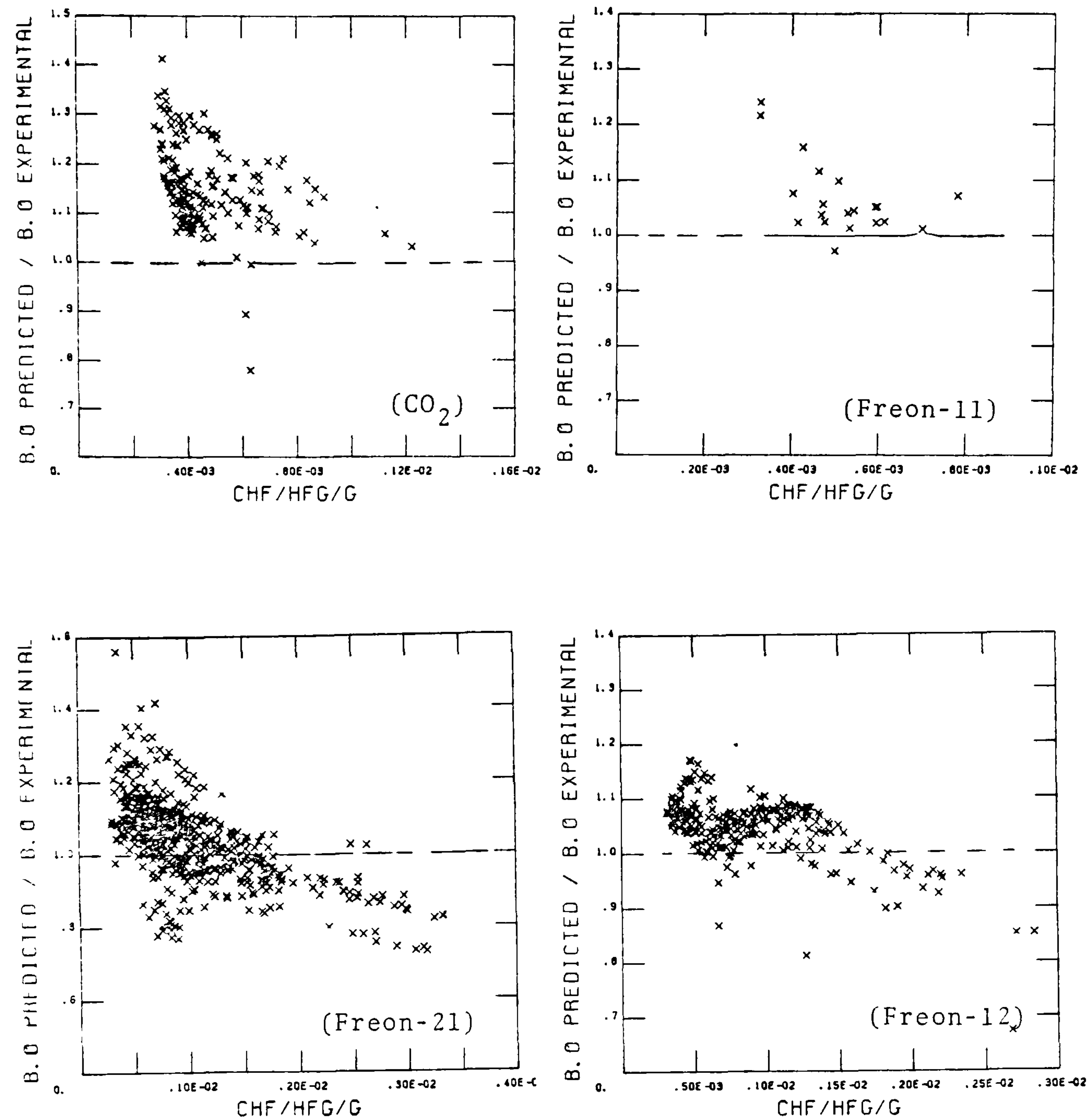


FIGURE 4.18 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_{γ} VERSUS BOILING NUMBER

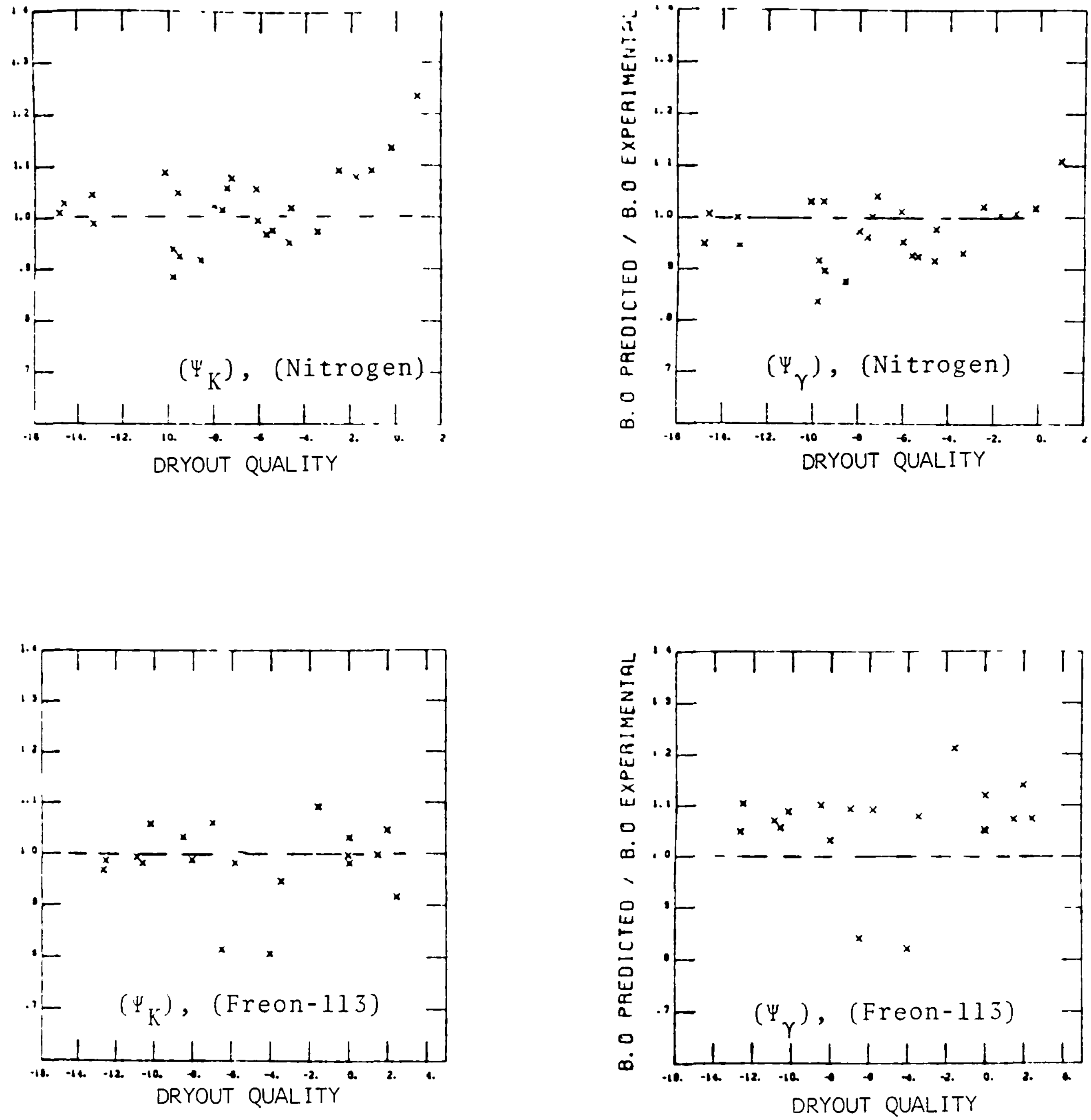


FIGURE 4.19 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_K AND Ψ_γ RESPECTIVELY VERSUS DRYOUT QUALITY

Ψ_γ were most accurate at large inlet subcoolings (inlet subcooling ratio greater than 0.2). This is illustrated in Fig. 4.12 for Ψ_K and and Fig. 4.16 for Ψ_γ. Also, the non-dimensional table gave adequate predictions when two-phase flow is encountered at the tube inlet. This is illustrated in Fig. 4.12 for water. The table is not recommended for use when the mass flux approaches zero. In this case the boiling number tends to infinity. Zuber's correlation is recommended in pool boiling situations. However, for mass fluxes between zero and the ones available in the table, interpolation between Zuber's and the non-dimensional table predictions is advised.

In summary, the non-dimensional table predicted CHF adequately for non-aqueous fluids as well as water. The dryout quality range is -15% to 100%. In general, the parameter Ψ_K is recommended. However, if values of surface tension are unknown or suspect Ψ_γ is recommended. The non-dimensional table has a wide range of conditions, but it does not cover pool boiling conditions or dryout qualities less than -15%.

4.5 <u>Dryout Quality Range Covered by all Tested CHF Prediction Methods</u>

Figures 4.20 to 4.23 illustrate the dryout quality range covered with each fluid for Weisman & Pei's model, Katto's correlation and the non-dimensional CHF table using Ψ_K and Ψ_γ respectively. It is observed that the water data have the largest errors. This is because the water data covered the widest range of parameters.

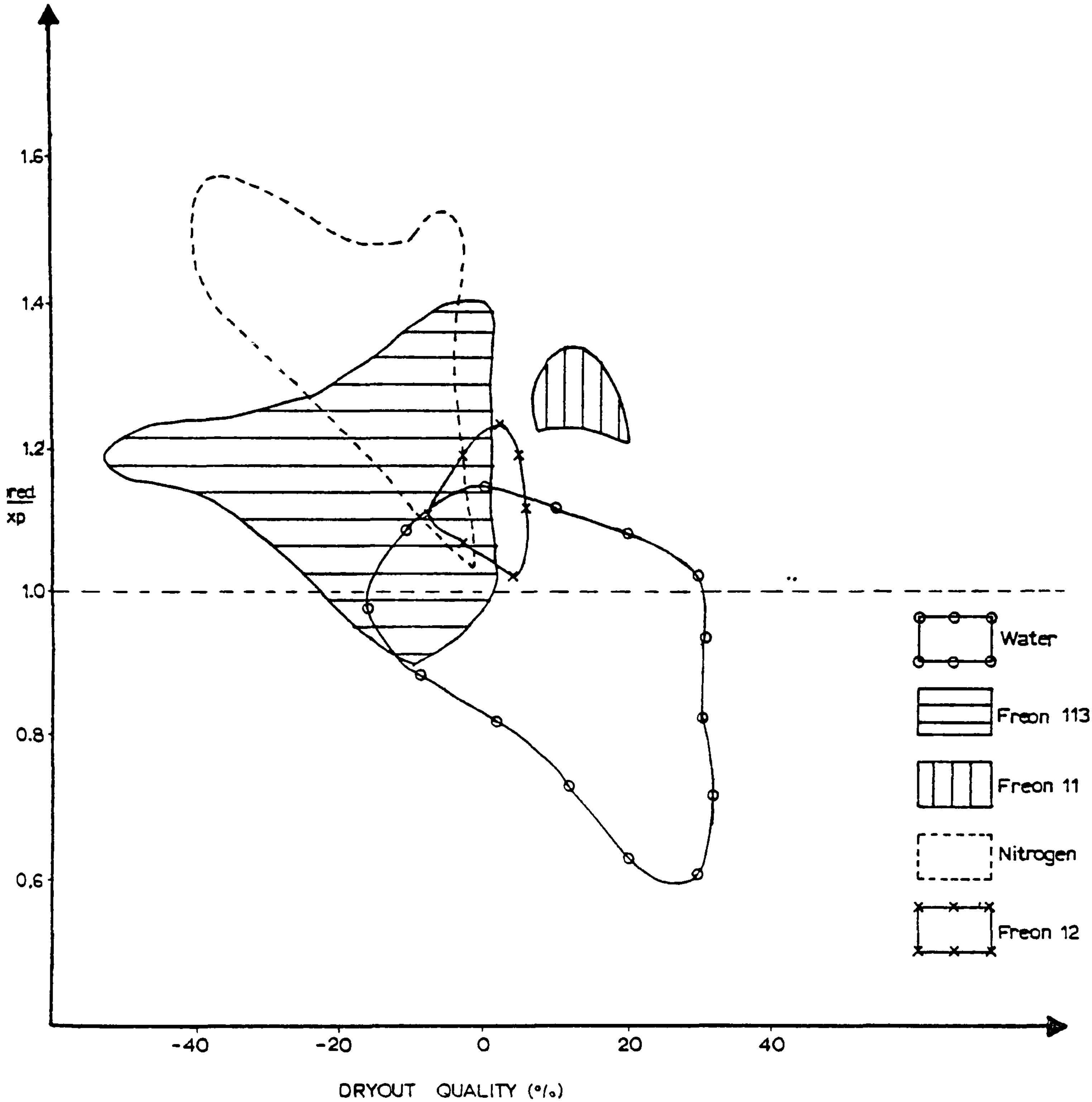


FIGURE 4.20. WEISMAN & PEI'S MODEL CHF PREDICTIONS VERSUS DRYOUT QUALITY FOR ALL TESTED FLUIDS

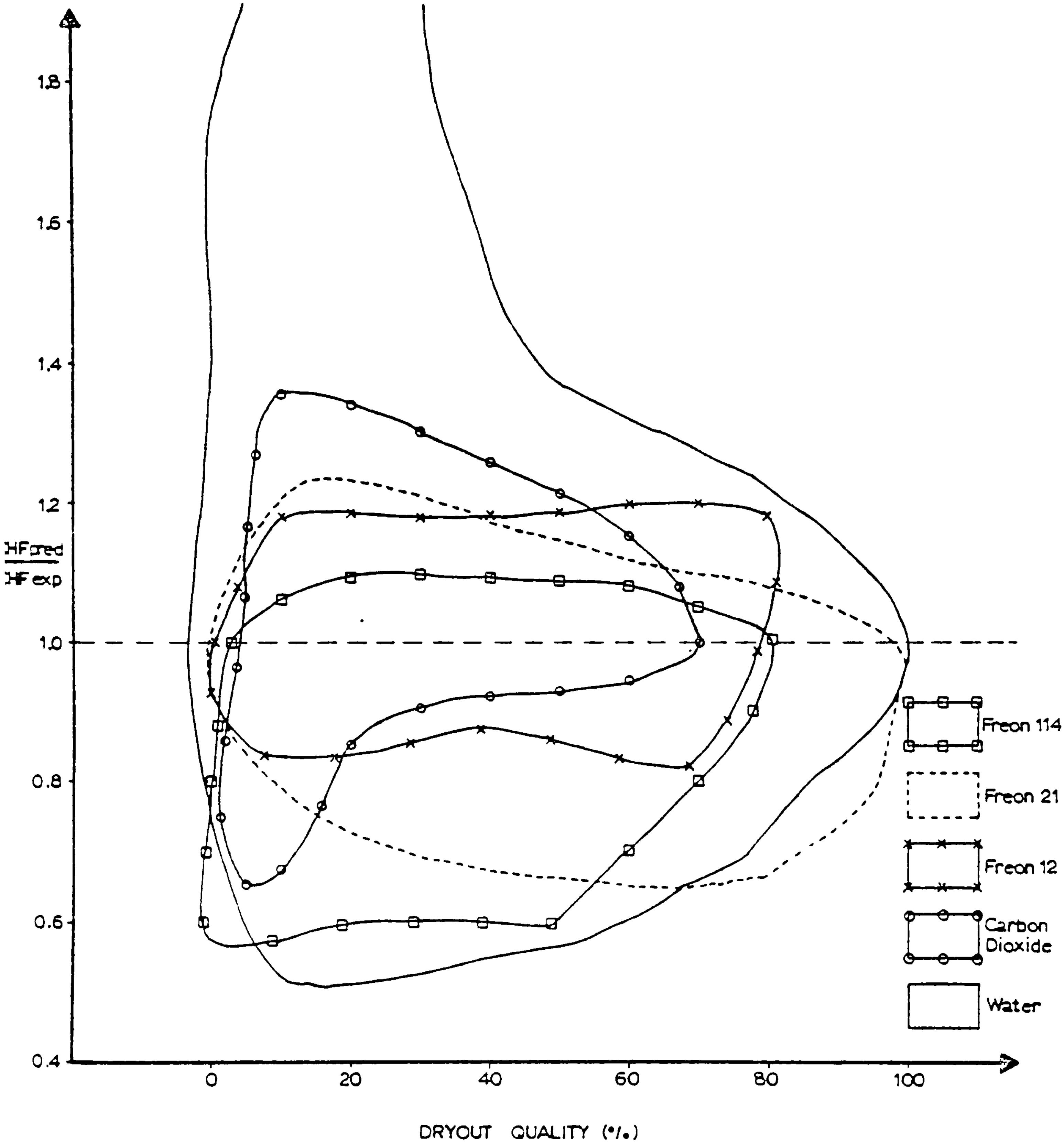


FIGURE 4.21 KATTO'S CORRELATION CHF PREDICTIONS VERSUS DRYOUT QUALITY FOR ALL TESTED FLUIDS

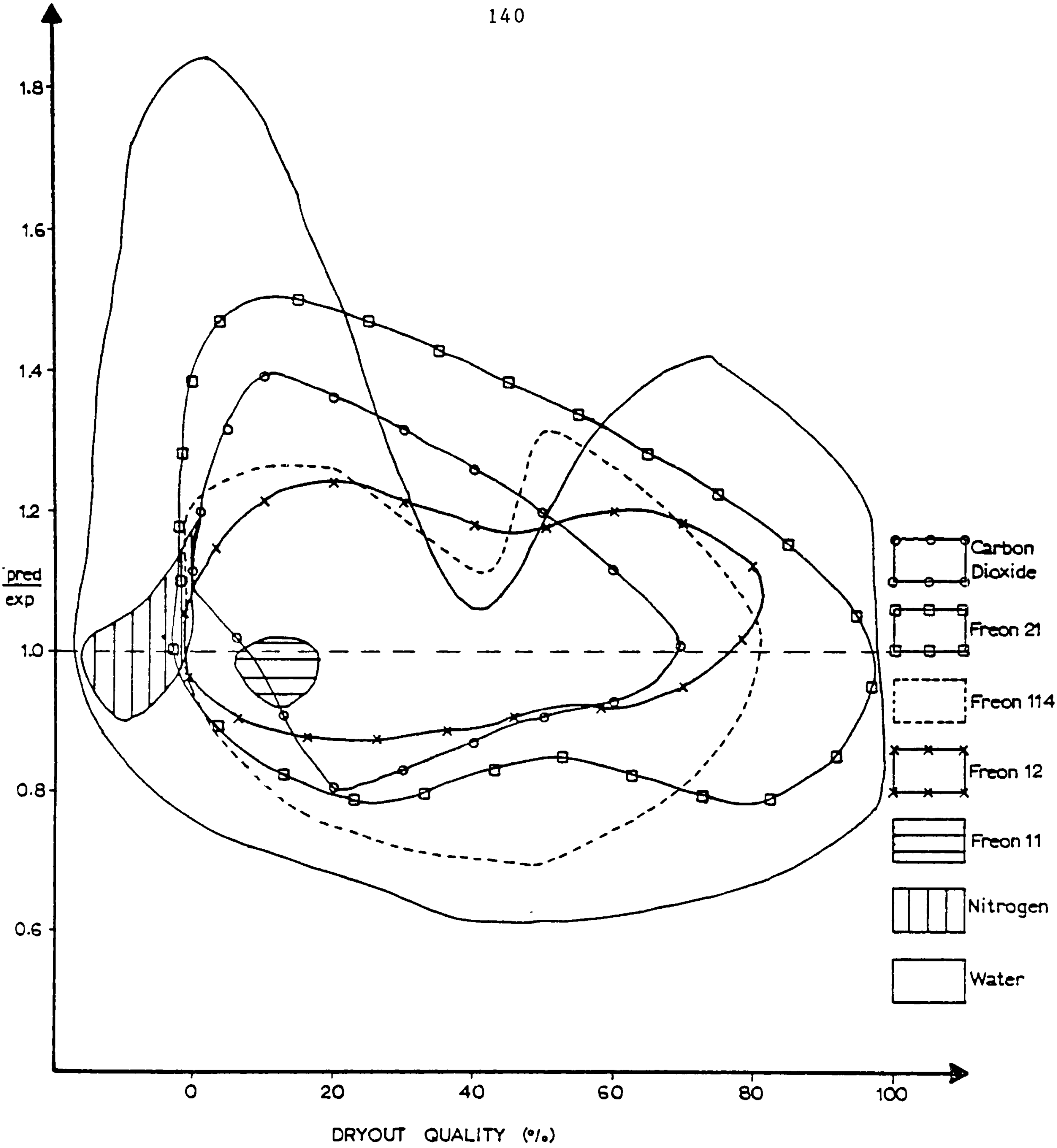


FIGURE 4.22 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_K VERSUS DRYOUT QUALITY FOR ALL TESTED FLUIDS

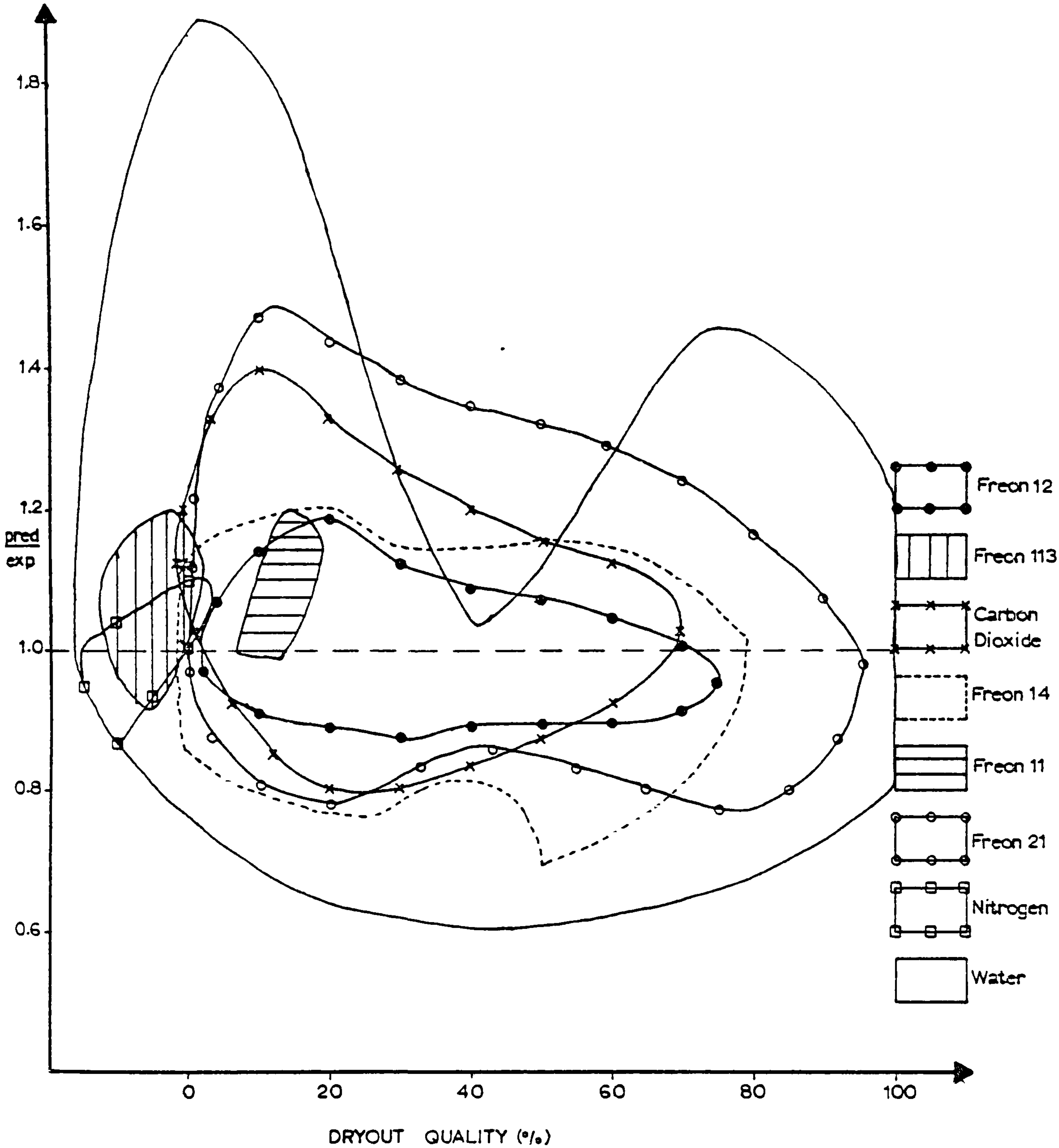


FIGURE 2.23 NON-DIMENSIONAL TABLE CHF PREDICTIONS USING Ψ_γ VERSUS DRYOUT QUALITY FOR ALL TESTED FLUIDS

5. Conclusions

- Weisman and Pei's model predicted CHF adequately for all tested fluids. The model is limited to high mass fluxes and pressures above 1000 $kg/m^2/s$ and 2 MPa for water, respectively. Also the model is not applicable at dryout qualities higher than 20%.
- Katto's correlation gave good CHF predictions for all tested fluids. The correlation is limited to positive dryout quality range. Also, the correlation is not recommended for short tube length; L/D less than 50 or for mass fluxes lower than 2 000 $Kg/m^2/s$ for water. Finally, the correlation is definitely not recommended for situations where two-phase flow is encountered at the tube inlet.
- A non-dimensional table used for predicting convective boiling CHF for all fluids was created. The table was created by non-dimensionalizing Groeneveld's standard table for predicting CHF in water using modelling techniques such as Ahmad's and Katto's. The table covers a wide range of conditions: dryout quality (-15% - 100%), atmospheric to water equivalent critical pressure, single and two-phase inlet flows and water equivalent mass flux of 50 - 7500 $kg/m^2/s$. The table is limited to flow boiling situations and it is not applicable when dryout quality is less than -15%.
- Finally, the non-dimensional table gave accurate CHF predictions for fluids other than water. The table covers the widest range of parameters among existing CHF prediction techniques.

6. Recommendations

- Future work should be concentrated on expanding the non-dimensional CHF table to dryout qualities lower than -15%. Experimental CHF data in various fluids having dryout qualities less than -15% can be used for this purpose. These data can be non-dimensionalized into Ahmad's and Katto's dimensionless parameters. The obtained data can be added to the present non-dimensional table by statistically averaging the boiling number within each ρ_f/ρ_g, Ψ and x intervals. A similar approach was followed in creating the dimensional CHF table (Groeneveld (1986)).

- The effect of diameter on CHF should be studied in detail. A correction factor for diameters smaller than 0.002 m should be provided.

7. Summary of Thesis Work

An introduction to the CHF in temperature and heat-flux-controlled systems is presented. The mechanisms with the greatest promise for explaining CHF are described. The factors affecting the CHF such as flow parameters, geometry and miscellaneous effects are described in detail.

A detailed literature survey of CHF predicting methods applicable to non-aqueous fluids was made. A summary of the various empirical and theoretically-based methods is presented. Also, a summary of the various CHF scaling techniques between different fluids is made. The two methods which appeared to be the most promising for predicting CHF in non-aqueous fluids were selected for further study: (i) Weisman & Pei's theoretically based model for predicting CHF at low qualities, and (ii) Katto's latest empirical correlation for predicting CHF in various fluids at positive dryout qualities.

A detailed literature survey of experimental CHF data for fluids other than water was made. A summary of the available and selected data are presented. The experimental water CHF data were selected from the AECL-CHF data bank.

A new method for predicting CHF in non-aqueous fluids is created by non-dimensionalizing Groeneveld's standard CHF table using Ahmad's & Katto's CHF scaling techniques.

A comparison of predicted CHF values with experimental CHF values for water, carbon dioxide, nitrogen and different Freon types is made. It has been found that the non-dimensional CHF table predicting method is the most accurate over a wide range of pressures, qualities and mass flows.

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A P P E N D I X   A

Non-Aqueous Fluids Experimental CHF Data

Freon-113 - Coffield (1969); Liquid Nitrogen - Pappell (1966);

Freon-11 - Leung (1980); Freon-12 - Groeneveld (1969);

Helium - Katto (1983); Freon-114 - Dix (1970);

Freon-21 - Barnett & Wood (1965);

Carbon Dioxide - Rotem & Hauptmann (1970); and

Potassium - Hoffmann & Krakoviak (1964)

FREON-113 CHF DATA, COFFIELD (1969)

TABLE IV-a.

SUBCOOLED AND LOW QUALITY FREON-113 DATA

Run No.	Date	Critical Heat Flux $q''_{DNB} \times 10^{-5}$ Btu/hr-ft^2	Absolute Pressure P, lb/in.^{2}	Mass Flow Rate $G \times 10^{-6}$, lb/hr-ft^2	Inlet Subcooling ΔH_i, Btu/lb	Exit Quality x_{DNB}	Inlet Temperature T_i, F
1	9/25	1.110	137	3.970	12.02	-0.07750	221.70
2	9/28	1.745	137	4.130	23.68	-0.23500	174.70
3	9/28	1.440	137	2.600	19.47	-0.27600	151.00
4	9/30	1.210	137	2.000	19.85	-0.24950	148.70
5	9/30	0.875	136	1.040	30.87	-0.12150	144.70
6	9/30	0.668	135	0.980	20.25	+0.00317	189.17
7	10/1	1.050	137	1.960	40.11	-0.19600	104.10
8	10/1	1.125	137	2.500	22.00	-0.18150	181.70
9	10/1	1.545	137	4.000	21.00	-0.20000	185.70
10	10/1	0.849	137	2.420	13.54	-0.06620	215.90
11	10/2	1.085	137	1.000	44.40	-0.25200	84.70
12	10/2	0.626	137	2.420	7.00	+0.01230	249.70
13	10/2	0.688	132	3.900	5.25	-0.00523	247.10
14	10/7	1.765	185	4.000	24.80	-0.26700	196.70
15	10/8	1.535	188	4.000	20.50	-0.20900	255.00
16	10/8	1.145	188	4.000	13.00	-0.10200	225.30
17	10/8	0.658	190	3.900	5.00	+0.00690	284.30
18	10/8	1.450	193	2.510	32.50	-0.35400	188.00
19	10/8	1.200	193	2.500	24.20	-0.22900	209.30
20	10/8	0.900	190	2.500	15.00	-0.09650	244.70

TABLE IV-b.

SUBCOOLED AND LOW QUALITY FREON-113 DATA

Run No.	Date	Critical Heat Flux $q_{DNB} \times 10^{-5}$ Btu/hr-ft^2	Absolute Pressure, P, lb/in.^{2}	Mass Flow Rate $G \times 10^{-6}$ lb/hr-ft^2	Inlet Subcooling ΔH_i, Btu/lb	Exit Quality x_{DNB}	Inlet Temperature T_i, F
21	10/8	0.491	100	2.500	5.00	+0.02010	276.70
22	10/8	1.7[illegible]0	300	4.000	30.50	-0.52300	243.10
23	10/8	1.390	300	4.000	21.50	-0.33200	279.00
24	10/9	0.925	302	4.000	12.50	-0.19700	312.30
25	10/9	0.650	305	4.000	6.00	-0.02420	337.40
26	10/9	1.325	315	2.450	33.70	-0.54400	237.00
27	10/9	1.035	315	2.500	24.50	-0.37900	271.30
28	10/9	0.[illegible]67	315	2.500	13.72	-0.18200	303.00
29	10/9	0.571	317	2.400	9.00	-0.06030	332.70
30	10/9	1.055	195	1.000	41.45	-0.24100	140.30
31	10/9	0.835	195	1.000	31.80	-0.16100	181.00
32	10/9	0.655	193	1.000	23.04	-0.08100	214.00
33	10/9	0.516	193	1.000	16.00	-0.01385	250.00
34	10/10	0.740	305	1.000	37.29	-0.46700	215.00
35	10/10	0.655	309	0.950	31.01	-0.32200	244.00
36	10/10	0.548	312	1.000	20.50	-0.13000	278.30
37	10/10	0.432	300	1.000	12.00	+0.02540	309.30
38	10/10	1.079	315	2.500	24.50	-0.36700	272.00
39	10/10	1.215	193	2.500	24.30	-0.22700	208.30
40	10/10	1.130	189	4.000	13.00	-0.10400	256.30

LIQUID NITROGEN CHF DATA, PAPPELL (1966)

Units

P	(psi)
L	(in)
D	(in)
G	(10^6 × lb/hr/ft^2)
ΔH_{sub}	(Btu/lb)
q''_{DNB}	(Btu/hr/ft^2)

REF. NO.	P	DIA.	LENG.	$G^{\bullet}$	Δh_{SUB}	$\dot{q}''_{INB}$ EXP.	$\dot{q}''_{INB}$ PRED.	X_{BO}
84	50.	0.505	12.0	1.060	5.50	70000.	71870.	0.010
84	50.	0.505	12.0	1.235	5.50	70000.	79193.	-0.002
84	50.	0.505	12.0	1.410	5.50	70000.	87005.	-0.010
84	50.	0.505	12.0	1.590	5.50	70000.	93352.	-0.044
84	50.	0.505	12.0	1.850	5.50	70000.	102629.	-0.047
84	75.	0.505	12.0	1.129	10.20	68000.	93352.	-0.060
84	75.	0.505	12.0	1.235	10.20	75200.	98723.	-0.059
84	75.	0.505	12.0	1.191	10.20	76000.	102395.	-0.063
84	75.	0.505	12.0	1.446	10.20	75000.	109464.	-0.071
84	75.	0.505	12.0	1.632	10.20	81900.	118740.	-0.073
84	75.	0.505	12.0	1.810	10.20	88100.	126064.	-0.075
84	100.	0.505	12.0	1.051	13.50	82900.	98723.	-0.085
84	100.	0.505	12.0	1.226	13.50	88100.	108488.	-0.094
84	100.	0.505	12.0	1.261	13.50	88100.	110441.	-0.097
84	100.	0.505	12.0	1.637	13.50	114600.	131923.	-0.097
84	150.	0.505	12.0	1.043	18.50	94900.	108483.	-0.154
84	150.	0.505	12.0	1.217	18.50	101100.	120205.	-0.15[illegible]
84	150.	0.505	12.0	1.321	18.50	98500.	127040.	-0.17[illegible]
84	150.	0.505	12.0	1.600	18.50	111500.	144129.	[illegible]
84	150.	0.505	12.0	1.860	18.50	117200.	160240.	-0.195
84	200.	0.505	12.0	1.047	23.50	92300.	119229.	.246
84	200.	0.505	12.0	1.090	23.50	90000.	122158.	.255
84	200.	0.505	12.0	1.104	23.50	101100.	125088.	-0.255
84	200.	0.505	12.0	1.204	23.50	102600.	130946.	-0.261
84	200.	0.505	12.0	1.256	23.50	98500.	134852.	-0.272
84	200.	0.505	12.0	1.260	23.50	109900.	13554[illegible]	-0.258
84	200.	0.505	12.0	1.622	23.50	115900.	1601[illegible]	-0.287
84	200.	0.505	12.0	1.800	23.50	133700.	1719[illegible]	-0.279
84	240.	0.505	12.0	1.041	28.70	95900.	126[illegible]4.	-0.351
84	240.	0.505	12.0	1.142	28.70	91760.	13[illegible]829.	-0.385
84	240.	0.505	12.0	1.121	28.70	102100	1[illegible]567.	[illegible]

REF. NO.	P	DIA.	LENG.	G^*	Δh_{SUB}	q''^*_{DNB} EXP.	q''^*_{DNB} PRED.	X_{EO}
84	240.	0.505	12.0	1.212	28.70	106300.	141687.	-0.372
84	240.	0.505	12.0	1.282	28.70	103700.	147546.	-0.384
84	240.	0.505	12.0	1.282	28.70	106300.	147546.	-0.381
84	240.	0.505	12.0	1.300	28.70	107830.	148523.	-0.381
84	240.	0.505	12.0	1.634	28.70	122860.	173911.	-0.394
84	240.	0.505	12.0	1.845	28.70	132700.	188558.	-0.400
84	240.	0.505	12.0	1.862	28.70	135800.	189534.	-0.398
84	100.	0.505	12.0	1.045	8.50	67400.	79682.	-0.033
84	100.	0.505	12.0	1.264	8.50	70500.	89935.	-0.045
84	100.	0.505	12.0	1.474	8.50	81400.	99699.	-0.046
84	100.	0.505	12.0	1.720	8.50	85500.	109464.	-0.053
84	150.	0.505	12.0	1.060	11.50	71000.	87005.	-0.080
84	150.	0.505	12.0	1.480	11.50	83000.	107999.	-0.096
84	150.	0.505	12.0	1.710	11.50	89200.	118740.	-0.102
84	200.	0.505	12.0	1.080	14.70	76700.	94817.	-0.135
84	200.	0.505	12.0	1.193	14.70	85500.	101652.	-0.134
84	200.	0.505	12.0	1.520	14.70	95900.	119229.	-0.141
84	200.	0.505	12.0	1.770	14.70	106800.	129970.	-0.15[illegible]

FREON-11 CHF DATA, LEUNG (1980)

Units

P	(psi)
L	(in)
D	(in)
G	($10^6 \times$ lb/hr/ft^2)
ΔH_{sub}	(Btu/lb)
q''_{DNB}	(Btu/hr/ft^2)

REF. NO.	P	DIA.	LENG.	$\dot{G}$	Δh_{SUB}	$\dot{q}''_{CNB}$ EXP.	$\dot{q}''_{CNB}$ PRED.	X_{BO}
82	288.4	0.461	107.88	1.999	8.23	33000.	37694.	0.15
82	291.3	0.461	107.88	2.036	8.52	33380.	38670.	0.14
82	353.6	0.461	107.88	2.017	12.42	36930.	43064.	0.11
82	347.8	0.461	107.88	1.996	11.85	37970.	42332.	0.13
82	389.9	0.461	107.88	2.043	14.87	43470.	45261.	0.12
82	394.2	0.461	107.88	2.060	15.56	41085.	45994.	0.08
82	387.0	0.461	107.88	2.036	14.86	40812.	45277.	0.09
82	420.3	0.461	107.88	2.025	17.00	43380.	45872.	0.08
82	315.9	0.461	107.88	1.515	16.40	37050.	39647.	0.14
82	400.0	0.461	107.88	1.026	24.62	33475.	33544.	0.15
82	391.3	0.461	107.88	1.433	23.28	42645.	42820.	0.11
82	320.3	0.461	107.88	1.477	11.99	32650.	33788.	0.18
82	308.7	0.461	107.88	1.539	10.62	32920.	34276.	0.18
82	384.1	0.461	107.88	1.257	17.75	33199.	33910.	0.17
82	382.6	0.461	107.88	1.284	17.57	32740.	34276.	0.15
82	371.0	0.461	107.88	1.463	16.51	35040.	37206.	0.14
82	368.1	0.461	107.88	1.526	16.12	35768.	38243.	0.13
82	347.5	0.461	107.88	1.745	14.33	38060.	40989.	0.14
82	358.4	0.461	107.89	1.466	18.26	37200.	35670.	0.13
82	313.0	0.461	107.88	1.494	21.41	43105.	45017.	0.12

FREON-12 CHF DATA, GROENEVELD (1969)

TABLE I - FREON-12 DRYOUT DATA

RUN	D INCHES	L INCHES	G E-6 LB/HR FT^2	X	CHF BTU/HR FT^2	INLET SUBC BTU/LB	P PSIA
1.	.431	72.00	.383	.732	23360	1.31	155.0
2.	.431	72.00	.385	.730	24240	2.79	155.7
3.	.431	72.00	.387	.718	25290	5.05	155.7
4.	.431	72.00	.399	.679	27130	8.98	157.0
6.	.431	72.00	.490	.647	25703	.10	153.5
7.	.431	72.00	.490	.638	26900	2.18	153.5
8.	.431	72.00	.474	.646	28417	5.20	154.0
9.	.431	72.00	.492	.602	30384	8.84	155.0
10.	.431	72.00	.505	.566	32177	12.04	155.2
11.	.431	72.00	.768	.459	29694	1.07	154.2
12.	.431	72.00	.765	.450	31586	3.33	154.5
13.	.431	72.00	.742	.446	34259	6.89	155.5
14.	.431	72.00	.749	.426	35967	9.23	156.5
15.	.431	72.00	.771	.386	38235	12.30	154.8
16.	.431	72.00	.942	.391	30990	.91	155.0
17.	.431	72.00	.914	.386	32397	2.88	155.5
18.	.431	72.00	.977	.340	35531	6.03	156.5
19.	.431	72.00	.977	.339	38245	7.87	153.5
20.	.431	72.00	.993	.286	40838	12.04	155.2
21.	.431	72.00	1.512	.270	33919	.46	156.0
22.	.431	72.00	1.506	.246	36693	3.01	155.0
23.	.431	72.00	1.516	.208	39431	6.16	156.0
23.1	.431	72.00	1.541	.228	40267	5.15	152.5
24.	.431	72.00	1.538	.191	42740	8.32	156.5
25.	.431	72.00	1.556	.145	45479	11.71	154.8
26.	.431	72.00	1.940	.221	36382	.64	156.5
26.1	.431	72.00	1.924	.215	36676	1.18	157.2
27.	.431	72.00	1.943	.192	40177	3.46	154.5
28.	.431	72.00	1.961	.167	41479	5.13	155.0
29.	.431	72.00	1.952	.126	43707	8.19	155.0
30.	.431	72.00	1.984	.077	47697	11.93	157.0
31.	.431	65.01	.496	.622	28656	1.39	155.2
32.	.431	65.01	.497	.605	29476	3.11	155.7
33.	.431	65.01	.499	.590	30967	5.56	153.2
34.	.431	65.01	.497	.573	32347	8.45	155.5
35.	.431	65.01	.500	.548	34884	12.61	155.5
36.	.431	65.01	.997	.361	34280	1.29	155.5
37.	.431	65.01	.987	.347	36452	3.56	154.2
38.	.431	65.01	.996	.325	38657	5.91	155.0
39.	.431	65.01	.984	.300	41334	9.17	155.5
40.	.431	65.01	1.004	.279	43932	11.35	154.0
41.	.431	65.01	1.987	.207	38436	.52	155.5
42.	.431	65.01	1.987	.177	40863	2.88	154.0
43.	.431	65.01	1.981	.127	43976	6.58	156.2
44.	.431	65.01	1.981	.100	46991	8.91	155.0
45.	.431	65.01	1.981	.078	51019	11.35	155.5

TABLE I (Cont'd.)

RUN	D INCHES	L INCHES	G E-6 $LB/HR\ FT^2$	X	CHF $BTU/HR\ FT^2$	INLET SUBC BTU/LB	P PSIA
46.	.431	66.61	.417	.711	26280	.63	155.2
47.	.431	66.61	.418	.695	26935	2.41	154.8
48.	.431	66.61	.405	.706	28570	5.59	154.5
49.	.431	66.61	.414	.682	30380	8.68	155.2
50.	.431	66.61	.412	.659	31462	11.71	154.8
51.	.431	66.61	.844	.414	32165	1.31	156.7
52.	.431	66.61	.842	.395	34263	3.93	156.7
53.	.431	66.61	.849	.381	36735	6.21	154.8
54.	.431	66.61	.849	.360	38991	9.00	155.2
55.	.431	66.61	.849	.340	41635	11.97	154.8
56.	.431	66.61	1.657	.246	37206	.63	155.2
57.	.431	66.61	1.657	.226	39412	2.56	155.5
58.	.431	66.61	1.657	.196	42198	5.20	155.0
59.	.431	66.61	1.659	.154	44789	8.38	155.5
60.	.431	66.61	1.627	.123	48072	11.67	156.0
63.	.431	33.37	.420	.550	41966	1.38	156.7
64.	.431	33.37	.415	.541	44088	3.72	155.5
65.	.431	33.37	.416	.534	45106	4.87	155.5
66.	.431	33.37	.412	.503	47485	8.64	156.0
67.	.431	33.37	.412	.466	49661	12.27	156.0
68.	.431	33.37	.846	.290	45953	1.24	156.7
69.	.431	33.37	.840	.274	48760	3.23	156.2
70.	.431	33.37	.833	.249	52586	6.14	154.8
71.	.431	33.37	.847	.215	55812	8.88	156.2
72.	.431	33.37	.843	.182	59745	12.10	154.8
73.	.431	33.37	1.660	.146	46842	.87	156.2
74.	.431	33.37	1.669	.107	50400	3.58	156.5
75.	.431	33.37	1.660	.071	56530	6.74	156.5
76.	.431	33.37	1.665	.055	60270	8.25	155.5
77.	.431	33.37	1.656	.018	70010	12.14	154.0
78.	.431	51.18	.496	.580	33467	.81	155.7
79.	.431	51.18	.497	.562	34822	3.03	155.7
80.	.431	51.18	.497	.536	36817	6.33	155.7
81.	.431	51.18	.489	.534	38018	8.13	155.5
82.	.431	51.18	.488	.507	39851	11.48	155.0
83.	.431	51.18	.993	.321	39184	1.48	155.5
84.	.431	51.18	.995	.298	41242	3.64	156.0
85.	.431	51.18	.995	.275	43756	6.15	159.0
86.	.431	51.18	.993	.258	46881	8.51	155.0
87.	.431	51.18	.989	.226	50351	11.97	153.2
88.	.431	51.18	1.978	.171	41094	.66	155.5
89.	.431	51.18	1.984	.130	43461	3.39	155.0
90.	.431	51.18	1.984	.092	48153	6.55	155.5
91.	.431	51.18	1.987	.066	52802	9.07	155.7
92.	.431	51.18	1.982	.041	52830	11.41	153.5
93.	.307	43.09	.554	.603	33282	1.20	154.5
94.	.307	43.09	.560	.584	35188	3.75	154.8

TABLE I (Cont'd.)

RUN	D	L	G E-6	X	CHF	INLET SUBC	P
	INCHES	INCHES	$LB/HR\ FT^2$		$BTU/HR\ FT^2$	BTU/LB	PSIA
95.	.307	43.09	.555	.571	36801	6.46	155.0
96.	.307	43.09	.574	.528	39186	9.88	155.5
98.	.307	43.18	1.183	.335	39747	.81	153.0
99.	.307	43.18	1.196	.324	41555	2.04	154.2
100.	.307	43.18	1.194	.297	45078	5.20	154.0
101.	.307	43.18	1.194	.274	45860	6.84	154.8
102.	.307	43.18	1.196	.230	52801	12.51	157.0
103.	.307	43.18	2.359	.179	43480	.76	157.2
104.	.307	43.18	2.356	.140	46081	3.46	157.0
105.	.307	43.18	2.356	.120	48333	5.08	154.7
106.	.307	43.18	2.369	.083	54644	8.48	154.2
107.	.307	43.18	2.356	.054	60396	11.49	154.8
108.	.307	36.44	.552	.571	38032	1.91	155.2
109.	.307	36.44	.548	.564	38708	3.14	155.2
110.	.307	36.44	.552	.541	40474	5.65	154.8
111.	.307	36.44	.557	.496	43881	10.66	154.8
113.	.307	36.44	1.097	.323	41964	.77	156.0
114.	.307	36.44	1.091	.310	45109	2.96	156.7
115.	.307	36.44	1.099	.288	47730	5.14	156.0
116.	.307	36.44	1.091	.257	51344	8.47	153.0
117.	.307	36.44	1.092	.234	54062	10.90	155.0
118.	.307	36.44	2.176	.165	45536	1.04	155.7
119.	.307	36.44	2.179	.140	47744	2.89	155.7
120.	.307	36.44	2.182	.098	54020	6.49	155.2
121.	.307	36.44	2.208	.065	61028	9.61	157.0
122.	.307	36.44	2.208	.046	66790	11.89	156.2
124.	.307	23.70	.393	.615	46115	3.17	155.5
125.	.307	23.70	.408	.577	49084	6.03	154.5
126.	.307	23.70	.399	.548	50979	10.00	155.2
128.	.307	23.70	.815	.326	49863	1.37	155.5
129.	.307	23.70	.790	.324	51926	2.86	155.5
130.	.307	23.70	.798	.284	56769	6.64	155.2
131.	.307	23.70	.802	.250	60770	9.89	154.0
133.	.307	23.67	1.575	.180	51759	.44	155.0
134.	.307	23.67	1.575	.152	54120	2.42	155.2
135.	.307	23.67	1.575	.107	59876	5.98	155.7
136.	.307	23.67	1.575	.085	65147	8.21	155.7
137.1	.307	23.67	2.205	.000	89120	12.48	154.0
137.2	.307	23.67	1.577	.040	76910	12.86	155.7
139.	.307	47.34	.394	.732	27630	3.75	154.8
140.	.307	47.34	.403	.734	30040	6.36	153.0
141.	.307	47.34	.408	.721	31380	8.47	153.0
143.	.307	47.34	.777	.473	34085	1.48	153.0
144.	.307	47.34	.790	.461	35300	2.68	154.0
145.	.307	47.34	.792	.437	37334	5.50	154.8
146.	.307	47.34	.799	.400	40413	9.71	157.0
148.	.307	47.34	1.573	.276	39901	.78	155.2

TABLE I (Cont'd.)

RUN	D INCHES	L INCHES	G E-6 LB/HR FT^2	X	CHF BTU/HR FT^2	INLET SUBC BTU/LB	P PSIA
149.	.307	47.34	1.573	.263	42032	2.31	154.8
150.	.307	47.34	1.575	.229	45600	5.52	154.5
151.	.307	47.34	1.573	.203	47879	7.84	154.5
152.	.307	47.34	1.588	.145	52832	12.71	156.5
153.	.307	46.34	.529	.631	31212	1.64	154.8
154.	.307	46.34	.536	.615	32344	3.28	154.2
155.	.307	46.34	.554	.582	34454	6.20	155.0
156.	.307	46.34	.564	.551	36935	9.89	156.0
158.	.307	46.31	1.089	.379	37709	.45	154.2
159.	.307	46.31	1.089	.354	39974	3.10	155.7
160.	.307	46.31	1.083	.340	42804	5.49	154.2
161.	.307	46.31	1.089	.306	46407	9.25	156.2
162.	.307	46.31	1.076	.291	48302	11.41	154.5
163.	.307	46.31	2.176	.206	42456	.67	156.5
164.	.307	46.31	2.176	.169	45243	3.47	156.2
165.	.307	46.31	2.176	.141	47616	5.59	154.2
166.	.307	46.31	2.189	.093	52787	9.59	158.5
167.	.307	46.31	2.176	.076	57642	11.86	153.2
168.	.307	54.98	.555	.642	27931	1.46	154.5
169.	.307	54.98	.542	.640	28666	3.34	154.8
170.	.307	54.98	.555	.608	30310	6.38	154.8
171.	.307	54.98	.557	.594	31853	9.03	155.7
173.	.307	54.90	1.184	.378	34208	.32	155.7
174.	.307	54.90	1.184	.370	36038	1.86	155.2
175.	.307	54.90	1.181	.344	39984	5.62	153.3
176.	.307	54.90	1.171	.324	42578	8.55	155.2
177.	.307	54.90	1.171	.286	46212	12.80	155.2
178.	.307	54.90	2.365	.214	40693	.84	157.5
179.	.307	54.90	2.362	.189	42790	2.82	157.2
180.	.307	54.90	2.346	.161	45329	5.11	152.5
181.	.307	54.90	2.359	.110	50296	9.31	153.5
182.	.307	54.90	2.382	.080	56421	12.60	153.7
183.	.307	53.84	.543	.638	27973	1.67	153.7
184.	.307	53.84	.534	.645	28742	2.88	153.5
185.	.307	53.84	.555	.604	31002	6.61	155.0
186.	.307	53.84	.551	.589	32615	9.75	154.5
188.	.307	53.81	1.089	.398	34097	.55	155.5
189.	.307	53.81	1.089	.388	34923	1.55	154.8
190.	.307	53.81	1.092	.355	36687	4.39	154.5
191.	.307	53.81	1.091	.346	41378	7.98	155.2
192.	.307	53.81	1.064	.326	44915	11.96	152.0
193.	.307	53.81	2.170	.223	40477	1.12	157.2
194.	.307	53.81	2.170	.204	42720	2.79	154.5
195.	.307	53.81	2.170	.168	45197	5.54	154.2
196.	.307	53.81	2.170	.131	48509	8.65	156.0
197.	.307	53.81	2.183	.096	52619	11.75	157.5
201.	.307	71.31	.410	.775	19930	3.55	156.5

TABLE I (Cont'd.)

RUN	D INCHES	L INCHES	G E-6 LB/HR FT^2	X	CHF BTU/HR FT^2	INLET SUBC BTU/LB	P PSIA
202.	.307	71.31	.390	.790	20360	5.96	154.8
203.	.307	71.31	.407	.752	22020	9.70	153.8
205.	.307	71.31	.779	.530	24710	.83	153.5
206.	.307	71.31	.742	.534	25310	3.02	158.0
207.	.307	71.31	.776	.502	26890	5.14	154.8
208.	.307	71.31	.779	.473	29520	9.73	154.8
210.	.307	70.56	1.586	.330	32083	.87	156.0
211.	.307	70.56	1.586	.314	33998	2.79	155.7
212.	.307	70.56	1.586	.294	37182	5.70	154.8
213.	.307	70.56	1.586	.277	39197	7.80	156.2
214.	.307	70.56	1.573	.239	43421	12.46	154.2
215.	.307	60.75	.564	.645	25857	1.62	156.2
216.	.307	60.75	.544	.648	26590	3.75	154.8
217.	.307	60.75	.566	.615	28278	6.44	155.2
218.	.307	60.75	.564	.605	29718	9.12	155.2
220.	.307	60.81	1.194	.382	32116	.74	156.2
221.	.307	60.81	1.181	.374	33686	2.45	155.5
222.	.307	60.81	1.181	.359	35798	4.68	156.0
223.	.307	60.81	1.181	.339	39214	8.01	154.2
224.	.307	60.81	1.168	.311	42704	12.24	155.7
225.	.307	60.81	2.346	.237	38798	.33	154.5
226.	.307	60.81	2.359	.216	40901	2.07	154.5
227.	.307	60.81	2.356	.173	44408	5.60	153.5
228.	.307	60.81	2.369	.132	46611	8.45	153.2
229.	.307	60.81	2.359	.090	51839	12.54	154.5
230.	.633	72.00	.453	.552	31341	1.78	155.4
231.	.633	72.00	.453	.538	32265	3.47	155.3
232.	.633	72.00	.452	.522	33734	5.84	154.7
233.	.633	72.00	.450	.510	35224	8.05	153.7
234.	.633	72.00	.453	.498	38827	12.02	153.0
235.	.633	72.00	.909	.313	36689	1.54	155.5
236.	.633	72.00	.901	.295	38527	3.55	154.7
237.	.633	72.00	.909	.264	41554	6.58	154.4
238.	.633	72.00	.907	.238	44322	9.46	155.7
239.	.633	72.00	.903	.225	47199	11.67	155.7
240.	.633	72.00	1.824	.155	39120	1.43	158.1
241.	.633	72.00	1.809	.134	40910	3.09	154.7
242.	.633	72.00	1.826	.090	45586	6.59	156.5
243.	.633	72.00	1.808	.065	49585	8.95	155.4
245.	.633	61.99	.413	.570	33514	.93	153.0
246.	.633	61.99	.417	.546	34752	3.36	157.3
247.	.633	61.99	.410	.540	36425	5.74	155.5
248.	.633	61.99	.405	.529	37880	8.13	154.7
249.	.633	61.99	.416	.481	40945	12.72	156.5
250.	.633	61.99	.825	.319	38137	.95	155.8
251.	.633	61.99	.829	.297	41479	3.55	153.0
252.	.633	61.99	.831	.261	44390	6.90	157.0

TABLE I (Cont'd.)

RUN	D INCHES	L INCHES	G E-6 LB/HR FT^2	X	CHF BTU/HR FT^2	INLET SUBC BTU/LB	P PSIA
253.	.633	61.99	.830	.235	47020	9.61	158.9
254.	.633	61.99	.832	.207	50650	12.72	155.7
255.	.633	61.99	1.663	.143	41400	2.07	157.0
256.	.633	61.99	1.486	.138	43804	4.14	156.5
257.	.633	61.99	1.654	.100	46620	5.62	153.0
258.	.633	61.99	1.658	.062	52636	9.10	156.2
259.	.633	61.99	1.651	.040	56844	11.34	154.8
260.	.633	51.00	.378	.566	37580	1.56	154.8
261.	.633	51.00	.375	.563	38496	2.71	154.6
262.	.633	51.00	.374	.543	40200	5.35	154.1
263.	.633	51.00	.376	.523	42772	8.36	152.8
264.	.633	51.00	.374	.487	44509	12.15	157.0
265.	.633	51.00	.756	.302	41673	1.54	157.2
266.	.633	51.00	.754	.285	44106	3.49	155.4
267.	.633	51.00	.754	.260	47250	6.24	156.6
268.	.633	51.00	.755	.232	50959	9.24	155.2
269.	.633	51.00	.751	.210	53714	11.76	155.6
270.	.633	51.00	1.511	.144	42835	1.38	157.2
271.	.633	51.00	1.505	.121	45474	3.23	156.2
272.	.633	51.00	1.509	.081	51170	6.56	157.9
273.	.633	51.00	1.508	.056	56415	9.04	154.5
274.	.633	51.00	1.501	.027	61349	11.74	155.8
275.	.633	25.50	.377	.407	53610	.96	154.6
276.1	.633	25.50	.374	.396	54910	2.23	153.6
276.2	.633	25.50	.374	.403	55510	2.13	153.6
277.	.633	25.50	.376	.370	58310	5.00	153.8
278.	.633	25.50	.376	.343	63110	8.57	154.4
279.	.633	25.50	.374	.317	66610	11.58	153.8
280.	.633	25.50	.754	.197	54850	1.13	156.8
281.	.633	25.50	.753	.178	59480	3.15	154.7
282.	.633	25.50	.753	.148	65040	5.96	155.6
283.	.633	25.50	.753	.117	71470	8.99	156.5
284.	.633	25.50	.753	.092	78100	11.75	156.7
285.	.633	25.50	1.508	.090	54940	1.03	156.0
286.	.633	25.50	1.512	.046	59930	3.93	156.9
288.	.633	25.50	1.504	-.018	73880	8.90	157.1
287.	.633	25.50	1.503	.023	64240	5.64	155.6
289.	.633	25.50	1.503	-.054	84410	11.97	155.6
289.1	.633	25.50	1.503	-.056	85080	12.11	157.1
289.2	.633	25.50	1.503	-.062	84430	12.35	158.5

HELIUM CHF DATA, KATTO (1983)

EXPT NO	p	d	l/d	G	ΔH$_i$	q$_i$	X$_{ex}$	q$_{co}$	K
	MPa	mm		kg/m^{2}s	kJ/kg	kW/m^2		kW/m^2	
1	0.199	1.0	25	10.47	5.3740	1.161[illegible]	0.50570	0.7748	1.0740
2	0.199	1.0	25	10.47	3.5260	1.0230	0.55240		
3	0.199	1.0	25	10.47	1.7770	0.9279	0.62700		
4	0.199	1.0	25	10.47	-0.0683	0.7982	0.68070		
5	0.199	1.0	25	10.47	-1.8920	0.6062	0.67980		
6	0.199	1.0	25	17.46	5.3740	1.2600	0.16300	0.8418	1.094[illegible]
7	0.199	1.0	25	17.46	3.5400	1.1630	0.27610		
8	0.199	1.0	25	17.46	1.7170	0.9688	0.33900		
9	0.199	1.0	25	17.46	-0.1061	0.8399	0.43500		
10	0.199	1.0	25	17.46	-1.9190	0.6785	0.51370		
11	0.199	1.0	25	24.48	5.5360	1.4260	0.02558	0.9642	0.9962
12	0.199	1.0	25	24.48	2.9220	1.2140	0.18020		
13	0.199	1.0	25	24.48	0.3317	1.0160	0.33790		
14	0.199	1.0	25	24.48	-2.2490	0.75[illegible]8	0.47260		
15	0.199	1.0	25	35.02	5.5360	1.6620	-0.06992	1.0910	1.0970
16	0.199	1.0	25	35.02	3.7170	1.4820	0.04556		
17	0.199	1.0	25	35.02	1.8880	1.3180	0.16590		
18	0.199	1.0	25	35.02	0.0780	1.1130	0.27430		
19	0.199	1.0	25	35.02	-1.7390	0.8675	0.37710		
20	0.199	1.0	25	52.97	5.5900	2.0340	-0.15480	1.2740	1.22[illegible]
21	0.199	1.0	25	52.97	4.3880	1.902[illegible]	-0.07038		
22	0.199	1.0	25	52.97	3.1520	1.7140	0.00742		
23	0.199	1.0	25	52.97	1.9600	1.5230	0.08349		
24	0.199	1.0	25	52.97	0.7238	1.7690	0.16450		
25	0.199	1.0	25	52.97	-0.4781	1.217[illegible]	0.24490		
26	0.199	1.0	25	52.97	-1.5040	1.0640	0.31080		
27	0.199	1.0	25	70.84	5.5760	2.5[illegible]	-0.1655[illegible]	1.6840	1.1220
28	0.199	1.0	25	70.84	4.6750	2.4480	-0.10790		
29	0.199	1.0	25	70.84	3.5740	2.3[illegible]	-0.02821		
30	0.199	1.0	25	70.84	2.09[illegible]	2.0980	0.07686		
31	0.199	1.0	25	70.84	1.1890	1.8[illegible]	0.12460		
32	0.199	1.0	25	70.84	0.3076	1.717[illegible]	0.18670		
33	0.199	1.0	25	70.84	-0.6051	1.5950	0.25280		
34	0.199	1.0	25	70.84	-1.5530	1.4210	0.31490		
35	0.199	1.0	25	82.01	5.0060	3.15[illegible]	-0.17050	2.151[illegible]	.6777
36	0.199	1.0	25	82.01	4.4400	2.915[illegible]	-0.07836		
37	0.199	1.0	25	82.01	2.8770	2.6770	0.03426		
38	0.199	1.0	25	82.01	1.3360	2.37[illegible]	0.13840		
39	0.199	1.0	25	82.01	-0.2109	2.0970	0.24490		
40	0.199	1.0	25	89.51	5.3740	3.3210	-0.14720	------	-----
41	0.199	1.0	25	89.51	4.6600	3.2430	-0.09176		
42	0.199	1.0	25	89.51	3.9490	3.3270	-0.02093		
43	0.199	1.0	25	89.51	3.2440	3.4980	0.05875		
44	0.199	1.0	25	39.51	1.1120	3.3700	0.23080		
45	0.199	1.	25	89.51	-0.5049	3.0720	0.34830		
46	0.199	1.0	50	10.52	2.3900	0.6545	0.88960	0.5348	1.1040
47	0.199	1.0	50	10.52	-0.6638	0.5133	0.92230		
48	0.199	1.0	50	10.52	-2.6390	0.3888	0.88760		
49	0.199	1.0	50	17.58	5.0300	0.9419	0.50310	0.6460	1.03[illegible]0
50	0.199	1.0	50	17.58	1.3800	0.7307	0.61350		
51	0.199	1.0	50	17.58	-0.4120	0.6192	0.65980		
52	0.199	1.0	50	17.58	-2.2570	0.5128	0.71610		
53	0.199	1.0	50	24.47	5.8480	1.1310	0.29980	0.7310	1.0510
54	0.199	1.0	50	24.47	3.1960	0.9436	0.39910		
55	0.199	1.0	50	24.49	0.5800	0.7718	0.50640		
56	0.199	1.0	50	24.49	-1.6900	0.6167	0.59520		
57	0.199	1.0	50	35.25	5.8480	1.2320	0.10100	0.7838	1.0650
58	0.199	1.0	50	35.25	4.0220	1.0800	0.18630		

EXPT NO	p MPa	d mm	l/d	G kg/m²s	ΔHᵢ kJ/kg	qc kW/m²	Xex	qco kW/m²	K
[illegible]	0.199	1.0	50	35.25	2.2180	0.9425	0.[illegible]690		
[illegible]	0.199	1.0	50	35.25	0.3901	0.8120	0.37310		
[illegible]	0.199	1.0	50	35.25	-1.3670	0.6915	0.46810		
[illegible]	0.199	1.0	50	35.25	-3.1140	0.5462	0.54980		
[illegible]	0.199	1.0	50	53.11	5.4280	1.678[illegible]	0.07884	1.0410	1.3060
[illegible]	0.199	1.0	50	53.11	4.2050	1.5610	0.14300		
[illegible]	0.199	1.0	50	53.11	3.0160	1.3910	0.19660		
[illegible]	0.199	1.0	50	53.11	1.8080	1.2820	0.26[illegible]20		
[illegible]	0.199	1.0	50	53.11	0.5855	1.1310	0.32500		
[illegible]	0.199	1.0	50	53.11	-0.5499	0.9478	0.36450		
[illegible]	0.199	1.0	50	71.10	5.4280	2.34[illegible]0	0.10230	1.3990	1.4300
[illegible]	0.199	1.0	50	71.10	3.6090	2.0590	0.19310		
[illegible]	0.199	1.0	50	71.10	1.8130	1.7360	0.27170		
[illegible]	0.199	1.0	50	71.10	0.9483	1.5620	0.30480		
[illegible]	0.199	1.0	50	71.10	0.0226	1.3890	0.34370		
[illegible]	0.199	1.0	50	89.30	4.5600	2.6270	0.11710	1.4950	1.8380
[illegible]	0.199	1.0	50	89.30	3.1060	2.1930	0.15770		
[illegible]	0.199	1.0	50	89.30	1.6750	1.9270	0.23360		
[illegible]	0.199	1.0	50	107.60	5.8480	3.5220	0.06181	------	------
[illegible]	0.199	1.0	50	107.60	5.2470	3.4390	0.10130		
[illegible]	0.199	1.0	50	107.60	4.6560	3.3500	0.13880		
[illegible]	0.199	1.0	50	107.60	4.0620	3.2680	0.17800		
[illegible]	0.199	1.0	50	107.60	3.4690	3.1610	0.21620		
[illegible]	0.199	1.0	50	107.60	2.8670	3.1010	0.25630		
[illegible]	0.199	1.0	50	107.60	2.2960	3.1030	0.30720		
[illegible]	0.199	1.0	100	10.56	5.4280	0.4100	0.89400	0.7663	1.1110
[illegible]	0.199	1.0	100	10.56	2.4230	0.7258	0.87760		
[illegible]	0.199	1.0	100	10.56	-0.6465	0.2526	0.90390		
[illegible]	0.199	1.0	100	10.56	-3.6450	0.1700	[illegible]		
[illegible]	0.199	1.0	100	17.64	6.9500	0.5347	0.45790	0.3[illegible]	1.1850
[illegible]	0.199	1.0	100	17.64	3.2940	0.4094	0.53000		
	0.199	1.0	100	17.64	-0.3006	0.3007	0.62990		
[illegible]	0.199	1.0	100	24.75	6.2490	0.6359	0.36210	0.35[illegible]6	1.1590
[illegible]	0.199	1.0	100	24.75	3.6410	0.5749	0.44280		
[illegible]	0.199	1.0	100	24.75	1.0630	0.4393	0.53490		
[illegible]	0.199	1.0	100	24.75	1.5070	0.3264	0.60[illegible]10		
[illegible]	0.199	1.0	100	35.44	5.6480	0.9220	0.40280	0.4978	1.6820
[illegible]	0.199	1.0	100	35.44	4.0300	[illegible]	0.43790		
	0.199	1.0	100	35.44	2.2310	0.6778	0.47950		
	0.199	1.0	100	35.44	0.4195	0.5360	0.49820		
[illegible]	0.199	1.0	100	35.44	-1.[illegible]	0.3010	0.50520		
	0.199	1.0	100	53.51	5.8480	1.1550	0.24550	0.6727	1.3020
	0.199	1.0	100	53.51	4.6540	1.0150	0.25950		
[illegible]	0.199	1.0	100	53.51	3.4580	0.9216	0.30360		
[illegible]	0.199	1.0	100	53.51	2.2350	0.8267	0.35570		
[illegible]	0.199	1.0	100	53.51	1.0410	0.7551	0.40750		
[illegible]	0.199	1.0	100	53.51	-0.1165	0.6786	0.45930		
[illegible]	0.199	1.0	100	71.21	4.560	1.4690	0.32060	0.8433	1.7700
[illegible]	0.199	1.0	100	71.21	3.6550	1.2070	0.32620		
[illegible]	0.199	1.0	100	71.21	2.7600	1.2080	0.35620		
[illegible]	0.199	1.0	100	71.21	1.8600	1.1080	0.38610		
	0.199	1.0	100	71.21	0.9487	0.9662	0.39630		
[illegible]	0.199	1.0	100	89.38	5.8480	2.0770	0.[illegible]100	------	------
[illegible]	0.199	1.0	100	89.38	5.1290	2.0170	0.34490		
[illegible]	0.199	1.0	100	89.38	4.0760	2.0110	0.43570		
[illegible]	0.199	1.0	100	89.38	3.7030	1.9150	0.44260		
[illegible]	0.199	1.0	100	89.38	2.9770	2.0700	0.55950		
[illegible]	0.199	1.0	100	89.38	2.2960	2.0120	0.59360		
[illegible]	0.199	1.0	100	89.38	1.5900	2.0140	0.65690		

FREON-114 CHF DATA, DIX (1970)

APPENDIX A

FREON-114 CRITICAL HEAT FLUX DATA FOR A ROUND TUBE

RUN IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
101568001	0.3930	39.7500	122.0000	0.6537	7.5880	0.3849	0.3564
101568002	0.3930	39.7500	122.0000	0.6145	7.4130	0.3683	0.3696
101568003	0.3930	39.7500	122.0000	0.5342	7.3470	0.3481	0.4178
101568004	0.3930	39.7500	124.0000	0.8864	6.3640	0.4016	0.2635
101568005	0.3930	39.7500	127.0000	1.0533	5.8220	0.3984	0.2098
101568006	0.3930	39.7500	120.0000	1.2270	5.4020	0.3948	0.1660
101568007	0.3930	39.7500	126.0000	1.3904	5.2650	0.4036	0.1428
101568008	0.3930	39.7500	123.0000	0.3550	8.1630	0.3002	0.5740
101568009	0.3930	39.7500	121.0000	1.5319	17.4870	0.6911	0.0125
101568010	0.3930	39.7500	120.0000	1.3410	17.2000	0.6428	0.0439
101568011	0.3930	39.7500	124.0000	1.1487	18.1660	0.6186	0.0756
101568012	0.3930	39.7500	127.0000	0.9489	19.9230	0.5794	0.1015
101568013	0.3930	39.7500	123.0000	0.7532	19.3540	0.5378	0.2059
101568014	0.3930	39.7500	121.0000	0.5775	20.5080	0.4776	0.2801
101568015	0.3930	39.7500	122.0000	0.3804	20.5900	0.3964	0.4708
101568016	0.3930	39.7500	122.0000	1.4014	2.1590	0.3564	0.1789
101568017	0.3930	39.7500	124.0000	1.3959	2.0470	0.3525	0.1805
101568018	0.3930	39.7500	124.0000	1.2208	2.0640	0.3489	0.2099
101568019	0.3930	39.7500	124.0000	1.0444	2.2510	0.3509	0.2507
101568020	0.3930	39.7500	124.0000	0.8761	2.4280	0.3481	0.3017
101568021	0.3930	39.7500	122.0000	0.6956	2.4860	0.3279	0.3654
101568022	0.3930	39.7500	122.0000	0.5232	3.3240	0.3038	0.4443
101568023	0.3930	39.7500	123.0000	0.3241	4.1020	0.2693	0.6517
101568024	0.3930	39.7500	127.0000	1.3588	1.5180	0.3497	0.1978
101568025	0.3930	39.7500	127.0000	1.2188	1.6340	0.3485	0.2210
101568026	0.3930	39.7500	128.0000	1.0402	1.5630	0.3493	0.2681
101568027	0.3930	39.7500	128.0000	0.8700	2.1230	0.3438	0.3091
101568028	0.3930	39.7500	128.0000	0.6969	2.3190	0.3287	0.3738
101568029	0.3930	39.7500	127.0000	0.4882	2.7170	0.2931	0.4801
101568030	0.3930	39.7500	127.0000	0.3474	3.6020	0.2701	0.6198
101768001	0.3930	39.7500	122.0000	1.4096	3.3660	0.3743	0.1619
101768002	0.3930	39.7500	122.0000	1.2380	3.4540	0.3731	0.1920
101768003	0.3930	39.7500	124.0000	1.0601	3.6050	0.3695	0.2316
101768004	0.3930	39.7500	122.0000	0.8844	3.6470	0.3679	0.2900
101768005	0.3930	39.7500	123.0000	0.7045	4.0290	0.3568	0.3630
101768006	0.3930	39.7500	124.0000	0.5198	4.0410	0.3208	0.4627
101768007	0.3930	39.7500	123.0000	0.3467	5.1280	0.2899	0.6333
101768008	0.3930	39.7500	124.0000	1.4158	3.6780	0.3782	0.1570
101768009	0.3930	39.7500	123.0000	1.2263	3.6090	0.3770	0.1943
101768010	0.3930	39.7500	124.0000	1.0601	3.8770	0.3719	0.2276
101768011	0.3930	39.7500	123.0000	0.8803	3.7220	0.3687	0.2915
101768012	0.3930	39.7500	121.0000	0.6962	3.8970	0.3477	0.3582
101768013	0.3930	39.7500	124.0000	0.5232	4.3590	0.3145	0.4412
101768014	0.3930	39.7500	125.0000	0.3495	5.0930	0.2836	0.6145
102168009	0.3930	39.7500	123.0000	1.4673	14.5280	0.5889	0.0341
102168010	0.3930	39.7500	125.0000	1.3101	14.7840	0.5636	0.0544
102168011	0.3930	39.7500	125.0000	1.1219	15.6890	0.5323	0.0738
102168012	0.3930	39.7500	124.0000	0.9297	15.3500	0.5125	0.1502
102168013	0.3930	39.7500	125.0000	0.7532	15.7150	0.4784	0.2176
102168014	0.3930	39.7500	125.5000	0.5534	15.3220	0.4194	0.3370
102168015	0.3930	39.7500	125.0000	0.3694	15.5210	0.3537	0.5115
101868001	0.3930	59.0600	122.0000	1.3787	2.4540	0.3051	0.2388
101868002	0.3930	59.0600	122.0000	1.2174	2.6310	0.3068	0.2756
101868003	0.3930	59.0600	124.0000	1.0416	2.6970	0.2977	0.3202
101868004	0.3930	59.0600	124.0000	0.8727	2.8130	0.2788	0.3625
101868005	0.3930	59.0600	125.0000	0.7004	3.2120	0.2591	0.4216
101868006	0.3930	59.0600	125.0000	0.5232	3.7000	0.2322	0.5092
101868007	0.3930	59.0600	125.0000	0.3488	4.4330	0.2106	0.7062

RUN IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
101868008	0.3930	59.0600	125.0000	1.3918	2.2360	0.3044	0.2417
101868009	0.3930	59.0600	124.0000	1.2174	2.4130	0.2999	0.2740
101868010	0.3930	59.0600	124.0000	1.0444	2.5460	0.2940	0.3179
101868011	0.3930	59.0600	124.0000	0.8686	2.5890	0.2745	0.3629
101868012	0.3930	59.0600	124.0000	0.7004	3.6530	0.2532	0.3997
101868013	0.3930	59.0600	123.0000	0.5184	3.1160	0.2290	0.5175
101868014	0.3930	59.0600	123.0000	0.3296	4.3570	0.2090	0.7455
101868015	0.3930	59.0600	124.0000	1.4186	5.3980	0.3297	0.1886
101868016	0.3930	59.0600	122.0000	1.2291	4.7330	0.3260	0.2462
101868017	0.3930	59.0600	125.0000	1.0670	5.1810	0.3214	0.2856
101868018	0.3930	59.0600	125.0000	0.8706	5.0460	0.2985	0.3442
101868019	0.3930	59.0600	125.0000	0.6935	5.4020	0.2748	0.4075
101868020	0.3930	59.0600	123.0000	0.5184	5.5940	0.2415	0.4941
101868021	0.3930	59.0600	124.0000	0.3454	6.1450	0.2196	0.7092
102168001	0.3930	59.0600	123.0000	2.8825	8.9520	0.5176	0.0385
102168002	0.3930	59.0600	123.0000	1.5271	19.3580	0.5376	0.0350
102168003	0.3930	59.0600	124.0000	1.3437	19.4600	0.4984	0.0579
102168004	0.3930	59.0600	123.0000	1.1432	19.7290	0.4675	0.1023
102168005	0.3930	59.0600	124.0000	0.9599	20.0670	0.4403	0.1612
102168006	0.3930	59.0600	124.0000	0.7718	19.9260	0.4027	0.2484
102168007	0.3930	59.0600	123.0000	0.5417	20.4040	0.3468	0.3946
102168008	0.3930	59.0600	124.0000	0.3811	20.5240	0.2937	0.5666
102168016	0.3930	59.5000	124.5000	1.4975	15.7340	0.4654	0.0645
102168017	0.3930	59.5000	126.0000	1.3094	15.5350	0.4403	0.1035
102168018	0.3930	59.5000	125.0000	1.1329	15.8240	0.4217	0.1451
102158019	0.3930	59.5000	125.0000	0.9366	15.8040	0.3961	0.2137
102168020	0.3930	59.5000	125.5000	0.7450	15.6950	0.3651	0.3068
102168021	0.3930	59.5000	127.0000	0.5623	15.8240	0.3216	0.4152
102168022	0.3930	59.5000	124.5000	0.3749	15.8040	0.2667	0.6010
102368043	0.5090	36.0000	122.5000	0.3529	5.3050	0.3552	0.5177
102368044	0.5090	36.0000	125.0000	0.5266	5.5390	0.3866	0.3420
102268045	0.5090	36.0000	123.5000	0.7010	5.4390	0.4043	0.2435
102368046	0.5090	36.0000	124.5000	1.0540	5.3060	0.4248	0.1368
102368047	0.5090	36.0000	124.0000	0.8803	5.3940	0.4125	0.1762
102368048	0.5090	36.0000	126.5000	1.2229	5.9330	0.4289	0.0898
102368049	0.5090	36.0000	125.0000	1.3959	5.5570	0.4303	0.0710
102368050	0.5090	36.0000	124.0000	1.3993	5.4230	0.4303	0.0734
102368051	0.5090	36.0000	124.5000	1.2318	5.4940	0.4221	0.0942
102368052	0.5090	36.0000	123.0000	1.0505	5.3310	0.4207	0.1342
10[illegible]366 53	0.5090	36.0000	125.0000	0.7024	5.6190	0.4057	0.2407
102368 54	0.5090	36.0000	125.0000	0.7052	5.6190	0.4065	0.2400
102368055	0.5090	36.0000	124.0000	0.5246	5.3590	0.3866	0.3471
102368056	0.5090	36.0000	123.5000	0.3502	5.2880	0.3579	0.5290
102468001	0.5090	36.0000	123.0000	1.4275	8.4550	0.5136	0.0386
102468002	0.5090	36.0000	124.0000	1.2497	8.6420	0.4916	0.0557
102468003	0.5090	36.0000	125.0000	1.0691	8.4710	0.4822	0.0963
102468004	0.5090	36.0000	125.0000	0.8933	8.8300	0.4726	0.1378
102468005	0.5090	36.0000	124.0000	0.7127	8.1860	0.4426	0.2103
102468006	0.5090	36.0000	123.0000	0.5363	8.4550	0.4194	0.3058
102468007	0.5090	36.0000	123.0000	0.3598	8.8210	0.3838	0.4777
102468008	0.5090	36.0000	124.0000	0.3591	8.7370	0.3811	0.4770
102468009	0.5090	36.0000	125.0000	0.5335	8.3290	0.4194	0.3124
102468010	0.5090	36.0000	123.0000	0.7395	8.4610	0.4494	0.1953
102468011	0.5090	36.0000	124.0000	0.8933	8.4500	0.4699	0.1441
102468012	0.5090	36.0000	124.0000	1.0718	8.5660	0.4822	0.0933
102468013	0.5090	36.0000	125.0000	1.2476	8.5450	0.4945	0.0599
102468014	0.5090	36.0000	124.0000	1.4282	8.6720	0.5122	0.0330
102468015	0.5090	36.0000	124.0000	1.4453	10.9450	0.5874	0.0124
102468016	0.5090	36.0000	125.0000	1.2703	11.2360	0.5628	0.0292
102468017	0.5090	36.0000	124.0000	1.0931	11.6400	0.5423	0.0537
102468018	0.5090	36.0000	125.0000	0.9098	11.6400	0.5286	0.1077
102468019	0.5090	36.0000	124.0000	0.7251	11.3220	0.4877	0.1727
102468020	0.5090	36.0000	124.0000	0.5431	11.4200	0.4549	0.2751
102468021	0.5090	36.0000	124.0000	0.3653	10.8780	0.4002	0.4508
102468022	0.5090	36.0000	124.0000	0.3625	11.3750	0.4030	0.4499
102468023	0.5090	36.0000	125.0000	0.5431	11.1580	0.4467	0.2719
102468024	0.5090	36.0000	124.0000	0.7319	11.6360	0.4918	0.1652
102468025	0.5090	36.0000	125.0000	0.9153	11.8200	0.5259	0.0996
102468026	0.5090	36.0000	126.0000	1.0910	11.3710	0.5396	0.0590
102468027	0.5090	36.0000	125.0000	1.2682	11.2180	0.5560	0.0266
102468028	0.5090	36.0000	124.0000	1.4474	10.9900	0.5874	0.0110
102268032	0.5090	50.8800	125.0000	1.4646	13.3060	0.5191	0.0194
102268033	0.5090	50.8800	125.0000	1.2867	13.3440	0.4978	0.0477
102268034	0.5090	50.8800	125.0000	1.0993	13.4340	0.4746	0.0860
102268035	0.5090	50.8800	125.0000	0.9201	13.3060	0.4485	0.1389
102268036	0.5090	50.8800	125.0000	0.7333	13.3060	0.4195	0.2148
102268037	0.5090	50.8800	125.0000	0.5507	13.1260	0.3818	0.3278
102268038	0.5090	50.8800	124.0000	0.3660	12.9470	0.3306	0.5193

RUN IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
102268029	0.5090	76.0000	123.5000	1.4570	10.9120	0.3759	0.1007
102268030	0.5090	76.0000	124.0000	1.2682	11.2450	0.3669	0.1352
102268031	0.5090	76.0000	124.0000	1.0842	11.0620	0.3507	0.1850
102368001	0.5090	76.0000	125.0000	1.4502	11.5100	0.3798	0.0928
102368002	0.5090	76.0000	125.0000	1.2696	11.5700	0.3649	0.1257
102368004	0.5090	76.0000	125.0000	0.9132	11.3700	0.3332	0.2340
102368005	0.5090	76.0000	124.0000	0.7251	10.8000	0.3048	0.3206
102368006	0.5090	76.0000	124.0000	0.5404	11.0100	0.2698	0.4215
102368007	0.5090	76.0000	124.0000	0.3639	11.0100	0.2368	0.6242
102368008	0.5090	76.0000	124.0000	0.3632	10.9700	0.2362	0.6245
102368009	0.5090	76.0000	124.0000	0.5431	10.8700	0.2724	0.4277
102368010	0.5090	76.0000	124.0000	0.7244	10.8700	0.3048	0.3196
102368011	0.5090	76.0000	123.0000	0.9063	10.9600	0.3319	0.2440
102368012	0.5090	76.0000	123.0000	1.0876	10.9100	0.3429	0.1771
102368013	0.5090	76.0000	123.0000	1.2682	10.8300	0.3559	0.1327
102368014	0.5090	76.0000	123.0000	1.4522	11.0700	0.3714	0.0940
102368015	0.5090	76.0000	125.0000	1.4275	8.4630	0.3391	0.1285
102368016	0.5090	76.0000	124.0000	1.2469	8.2150	0.3248	0.1645
102368017	0.5090	76.0000	124.0000	1.0739	8.3980	0.3209	0.2118
102368018	0.5090	76.0000	125.0000	0.8926	8.4320	0.3106	0.2773
102368019	0.5090	76.0000	124.0000	0.7168	8.8110	0.2899	0.3438
102368020	0.5090	76.0000	124.5000	0.5349	8.6770	0.2543	0.4423
102368021	0.5090	76.0000	125.5000	0.3564	9.0650	0.2265	0.6495
102368022	0.5090	76.0000	126.5000	0.3564	8.6480	0.2252	0.6553
102368023	0.5090	76.0000	126.5000	0.5369	8.4530	0.2536	0.4449
102368024	0.5090	76.0000	125.0000	0.7203	8.4560	0.2879	0.3462
102368025	0.5090	76.0000	124.0000	0.8906	8.2580	0.3067	0.2759
102368026	0.5090	76.0000	126.0000	1.0746	8.4210	0.3196	0.2102
102368027	0.5090	76.0000	126.0000	1.2531	8.2600	0.3287	0.1666
102368028	0.5090	76.0000	123.0000	1.4268	7.8560	0.3313	0.1345
102368029	0.5090	76.0000	123.0000	1.4007	5.1380	0.3061	0.1770
102368031	0.5090	76.0000	124.5000	1.0478	5.2690	0.3022	0.2682
102368032	0.5090	76.0000	124.0000	0.8775	5.5530	0.2879	0.3147
102368033	0.5090	76.0000	124.5000	0.7004	5.6840	0.2646	0.3787
102368034	0.5090	76.0000	125.0000	0.5294	5.9990	0.2426	0.4799
102368035	0.5090	76.0000	125.0000	0.3467	5.3510	0.2213	0.7358
102368036	0.5090	76.0000	127.5000	1.4096	6.3180	0.3106	0.1544
102368037	0.5090	76.0000	123.0000	1.2256	5.7540	0.3080	0.2070
102368038	0.5090	76.0000	124.0000	1.0505	5.5270	0.3028	0.2619
102368039	0.5090	76.0000	124.0000	0.8782	5.5370	0.2963	0.3275
102368040	0.5090	76.0000	125.0000	0.7004	5.6000	0.2659	0.3834
102368041	0.5090	76.0000	124.0000	0.5246	5.4210	0.2388	0.4878
102368042	0.5090	76.0000	122.5000	0.3467	5.3030	0.2252	0.7482
102568004	0.5550	25.0000	158.0000	0.8542	11.1100	0.6061	0.0401
102568005	0.5550	25.0000	158.0000	0.6804	11.1860	0.6079	0.1176
102568006	0.5550	25.0000	158.0000	0.5095	10.7150	0.5701	0.2262
102568007	0.5550	25.0000	157.0000	0.3248	9.7990	0.5250	0.4619
102568008	0.5550	25.0000	158.0000	0.3371	8.9000	0.5322	0.4679
102568009	0.5550	25.0000	158.0000	0.5129	12.4100	0.6152	0.2203
102568010	0.5550	25.0000	158.0000	0.6832	12.2200	0.6332	0.1073
102568011	0.5550	25.0000	158.0000	0.8548	12.2610	0.6350	0.0269
102568072	0.5550	25.0000	155.0000	1.1954	7.9010	0.5466	0.0080
102568073	0.5550	25.0000	158.0000	1.0354	8.4090	0.5484	0.0272
102568074	0.5550	25.0000	157.0000	0.8658	8.3400	0.5520	0.0752
102568075	0.5550	25.0000	154.5000	0.6839	7.7180	0.5466	0.1589
102568076	0.5550	25.0000	157.0000	0.5136	7.9500	0.5502	0.2713
102568077	0.5550	25.0000	155.5000	0.3378	7.5530	0.5141	0.4734
102568078	0.5550	25.0000	156.0000	0.3440	7.9310	0.5322	0.4757
102568079	0.5550	25.0000	156.5000	0.5095	8.0870	0.5430	0.2654
102568080	0.5550	25.0000	156.0000	0.6825	8.2260	0.5574	0.1548
102568081	0.5550	25.0000	158.0000	0.8542	8.2970	0.5556	0.0820
102568082	0.5550	25.0000	156.5000	1.0341	7.7800	0.5556	0.0454
102568083	0.5550	25.0000	158.0000	1.1968	8.0710	0.5556	0.0070
102868001	0.5550	25.0000	159.0000	1.3678	4.4810	0.4636	0.0390
102868002	0.5550	25.0000	159.0000	1.2002	4.3010	0.4564	0.0612
102868003	0.5550	25.0000	158.0000	1.0402	4.5000	0.4618	0.0838
102868004	0.5550	25.0000	160.0000	0.8576	4.5870	0.4636	0.1239
102868005	0.5550	25.0000	159.0000	0.6839	4.4090	0.4636	0.1873
102868006	0.5550	25.0000	159.0000	0.5136	4.1380	0.4582	0.2864
102868007	0.5550	25.0000	159.0000	0.3426	4.4970	0.4438	0.4520
102868008	0.5550	25.0000	158.0000	0.3426	4.2000	0.4492	0.4651
102868009	0.5550	25.0000	159.0000	0.5157	4.5180	0.4636	0.2802
102868011	0.5550	25.0000	159.0000	0.8638	4.5900	0.4618	0.1210
102868012	0.5550	25.0000	159.0000	1.0334	4.4530	0.4564	0.0841
102868013	0.5550	25.0000	158.0000	1.2002	4.1620	0.4546	0.0638
102868014	0.5550	25.0000	159.0000	1.3678	4.5770	0.4600	0.0356
102568017	0.5550	39.0000	158.0000	1.0279	12.5730	0.4915	0.0208
102568018	0.5550	39.0000	159.0000	0.8603	12.6040	0.4984	0.0883

RUN IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
102568019	0.5550	39.0000	159.0000	0.6839	12.5230	0.4880	0.1807
102568020	0.5550	39.0000	159.0000	0.5163	12.5600	0.4649	0.3058
102568021	0.5550	39.0000	160.0000	0.3426	12.4290	0.4140	0.5176
102568022	0.5550	39.0000	160.0000	0.3433	12.1060	0.4163	0.5283
102568023	0.5550	39.0000	158.0000	0.5150	12.2200	0.4626	0.3120
102568024	0.5550	39.0000	156.0000	0.6825	12.3400	0.4857	0.1828
102568025	0.5550	39.0000	156.0000	0.8583	12.0100	0.4880	0.0947
102568026	0.5550	39.0000	158.0000	1.0450	11.8420	0.4948	0.0381
102568057	0.5550	39.0000	157.0000	1.3547	8.0540	0.4383	0.0249
102568058	0.5550	39.0000	158.0000	1.2009	8.1920	0.4337	0.0469
102568059	0.5550	39.0000	159.0000	1.0272	8.5020	0.4290	0.0777
102568060	0.5550	39.0000	157.0000	0.8535	8.1890	0.4290	0.1419
102568061	0.5550	39.0000	159.0000	0.6873	8.6740	0.4302	0.2140
102568062	0.5550	39.0000	158.0000	0.5177	7.5860	0.4036	0.3430
102568063	0.5550	39.0000	160.0000	0.3406	7.5860	0.3816	0.5747
102568064	0.5550	39.0000	156.0000	0.3474	8.0170	0.3886	0.5587
102568065	0.5550	39.0000	156.0000	0.5163	8.1590	0.4186	0.3489
102568066	0.5550	39.0000	157.0000	0.6825	8.5660	0.4337	0.2221
102568067	0.5550	39.0000	158.5000	0.8569	8.5260	0.4475	0.1475
102568068	0.5550	39.0000	157.0000	1.0396	8.2970	0.4348	0.0827
102568069	0.5550	39.0000	154.0000	1.1892	8.0360	0.4394	0.0558
102568070	0.5550	39.0000	155.0000	1.3678	8.1400	0.4406	0.0218
102868015	0.5550	39.0000	158.0000	1.3726	4.5900	0.3781	0.0755
102868016	0.5550	39.0000	158.0000	1.2023	4.4230	0.3735	0.1032
102868017	0.5550	39.0000	158.0000	1.0368	4.4500	0.3724	0.1352
102868018	0.5550	39.0000	158.0000	0.8610	4.4780	0.3747	0.1857
102868019	0.5550	39.0000	158.0000	0.6880	4.6530	0.3735	0.2540
102868020	0.5550	39.0000	158.0000	0.5143	4.2420	0.3550	0.3630
102868021	0.5550	39.0000	158.0000	0.3426	4.6350	0.3388	0.5545
102868022	0.5550	39.0000	158.0000	0.3426	4.4950	0.3365	0.5534
102868023	0.5550	39.0000	157.0000	0.5136	4.2950	0.3550	0.3617
102868024	0.5550	39.0000	157.0000	0.6853	4.1760	0.3689	0.2618
102868025	0.5550	39.0000	158.0000	0.8617	4.2440	0.3724	0.1892
102868026	0.5550	39.0000	159.0000	1.0299	3.7230	0.3643	0.1492
102868027	0.5550	39.0000	158.0000	1.2030	4.2710	0.3712	0.1054
102868028	0.5550	39.0000	158.0000	1.3671	3.9520	0.3724	0.0887
102568030	0.5550	50.0000	158.0000	1.2009	12.3940	0.4321	0.0137
102568031	0.5550	50.0000	157.0000	1.0293	12.4210	0.4321	0.0647
102568032	0.5550	50.0000	157.0000	0.8583	12.4360	0.4321	0.1364
102568033	0.5550	50.0000	158.0000	0.6859	12.2870	0.4113	0.2232
102568034	0.5550	50.0000	156.5000	0.5129	11.9030	0.3833	0.3588
102568035	0.5550	50.0000	156.3000	0.3378	11.6630	0.3346	0.5735
102568036	0.5550	50.0000	157.0000	0.3378	11.6070	0.3401	0.5896
102568037	0.5550	50.0000	157.0000	0.5184	11.7410	0.3969	0.3788
102568038	0.5550	50.0000	158.0000	0.6839	12.2090	0.4167	0.2334
102568039	0.5550	50.0000	157.5000	0.8562	12.3640	0.4312	0.1384
102568040	0.5550	50.0000	158.5000	1.0341	12.2570	0.4330	0.0679
102568041	0.5550	50.0000	159.0000	1.2133	12.3330	0.4360	0.0148
102568043	0.5550	50.0000	161.0000	1.3712	8.4720	0.3861	0.0403
102568044	0.5550	50.0000	160.0000	1.2105	8.3000	0.3815	0.0735
102568045	0.5550	50.0000	158.0000	1.0313	7.8550	0.3743	0.1251
102568046	0.5550	50.0000	159.0000	0.8548	8.3520	0.3815	0.1854
102568047	0.5550	50.0000	155.0000	0.6818	7.6400	0.3716	0.2057
102568048	0.5550	50.0000	155.5000	0.5163	7.7960	0.3446	0.3873
102568049	0.5550	50.0000	157.5000	0.3440	7.8370	0.3094	0.5878
102568050	0.5550	50.0000	159.0000	0.3467	8.1980	0.3175	0.5949
102568051	0.5550	50.0000	158.5000	0.5157	8.3690	0.3554	0.3947
102568052	0.5550	50.0000	157.0000	0.6804	8.3260	0.3725	0.2725
102568053	0.5550	50.0000	156.5000	0.8748	7.9600	0.3859	0.1895
102568054	0.5550	50.0000	157.5000	1.0279	7.9390	0.3770	0.1263
102568055	0.5550	50.0000	158.5000	1.1988	8.0760	0.3779	0.0787
102568056	0.5550	50.0000	157.0000	1.3575	7.9410	0.3788	0.0505
102868029	0.5550	50.0000	158.0000	1.3705	4.5900	0.3346	0.1008
102868030	0.5550	50.0000	158.0000	1.2016	4.1810	0.3292	0.1363
102868031	0.5550	50.0000	158.0000	1.0334	4.0860	0.3265	0.1748
102868032	0.5550	50.0000	159.0000	0.8576	4.4360	0.3328	0.2291
102868033	0.5550	50.0000	158.0000	0.6853	4.2440	0.3265	0.3098
102868034	0.5550	50.0000	158.0000	0.5129	4.4990	0.3112	0.4158
102868035	0.5550	50.0000	161.0000	0.3447	4.8470	0.2886	0.6099
102868036	0.5550	50.0000	160.0000	0.3447	4.7980	0.2850	0.6009
102868037	0.5550	50.0000	159.0000	0.5143	4.2900	0.3112	0.4202
102868038	0.5550	50.0000	157.0000	0.6887	4.5190	0.3265	0.3003
102868039	0.5550	50.0000	159.0000	0.8562	4.5940	0.3328	0.2258
102868040	0.5550	50.0000	159.0000	1.0347	4.2090	0.3292	0.1741
102868041	0.5550	50.0000	159.0000	1.2030	4.6820	0.3337	0.1275
102868042	0.5550	50.0000	159.0000	1.3671	4.4990	0.3337	0.1031
101768015	0.3930	39.7500	165.0000	1.3712	5.0810	0.3731	0.1408
101768016	0.3930	39.7500	165.0000	1.2002	5.0970	0.3727	0.1777

N IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
01768017	0.3930	39.7500	165.0000	1.0203	5.5070	0.3576	0.2066
01768018	0.3930	39.7500	166.0000	0.8521	5.8060	0.3651	0.2756
01768019	0.3930	39.7500	163.0000	0.6784	5.6580	0.3449	0.3549
01768020	0.3930	39.7500	165.0000	0.5081	6.3540	0.3117	0.4413
01768021	0.3930	39.7500	163.0000	0.3426	7.5420	0.2729	0.5879
01768022	0.3930	39.7500	163.0000	1.3485	3.4220	0.3505	0.1686
01768023	0.3930	39.7500	163.0000	1.1789	3.3300	0.3453	0.2027
01768024	0.3930	39.7500	163.0000	1.0066	3.6320	0.3481	0.2466
01768025	0.3930	39.7500	164.0000	0.8466	3.9220	0.3430	0.2975
01768026	0.3930	39.7500	161.0000	0.6750	3.9620	0.3236	0.3664
01768027	0.3930	39.7500	165.0000	0.5081	4.7640	0.2950	0.4480
01768028	0.3930	39.7500	163.0000	0.3392	5.3170	0.2558	0.6007
02168030	0.3930	39.7500	166.0000	1.1165	21.9070	0.6247	0.0115
02168031	0.3930	39.7500	165.0000	0.9352	21.8000	0.5663	0.0588
02168032	0.3930	39.7500	166.0000	0.7477	22.0760	0.5406	0.1664
02168033	0.3930	39.7500	165.0000	0.5651	22.1370	0.4788	0.2353
02168034	0.3930	39.7500	164.0000	0.3728	21.0610	0.3893	0.5015
02168035	0.3930	39.7500	167.5000	1.4309	14.6160	0.5758	0.0361
02168036	0.3930	39.7500	165.0000	1.2572	14.4280	0.5311	0.0599
02168037	0.3930	39.7500	166.0000	1.0698	14.7420	0.4978	0.0941
02168038	0.3930	39.7500	162.5000	0.8754	14.0100	0.4669	0.1769
02168039	0.3930	39.7500	165.0000	0.7175	14.6900	0.4499	0.2522
02168040	0.3930	39.7500	165.0000	0.5356	14.4890	0.4020	0.3770
02168041	0.3930	39.7500	166.0000	0.3598	14.6550	0.3350	0.5493
02168022	0.3930	59.5000	164.0000	0.9318	21.6480	0.4399	0.1604
02168024	0.3930	59.5000	166.0000	0.7491	22.0540	0.4004	0.2419
02168025	0.3930	59.5000	166.0000	0.5644	21.7400	0.3490	0.3716
02168026	0.3930	59.5000	165.0000	0.3564	21.9820	0.2647	0.5469
02168027	0.3930	59.5000	166.0000	1.1178	20.7680	0.4642	0.0996
02168042	0.3930	59.5000	166.0000	0.3570	14.5940	0.2236	0.5569
02168043	0.3930	59.5000	165.0000	0.5411	14.5150	0.2876	0.4201
02168044	0.3930	59.5000	165.0000	0.7223	14.1700	0.3307	0.3214
02168045	0.3930	59.5000	166.5000	0.8960	14.3910	0.3614	0.2375
02168046	0.3930	59.5000	165.5000	1.0718	14.0100	0.3776	0.1721
02168047	0.3930	59.5000	165.0000	1.2586	14.3410	0.3998	0.1135
02168048	0.3930	59.5000	165.0000	1.4261	14.3410	0.4260	0.0860
02468029	0.5090	36.0000	193.0000	1.4364	15.0120	0.8032	0.0207
02468030	0.5090	36.0000	194.0000	1.0780	16.7580	0.6666	0.0189
02468031	0.5090	36.0000	192.0000	0.9022	18.8840	0.6420	0.0319
02468032	0.5090	36.0000	194.0000	0.7196	19.7590	0.5928	0.0911
02468033	0.5090	36.0000	193.0000	0.5417	20.1600	0.5218	0.1816
02468034	0.5090	36.0000	193.0000	0.5417	20.1880	0.5245	0.1845
02468035	0.5090	36.0000	193.0000	0.7161	19.7070	0.5778	0.0799
02468036	0.5090	36.0000	193.0000	0.8995	19.1380	0.6311	0.0182
02468037	0.5090	36.0000	193.0000	1.0821	16.7990	0.6680	0.0170
02468038	0.5090	36.0000	195.0000	1.4364	15.5270	0.8032	0.0075
102468039	0.5090	36.0000	195.0000	1.3822	11.5890	0.5956	0.0155
102468040	0.5090	36.0000	195.0000	1.0396	12.9970	0.5191	0.0291
102468041	0.5090	36.0000	194.0000	0.8672	13.0640	0.4918	0.0765
02468042	0.5090	36.0000	196.0000	0.6962	13.5430	0.4740	0.1474
102468043	0.5090	36.0000	193.0000	0.5205	13.2150	0.4289	0.2587
02468044	0.5090	36.0000	193.0000	0.5205	12.9330	0.4276	0.2642
102468045	0.5090	36.0000	191.0000	0.6914	12.4530	0.4644	0.1671
102468046	0.5090	36.0000	192.0000	0.8658	12.3420	0.4849	0.0896
102468047	0.5090	36.0000	191.0000	1.0361	12.0990	0.5027	0.0415
102468048	0.5090	36.0000	195.0000	1.3822	11.0920	0.5737	0.0167
102468049	0.5090	36.0000	195.0000	1.3314	7.2710	0.4358	0.0512
102468050	0.5090	36.0000	193.0000	1.0004	7.5900	0.4002	0.0955
02468051	0.5090	36.0000	193.0000	0.8377	8.0630	0.4112	0.1492
102468052	0.5090	36.0000	192.0000	0.6701	7.6680	0.3948	0.2301
102468053	0.5090	36.0000	192.0000	0.5047	8.1910	0.3729	0.3251
102468054	0.5090	36.0000	195.0000	0.5040	7.8690	0.3729	0.3360
102468055	0.5090	36.0000	190.0000	0.6688	7.9630	0.3948	0.2226
102468056	0.5090	36.0000	193.0000	0.8336	7.1940	0.4030	0.1661
102468057	0.5090	36.0000	196.0000	0.9984	7.6840	0.4084	0.1002
102468058	0.5090	36.0000	195.0000	1.3259	7.6540	0.4439	0.0468
102868070	0.5550	25.0000	207.5000	0.8240	11.7400	0.5665	0.0171
02868071	0.5550	25.0000	206.5000	0.6578	11.7200	0.5665	0.0999
102868072	0.5550	25.0000	205.5000	0.4930	11.9300	0.5610	0.2252
2868073	0.5550	25.0000	208.0000	0.4944	12.2700	0.5665	0.2211
2868 74	0.5550	25.0000	204.0000	0.6633	11.1800	0.5628	0.1076
102868075	0.5550	25.0000	208.5000	0.8267	11.4100	0.5574	0.0195
102868080	0.5550	25.0000	206.0000	1.2119	7.1940	0.4979	0.0055
102868081	0.5550	25.0000	209.0000	1.0361	7.7110	0.4997	0.0259
102868082	0.5550	25.0000	206.0000	0.8645	7.4940	0.4943	0.0738
2868083	0.5550	25.0000	209.0000	0.6921	7.5560	0.4997	0.1442
102868084	0.5550	25.0000	207.0000	0.5150	7.3260	0.4853	0.2543
2868085	0.5550	25.0000	208.0000	0.5115	7.5960	0.4943	0.2591

IDENT	DIAMETER (IN)	LENGTH (IN)	PRESSURE (PSIA)	FLOW*E-6 (LB/HR-FT2)	SUBCOOL (BTU/LB)	CHF*E-4 (BTU/HR-FT2)	EXIT QUAL
68086	0.5550	25.0000	208.0000	0.6894	7.4570	0.4889	0.1405
68087	0.5550	25.0000	208.0000	0.8638	7.4130	0.4961	0.0775
68088	0.5550	25.0000	207.0000	1.0361	7.4650	0.4997	0.0323
68089	0.5550	25.0000	206.5000	1.2071	7.3190	0.4961	0.0023
68018	0.5550	25.0000	208.0000	1.3787	4.1760	0.4167	0.0335
68019	0.5550	25.0000	208.0000	1.2091	4.1300	0.4077	0.0513
68020	0.5550	25.0000	207.0000	1.0306	3.8180	0.4059	0.0864
68021	0.5550	25.0000	207.0000	0.8610	3.8440	0.4131	0.1265
68022	0.5550	25.0000	209.0000	0.6887	4.1060	0.4149	0.1785
68023	0.5550	25.0000	207.0000	0.5184	3.9990	0.4167	0.2762
68024	0.5550	25.0000	208.0000	0.3426	4.0810	0.4077	0.4582
68025	0.5550	25.0000	207.0000	1.3787	3.8180	0.4041	0.0385
68026	0.5550	25.0000	206.0000	1.3691	1.7890	0.3680	0.0803
68027	0.5550	25.0000	208.0000	1.2140	2.1680	0.3716	0.0884
68028	0.5550	25.0000	209.0000	1.0327	2.0750	0.3716	0.1166
68029	0.5550	25.0000	207.0000	0.8562	2.0760	0.3734	0.1523
68030	0.5550	25.0000	207.0000	0.6605	2.0080	0.3662	0.2102
68054	0.5550	39.0000	205.0000	0.4951	11.5700	0.3653	0.2411
68057	0.5550	39.0000	207.5000	0.9894	11.6500	0.4371	0.0202
68058	0.5550	39.0000	206.5000	0.8267	11.6300	0.4406	0.0882
68059	0.5550	39.0000	207.5000	0.6598	11.8500	0.4464	0.1889
68060	0.5550	39.0000	207.0000	0.4930	11.4200	0.4186	0.3279
68062	0.5550	39.0000	207.0000	0.6647	11.7200	0.4475	0.1898
68063	0.5550	39.0000	205.0000	0.8281	11.0700	0.4383	0.0999
68064	0.5550	39.0000	209.5000	0.9915	11.5600	0.4429	0.0264
68091	0.5550	39.0000	206.0000	1.3815	7.2440	0.3920	0.0192
68092	0.5550	39.0000	209.5000	1.2023	7.5390	0.3874	0.0402
68093	0.5550	39.0000	208.0000	1.0327	7.6200	0.3886	0.0781
68094	0.5550	39.0000	207.5000	0.8624	7.2070	0.3851	0.1409
68096	0.5550	39.0000	207.5000	0.5198	7.2070	0.3735	0.3425
68097	0.5550	39.0000	208.5000	0.5211	7.7180	0.3747	0.3300
68098	0.5550	39.0000	207.5000	0.6935	7.5030	0.3897	0.2186
68099	0.5550	39.0000	208.0000	0.8645	7.6070	0.3828	0.1277
68100	0.5550	39.0000	208.0000	1.0347	7.3760	0.3851	0.0814
68101	0.5550	39.0000	207.0000	1.2071	7.3150	0.3920	0.0478
68102	0.5550	39.0000	209.5000	1.3877	7.7970	0.3978	0.0069
68009	0.5550	39.0000	208.0000	1.3753	3.8480	0.3377	0.0806
68010	0.5550	39.0000	208.0000	1.2023	4.1130	0.3365	0.0991
68011	0.5550	39.0000	208.0000	1.0368	4.2510	0.3365	0.1286
68012	0.5550	39.0000	208.0000	1.0347	4.1480	0.3330	0.1293
68013	0.5550	39.0000	208.0000	0.8624	4.0100	0.3365	0.1836
68014	0.5550	39.0000	209.0000	0.6894	4.3390	0.3377	0.2494
68015	0.5550	39.0000	208.0000	0.5205	4.1410	0.3261	0.3555
68017	0.5550	39.0000	209.0000	1.3760	3.9880	0.3330	0.0744
68044	0.5550	50.0000	208.0000	1.1439	11.4700	0.3824	0.0152
68045	0.5550	50.0000	209.0000	0.9887	11.9200	0.3869	0.0577
68046	0.5550	50.0000	209.0000	0.8226	11.5500	0.3843	0.1398
68047	0.5550	50.0000	210.0000	0.6626	12.0400	0.3779	0.2256
68048	0.5550	50.0000	209.0000	0.4903	11.0700	0.3491	0.3859
68050	0.5550	50.0000	208.0000	1.1528	11.7000	0.3879	0.0112
68051	0.5550	50.0000	208.5000	0.9894	11.6100	0.3879	0.0665
68052	0.5550	50.0000	208.5000	0.8240	11.9500	0.3861	0.1304
68053	0.5550	50.0000	209.0000	0.6605	12.2400	0.3843	0.2308
68103	0.5550	50.0000	208.5000	1.3808	7.7150	0.3401	0.0307
68104	0.5550	50.0000	207.5000	1.2078	7.6030	0.3401	0.0671
68105	0.5550	50.0000	209.0000	1.0361	7.8130	0.3392	0.1054
68106	0.5550	50.0000	207.5000	0.8597	7.5010	0.3382	0.1760
68108	0.5550	50.0000	208.0000	0.5157	7.3490	0.3238	0.4033
68109	0.5550	50.0000	207.0000	0.5170	7.2580	0.3256	0.4066
68110	0.5550	50.0000	209.0000	0.6880	7.7660	0.3364	0.2606
68111	0.5550	50.0000	209.0000	0.8562	7.6340	0.3364	0.1725
68112	0.5550	50.0000	208.0000	1.0341	7.3460	0.3364	0.1155
68113	0.5550	50.0000	208.0000	1.2064	7.4210	0.3419	0.0737
68114	0.5550	50.0000	209.0000	1.3787	7.6470	0.3428	0.0347
68001	0.5550	50.0000	209.0000	1.3794	4.2410	0.3010	0.0958
68002	0.5550	50.0000	206.0000	1.2050	3.9360	0.2950	0.1284
68003	0.5550	50.0000	210.0000	1.0347	4.2190	0.2968	0.1621
68004	0.5550	50.0000	209.0000	0.8706	4.4990	0.2968	0.2059
68005	0.5550	50.0000	208.0000	0.6894	4.1710	0.2941	0.2957
68006	0.5550	50.0000	208.0000	0.5184	4.2210	0.2823	0.4065
68008	0.5550	50.0000	208.0000	1.3767	3.8440	0.2977	0.1042

FREON-21 CHF DATA, BARNETT & WOOD (1965)

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BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY LB/HR.FT.^{2}	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX BTU/HR.FT^2	EXIT QUALITY
36.001	200	0.334	103.5	1407000	24.90	53440	0.29
36.002	200	0.334	103.5	1407000	24.90	53440	0.29
36.003	200	0.334	103.5	1407000	12.40	44500	0.35
36.004	200	0.334	103.5	1407000	12.40	44500	0.35
36.005	200	0.334	103.5	1407000	4.00	37500	0.38
36.006	200	0.334	103.5	1407000	4.00	37500	0.38
36.007	200	0.334	103.5	1407000	2.50	36360	0.39
36.008	200	0.334	103.5	1407000	2.50	36360	0.39
36.009	200	0.334	103.5	1407000	8.90	40950	0.36
36.010	200	0.334	103.5	1407000	8.90	40950	0.36
36.011	200	0.334	103.5	1407000	16.80	47200	0.33
36.012	200	0.334	103.5	1407000	16.80	47200	0.33
36.013	200	0.334	103.5	1740000	25.30	60800	0.24
36.014	200	0.334	103.5	1740000	25.30	60800	0.24
36.015	200	0.334	103.5	1740000	19.50	56390	0.27
36.016	200	0.334	103.5	1740000	19.50	56040	0.27
36.017	200	0.334	103.5	1740000	12.70	50650	0.31
36.018	200	0.334	103.5	1740000	12.70	50650	0.31
36.019	200	0.334	103.5	1740000	3.40	43900	0.37
36.020	200	0.334	103.5	1740000	3.40	43230	0.36
37.001	200	0.334	51.8	1407000	25.80	80930	0.13
37.002	200	0.334	51.8	1407000	25.80	80930	0.13
37.003	200	0.334	51.8	1407000	20.00	75250	0.17
37.004	200	0.334	51.8	1407000	20.00	75250	0.17
37.005	200	0.334	51.8	1407000	10.20	65020	0.24
37.006	200	0.334	51.8	1407000	10.20	65020	0.24
37.007	200	0.334	51.8	1407000	3.50	58800	0.30
37.008	200	0.334	51.8	1407000	3.50	58800	0.30
37.009	200	0.334	51.8	1740000	2.70	60420	0.25
37.010	200	0.334	51.8	1740000	25.50	87230	0.07
37.011	200	0.334	51.8	1740000	20.20	79340	0.11
37.012	200	0.334	51.8	1740000	20.00	79180	0.11
37.013	200	0.334	51.8	1740000	12.40	71000	0.17
38.001	200	0.334	25.9	1740000	18.50	111260	-0.02
38.002	200	0.334	25.9	1740000	24.30	127700	-0.02
38.003	200	0.334	25.9	1740000	18.50	111260	0.02
38.004	200	0.334	25.9	1740000	18.50	111260	0.02
38.005	200	0.334	25.9	1740000	10.30	90910	0.08
38.006	200	0.334	25.9	1740000	10.30	89640	0.07
38.007	200	0.334	25.9	1740000	3.10	76230	0.14
38.008	200	0.334	25.9	1740000	3.10	76230	0.14
38.009	200	0.334	25.9	1740000	6.30	80700	0.11
38.010	200	0.334	25.9	1740000	6.30	80700	0.11
38.011	200	0.334	25.9	1740000	14.50	101700	0.05
38.012	200	0.334	25.9	1740000	14.50	101600	0.05
38.013	200	0.334	25.9	1407000	24.00	121100	0.04
38.014	200	0.334	25.9	1407000	24.00	120700	0.03
38.015	200	0.334	25.9	1407000	19.40	107500	0.06
38.016	200	0.334	25.9	1407000	19.40	108000	0.06
38.017	200	0.334	25.9	1407000	13.00	92880	0.10
38.018	200	0.334	25.9	1407000	13.00	92880	0.10
38.019	200	0.334	25.9	1407000	4.70	78480	0.17
38.020	200	0.334	25.9	1407000	4.70	78770	0.17
38.021	200	0.334	25.9	1407000	8.70	85240	0.13
38.022	200	0.334	25.9	1407000	8.70	84790	0.13
39.001	106	0.334	26.2	1380000	21.70	124490	0.08
39.002	106	0.334	26.2	1380000	21.60	132320	0.10
39.003	106	0.334	26.2	1380000	14.90	115590	0.13
39.004	106	0.334	26.2	1380000	14.90	116340	0.13
39.005	106	0.334	26.2	1380000	8.40	107820	0.19
39.006	106	0.334	26.2	1380000	7.70	105370	0.19
39.007	106	0.334	26.2	1380000	7.70	104420	0.19
39.008	106	0.334	26.2	1380000	3.40	95893	0.21
39.009	106	0.334	26.2	1380000	3.40	95893	0.21

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN. NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
40.001	200	0.424	128.7	1740000	25.50	58070	0.20
40.002	200	0.424	128.7	1740000	25.50	58070	0.20
40.003	200	0.424	128.7	1740000	18.80	53130	0.24
40.004	200	0.424	128.7	1740000	18.80	53130	0.24
40.005	200	0.424	128.7	1740000	11.50	47100	0.28
40.006	200	0.424	128.7	1740000	11.50	47100	0.28
40.007	200	0.424	128.7	1740000	4.00	39890	0.31
40.008	200	0.424	128.7	1740000	4.00	39890	0.31
40.009	200	0.424	128.7	870000	25.00	40417	0.41
40.010	200	0.424	128.7	870000	25.00	40797	0.42
40.011	200	0.424	128.7	870000	25.00	40730	0.42
40.012	200	0.424	128.7	870000	20.00	38250	0.44
40.013	200	0.424	128.7	870000	20.00	38250	0.44
40.014	200	0.424	128.7	870000	10.50	32320	0.46
40.015	200	0.424	128.7	870000	10.50	32320	0.46
40.016	200	0.424	128.7	870000	3.50	28550	0.48
40.017	200	0.424	128.7	870000	3.50	28550	0.48
40.018	200	0.424	128.7	1403000	25.50	52970	0.27
40.019	200	0.424	128.7	1403000	25.50	53130	0.27
40.020	200	0.424	128.7	1403000	19.40	48530	0.30
40.021	200	0.424	128.7	1403000	19.40	48430	0.30
40.022	200	0.424	128.7	1403000	12.50	42630	0.32
40.023	200	0.424	128.7	1403000	12.50	42630	0.32
40.024	200	0.424	128.7	1403000	4.30	36070	0.35
40.025	200	0.424	128.7	1403000	4.30	36070	0.35
40.026	200	0.424	128.7	701000	26.90	39180	0.54
40.027	200	0.424	128.7	701000	26.90	38920	0.53
40.028	200	0.424	128.7	701000	10.50	30460	0.56
40.029	200	0.424	128.7	701000	10.50	30230	0.55
40.030	200	0.424	128.7	701000	5.00	27560	0.56
40.031	200	0.424	128.7	701000	5.00	27510	0.56
40.032	200	0.424	128.7	701000	16.90	33660	0.54
40.033	200	0.424	128.7	701000	16.90	33660	0.54
40.034	200	0.424	128.7	435000	29.40	30030	0.72
40.035	200	0.424	128.7	435000	29.40	30030	0.72
40.036	200	0.424	128.7	435000	20.80	27790	0.75
40.037	200	0.424	128.7	435000	20.80	27790	0.75
40.038	200	0.424	128.7	435000	12.30	25170	0.76
40.039	200	0.424	128.7	435000	12.30	25170	0.76
40.040	200	0.424	128.7	435000	4.70	23300	0.79
40.041	200	0.424	128.7	435000	4.70	23300	0.79
40.042	200	0.424	128.7	351000	27.00	25970	0.83
40.043	200	0.424	128.7	351000	27.00	25970	0.83
40.044	200	0.424	128.7	351000	18.50	24050	0.85
40.045	200	0.424	128.7	351000	18.50	24050	0.85
40.046	200	0.424	128.7	351000	9.70	21830	0.87
40.047	200	0.424	128.7	351000	9.70	21830	0.87
40.048	200	0.424	128.7	351000	4.30	20420	0.87
40.049	200	0.424	128.7	351000	4.30	20420	0.87
41.001	200	0.424	64.3	1740000	26.00	87810	0.06
41.002	200	0.424	64.3	1740000	26.00	87810	0.06
41.003	200	0.424	64.3	1740000	19.40	78230	0.10
41.004	200	0.424	64.3	1740000	19.40	78230	0.10
41.005	200	0.424	64.3	1740000	11.60	68380	0.16
41.006	200	0.424	64.3	1740000	11.60	67330	0.16
41.007	200	0.424	64.3	1740000	11.60	67740	0.16
41.008	200	0.424	64.3	1740000	5.00	59690	0.21
41.009	200	0.424	64.3	1740000	5.00	59620	0.21
41.010	200	0.424	64.3	1403000	24.30	79550	0.13
41.011	200	0.424	64.3	1403000	24.30	79550	0.13
41.012	200	0.424	64.3	1403000	19.30	73820	0.17
41.013	200	0.424	64.3	1403000	19.30	73820	0.17
41.014	200	0.424	64.3	1403000	11.40	64250	0.22
41.015	200	0.424	64.3	1403000	11.40	64350	0.22
41.016	200	0.424	64.3	1403000	4.00	55920	0.27
41.017	200	0.424	64.3	1403000	4.00	55920	0.27
41.018	200	0.424	[illegible]	[illegible]	25.50	69070	0.30

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BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
41.019	200	0.424	64.3	870000	25.50	69200	0.30
41.020	200	0.424	64.3	870000	19.80	63710	0.32
41.021	200	0.424	64.3	870000	19.80	63590	-0.32
41.022	200	0.424	64.3	870000	11.00	56200	0.37
41.023	200	0.424	64.3	870000	11.00	56200	0.37
41.024	200	0.424	64.3	870000	3.90	49670	0.40
41.025	200	0.424	64.3	870000	3.90	49510	0.40
41.026	200	0.424	64.3	701000	26.90	66190	0.40
41.027	200	0.424	64.3	701000	26.90	66120	0.40
41.028	200	0.424	64.3	701000	20.00	60730	0.43
41.029	200	0.424	64.3	701000	20.00	60730	0.43
41.030	200	0.424	64.3	701000	12.00	54390	0.46
41.031	200	0.424	64.3	701000	12.00	54390	0.46
41.032	200	0.424	64.3	701000	4.40	48150	0.49
41.033	200	0.424	64.3	701000	4.40	48150	0.49
41.034	200	0.424	64.3	435000	25.80	52810	0.63
41.035	200	0.424	64.3	435000	25.80	52810	0.63
41.036	200	0.424	64.3	435000	17.60	48560	0.66
41.037	200	0.424	64.3	435000	17.60	48560	0.66
41.038	200	0.424	64.3	435000	12.30	45550	0.67
41.039	200	0.424	64.3	435000	12.30	45550	0.67
41.040	200	0.424	64.3	435000	4.90	41690	0.70
41.041	200	0.424	64.3	435000	4.90	41690	0.70
41.042	200	0.424	64.3	351000	9.80	40670	0.80
41.043	200	0.424	64.3	351000	9.80	40670	0.80
41.044	200	0.424	64.3	351000	16.70	43590	0.77
41.045	200	0.424	64.3	351000	16.70	43590	0.77
41.046	200	0.424	64.3	351000	24.60	47070	0.75
41.047	200	0.424	64.3	351000	24.60	47070	0.75
41.048	200	0.424	64.3	351000	7.10	40000	0.82
41.049	200	0.424	64.3	351000	7.10	39630	0.81
42.001	200	0.424	32.1	1740000	25.10	130160	-0.03
42.002	200	0.424	32.1	1740000	25.10	130160	-0.03
42.003	200	0.424	32.1	1740000	18.60	111330	0.01
42.004	200	0.424	32.1	1740000	18.60	111230	0.01
42.005	200	0.424	32.1	1740000	12.30	93830	0.05
42.006	200	0.424	32.1	1740000	12.30	93830	0.05
42.007	200	0.424	32.1	1740000	5.50	77890	0.11
42.008	200	0.424	32.1	1740000	5.50	77890	0.11
42.009	200	0.424	32.1	1740000	11.50	91640	0.06
42.010	200	0.424	32.1	1403000	24.90	116500	0.00
42.011	200	0.424	32.1	1403000	24.90	116500	0.00
42.012	200	0.424	32.1	1403000	18.80	104500	0.05
42.013	200	0.424	32.1	1403000	18.80	104500	0.05
42.014	200	0.424	32.1	1403000	10.40	86290	0.11
42.015	200	0.424	32.1	1403000	10.40	86290	0.11
42.016	200	0.424	32.1	1403000	4.00	75640	0.16
42.017	200	0.424	32.1	1403000	4.00	75640	0.16
42.018	200	0.424	32.1	870000	27.00	106100	0.13
42.019	200	0.424	32.1	870000	27.00	106100	0.13
42.020	200	0.424	32.1	870000	19.70	94720	0.17
42.021	200	0.424	32.1	870000	19.70	94720	0.17
42.022	200	0.424	32.1	870000	11.90	83720	0.23
42.023	200	0.424	32.1	870000	11.90	83720	0.23
42.024	200	0.424	32.1	870000	6.30	75950	0.26
42.025	200	0.424	32.1	870000	6.30	75950	0.26
42.026	200	0.424	32.1	701000	5.20	73610	0.35
42.027	200	0.424	32.1	701000	5.20	73610	0.35
42.028	200	0.424	32.1	701000	11.10	80360	0.31
42.029	200	0.424	32.1	701000	11.10	80360	0.31
42.030	200	0.424	32.1	701000	18.60	89870	0.27
42.031	200	0.424	32.1	701000	18.60	89870	0.27
42.032	200	0.424	32.1	701000	24.90	97670	0.23
42.033	200	0.424	32.1	701000	24.90	97670	0.23
42.034	200	0.424	32.1	435000	26.10	84030	0.43
42.035	200	0.424	32.1	435000	26.10	84030	0.43
42.036	200	0.424	32.1	435000	18.50	78390	0.47
42.037	200	0.424	32.1	435000	18.50	78390	0.47
42.038	200	0.424		435000	12.10	73860	0.52
42.039	200	0.424	32.1	435000	12.10	73860	0.52

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BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
42.040	200	0.424	32.1	435000	3.90	68030	0.57
42.041	200	0.424	32.1	435000	3.90	68030	0.57
42.042	200	0.424	32.1	351000	6.00	65780	0.67
42.043	200	0.424	32.1	351000	6.00	65780	0.67
42.044	200	0.424	32.1	351000	25.60	78930	0.56
42.045	200	0.424	32.1	351000	25.60	78930	0.56
42.046	200	0.424	32.1	351000	18.40	74400	0.60
42.047	200	0.424	32.1	351000	18.40	74400	0.60
43.001	106	0.424	32.6	1720000	22.20	134980	0.02
43.002	106	0.424	32.6	1720000	22.20	134980	0.02
43.003	106	0.424	32.6	1720000	17.50	123220	0.05
43.004	106	0.424	32.6	1720000	17.30	124200	0.06
43.005	106	0.424	32.6	1720000	10.40	103900	0.09
43.006	106	0.424	32.6	1720000	10.40	103560	0.09
43.007	106	0.424	32.6	1720000	4.00	91580	0.14
43.008	106	0.424	32.6	1720000	4.00	91580	0.14
43.009	106	0.424	32.6	1380000	21.90	126320	0.07
43.010	106	0.424	32.6	1380000	21.90	125690	0.07
43.011	106	0.424	32.6	1380000	16.30	113200	0.10
43.012	106	0.424	32.6	1380000	16.30	113200	0.10
43.013	106	0.424	32.6	1380000	9.50	99470	0.15
43.014	106	0.424	32.6	1380000	9.50	99470	0.15
43.015	106	0.424	32.6	1380000	3.70	91890	0.19
43.016	106	0.424	32.6	1380000	3.70	92530	0.20
43.017	106	0.424	32.6	1380000	12.80	106890	0.13
43.018	106	0.424	32.6	1380000	12.80	106890	0.13
43.019	106	0.424	32.6	1380000	4.30	90880	0.18
43.020	106	0.424	32.6	1380000	4.30	90880	0.18
43.021	106	0.424	32.6	690000	22.90	104640	0.27
43.022	106	0.424	32.6	690000	22.90	105020	0.28
43.023	106	0.424	32.6	690000	17.10	98210	0.31
43.024	106	0.424	32.6	690000	17.10	98210	0.31
43.025	106	0.424	32.6	690000	9.30	89930	0.36
43.026	106	0.424	32.6	690000	9.30	89840	0.36
43.027	106	0.424	32.6	690000	3.70	84640	0.39
43.028	106	0.424	32.6	690000	3.70	84640	0.39
43.029	106	0.424	32.6	859000	22.80	111770	0.20
43.030	106	0.424	32.6	859000	22.80	111770	0.20
43.031	106	0.424	32.6	859000	16.60	102700	0.23
43.032	106	0.424	32.6	859000	16.60	102500	0.23
43.033	106	0.424	32.6	859000	8.20	90880	0.28
43.034	106	0.424	32.6	859000	8.20	90880	0.28
43.035	106	0.424	32.6	859000	4.10	85750	0.31
43.036	106	0.424	32.6	859000	4.10	85750	0.31
43.037	106	0.424	32.6	430000	21.90	93480	0.56
43.038	106	0.424	32.6	430000	21.90	93480	0.56
43.039	106	0.424	32.6	430000	14.40	88660	0.57
43.040	106	0.424	32.6	430000	14.40	89140	0.57
43.041	106	0.424	32.6	430000	3.60	80640	0.63
43.042	106	0.424	32.6	430000	3.60	80640	0.63
43.043	106	0.424	32.6	345000	3.70	74840	0.73
43.044	106	0.424	32.6	345000	3.70	74840	0.73
43.045	106	0.424	32.6	345000	13.20	81720	0.69
43.046	106	0.424	32.6	345000	13.20	81720	0.69
43.047	106	0.424	32.6	345000	22.10	87590	0.65
43.048	106	0.424	32.6	345000	22.10	87590	0.65
44.001	106	0.424	65.1	1720000	21.90	94560	0.14
44.002	106	0.424	65.1	1720000	21.90	94050	0.14
44.003	106	0.424	65.1	1720000	17.30	87750	0.16
44.004	106	0.424	65.1	1720000	17.30	87750	0.16
44.005	106	0.424	65.1	1720000	10.10	77950	0.21
44.006	106	0.424	65.1	1720000	10.10	77950	0.21
44.007	[illegible]	0.424	5.1	1720000	5.30	71740	0.23
44.[illegible]	106	0.424	[illegible]	1720000	5.30	71740	0.23

APPENDIX 2. (CONTINUED) (v)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
44.009	106	0.424	65.1	1380000	4.40	66410	0.29
44.010	106	0.424	65.1	1380000	4.40	66410	0.29
44.011	106	0.424	65.1	1380000	9.80	72310	0.26
44.012	106	0.424	65.1	1380000	9.80	72400	0.26
44.013	106	0.424	65.1	1380000	15.60	78810	0.23
44.014	106	0.424	65.1	1380000	15.60	78810	0.23
44.015	106	0.424	65.1	1380000	21.60	85340	0.19
44.016	106	0.424	65.1	1380000	21.60	85340	0.19
44.017	106	0.424	65.1	859000	21.80	74050	0.36
44.018	106	0.424	65.1	859000	21.80	74050	0.36
44.019	106	0.424	65.1	859000	16.90	70090	0.38
44.020	106	0.424	65.1	859000	16.90	70090	0.38
44.021	106	0.424	65.1	859000	8.40	62480	0.42
44.022	106	0.424	65.1	859000	8.40	62480	0.42
44.023	106	0.424	65.1	859000	3.80	57920	0.43
44.024	106	0.424	65.1	859000	3.80	57920	0.43
44.025	106	0.424	65.1	690000	4.20	55410	0.52
44.026	106	0.424	65.1	690000	4.20	55410	0.52
44.027	106	0.424	65.1	690000	10.00	59690	0.50
44.028	106	0.424	65.1	690000	10.00	59690	0.50
44.029	106	0.424	65.1	690000	16.00	64700	0.48
44.030	106	0.424	65.1	690000	16.00	64700	0.48
44.031	106	0.424	65.1	690000	23.20	70430	0.46
44.032	106	0.424	65.1	690000	23.20	70910	0.46
44.033	106	0.424	65.1	430000	22.40	55730	0.66
44.034	106	0.424	65.1	430000	22.40	55730	0.66
44.035	106	0.424	65.1	430000	14.80	51860	0.69
44.036	106	0.424	65.1	430000	14.80	51860	0.69
44.037	106	0.424	65.1	430000	10.80	49990	0.70
44.038	106	0.424	65.1	430000	10.80	49990	0.70
44.039	106	0.424	65.1	430000	4.30	46160	0.71
44.040	106	0.424	65.1	430000	4.30	46160	0.71
44.041	106	0.424	65.1	345000	4.10	41460	0.81
44.042	106	0.424	65.1	345000	4.10	41460	0.81
44.043	106	0.424	65.1	345000	9.60	43270	0.78
44.044	106	0.424	65.1	345000	9.60	43270	0.78
44.045	106	0.424	65.1	345000	15.10	46220	0.78
44.046	106	0.424	65.1	345000	15.10	46220	0.78
44.047	106	0.424	65.1	345000	22.60	49390	0.76
44.048	106	0.424	65.1	345000	22.60	49390	0.76
45.001	106	0.424	130.3	1720000	22.40	61750	0.25
45.002	106	0.424	130.3	1720000	22.40	61750	0.25
45.003	106	0.424	130.3	1720000	17.70	56740	0.26
45.004	106	0.424	130.3	1720000	17.70	56740	0.26
45.005	106	0.424	130.3	1720000	9.80	47830	0.28
45.006	106	0.424	130.3	1720000	9.80	47830	0.28
45.007	106	0.424	130.3	1720000	4.30	41560	0.29
45.008	106	0.424	130.3	1720000	4.30	41560	0.29
45.009	106	0.424	130.3	1380000	4.70	39090	0.35
45.010	106	0.424	130.3	1380000	4.70	39090	0.35
45.011	106	0.424	130.3	1380000	9.90	43650	0.34
45.012	106	0.424	130.3	1380000	9.90	43650	0.34
45.013	106	0.424	130.3	1380000	15.60	48600	0.32
45.014	106	0.424	130.3	1380000	15.60	48600	0.32
45.015	106	0.424	130.3	1380000	21.40	53380	0.30
45.016	106	0.424	130.3	1380000	21.40	53380	0.30
45.017	106	0.424	130.3	859000	23.10	44000	0.46
45.018	106	0.424	130.3	859000	23.10	44000	0.46
45.019	106	0.424	130.3	859000	16.70	40830	0.48
45.020	106	0.424	130.3	859000	16.70	40570	0.48
45.021	106	0.424	130.3	859000	10.10	36930	0.49
45.022	106	0.424	130.3	859000	10.10	36930	0.49
45.023	106	0.424	130.3	859000	3.80	33160	0.50
45.024	106	0.424	130.3	859000	3.80	33160	0.50
45.025	106	0.424	130.3	690000	4.50	31160	0.59
45.026	106	0.424	130.3	690000	4.50	31160	0.59
45.027	106	0.424	130.3	690000	10.30	33980	0.58
45.028	106	0.424	130.3	[illegible]	10.30	33980	0.58

APPENDIX 2. (CONTINUED) (vi)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
45.029	106	0.424	130.3	690000	16.10	36330	0.56
45.030	106	0.424	130.3	690000	16.10	36330	0.56
45.031	106	0.424	130.3	690000	21.80	38990	0.55
45.032	106	0.424	130.3	690000	21.80	38990	0.55
45.033	106	0.424	130.3	430000	22.30	30340	0.74
45.034	106	0.424	130.3	430000	22.30	30340	0.74
45.035	106	0.424	130.3	430000	14.80	28360	0.77
45.036	106	0.424	130.3	430000	14.80	28360	0.77
45.037	106	0.424	130.3	430000	8.40	26470	0.78
45.038	106	0.424	130.3	430000	8.40	26470	0.78
45.039	106	0.424	130.3	430000	4.20	25190	0.78
45.040	106	0.424	130.3	430000	4.20	25190	0.78
45.041	106	0.424	130.3	345000	23.30	26430	0.82
45.042	106	0.424	130.3	345000	23.30	26430	0.82
45.043	106	0.424	130.3	345000	16.80	25100	0.84
45.044	106	0.424	130.3	345000	16.80	25100	0.84
45.045	106	0.424	130.3	345000	11.50	23540	0.84
45.046	106	0.424	130.3	345000	11.50	23540	0.84
45.047	106	0.424	130.3	345000	3.30	21850	0.86
45.048	106	0.424	130.3	345000	3.30	21850	0.86
46.001	200	0.264	83.5	1740000	26.10	61430	0.24
46.002	200	0.264	83.5	1740000	26.10	61430	0.24
46.003	200	0.264	83.5	1740000	15.60	52370	0.30
46.004	200	0.264	83.5	1740000	15.60	52370	0.30
46.005	200	0.264	83.5	1740000	4.30	40380	0.33
46.006	200	0.264	83.5	1740000	4.30	40380	0.33
46.007	200	0.264	83.5	1403000	25.60	55310	0.32
46.008	200	0.264	83.5	1403000	25.60	55310	0.32
46.009	200	0.264	83.5	1403000	14.00	45200	0.35
46.010	200	0.264	83.5	1403000	14.00	45200	0.35
46.011	200	0.264	83.5	1403000	4.40	36740	0.38
46.012	200	0.264	83.5	1403000	4.40	36740	0.38
46.013	200	0.264	83.5	870000	28.10	43900	0.47
46.014	200	0.264	83.5	870000	28.10	43900	0.47
46.015	200	0.264	83.5	870000	13.20	35280	0.50
46.016	200	0.264	83.5	870000	13.20	35280	0.50
46.017	200	0.264	83.5	870000	4.30	29350	0.51
46.018	200	0.264	83.5	870000	4.30	29350	0.51
46.019	200	0.264	83.5	701000	26.10	38230	0.56
46.020	200	0.264	83.5	701000	26.10	38230	0.56
46.021	200	0.264	83.5	701000	12.70	32050	0.59
46.022	200	0.264	83.5	701000	12.70	32050	0.59
46.023	200	0.264	83.5	701000	6.20	29180	0.61
46.024	200	0.264	83.5	701000	6.20	29180	0.61
46.025	200	0.264	83.5	435000	7.90	25360	0.87
46.026	200	0.264	83.5	435000	7.90	25360	0.87
46.027	200	0.264	83.5	435000	27.10	30880	0.83
46.028	200	0.264	83.5	435000	27.10	30880	0.83
46.029	200	0.264	83.5	435000	17.00	28340	0.86
46.030	200	0.264	83.5	435000	17.00	28340	0.86
46.031	200	0.264	83.5	435000	17.00	28340	0.86
46.032	200	0.264	83.5	435000	47.00	28340	0.86
46.033	200	0.264	83.5	351000	19.10	25520	0.96
46.034	200	0.264	83.5	351000	19.10	24760	0.92
46.035	200	0.264	83.5	351000	28.20	26880	0.90
46.036	200	0.264	83.5	351000	28.20	26880	0.90
46.037	200	0.264	83.5	351000	15.00	23390	0.91
46.038	200	0.264	83.5	351000	15.00	23390	0.91
47.001	106	0.264	84.1	1720000	21.70	64220	0.30
47.002	106	0.264	84.1	1720000	21.70	64220	0.30
47.003	106	0.264	84.1	1720000	15.30	58520	0.32
47.004	106	[illegible]	84.1	1720000	15.30	58520	0.32
47.005	[illegible]	[illegible]	84.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]				

APPENDIX 2. (CONTINUED) (vii)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
47.007	106	0.264	84.1	1380000	23.40	59630	0.37
47.008	106	0.264	84.1	1380000	23.40	59630	0.37
47.009	106	0.264	84.1	1380000	15.70	52970	0.38
47.010	106	0.264	84.1	1380000	15.70	52970	0.38
47.011	106	0.264	84.1	1380000	7.60	45810	0.40
47.012	106	0.264	84.1	1380000	7.60	45810	0.40
47.013	106	0.264	84.1	859000	7.10	38860	0.58
47.014	106	0.264	84.1	859000	7.10	38860	0.58
47.015	106	0.264	84.1	859000	13.40	42290	0.57
47.016	106	0.264	84.1	859000	13.40	42290	0.57
47.017	106	0.264	84.1	859000	20.70	46920	0.57
47.018	106	0.264	84.1	859000	20.70	46920	0.57
47.019	106	0.264	84.1	690000	22.60	42860	0.65
47.020	106	0.264	84.1	690000	22.60	42860	0.65
47.021	106	0.264	84.1	690000	15.00	39120	0.66
47.022	106	0.264	84.1	690000	15.00	39120	0.66
47.023	106	0.264	84.1	690000	7.00	35950	0.69
47.024	106	0.264	84.1	690000	7.00	35950	0.69
47.025	106	0.264	84.1	430000	22.60	32840	0.86
47.026	106	0.264	84.1	430000	22.60	32620	0.86
47.027	106	0.264	84.1	430000	23.40	32940	0.86
47.028	106	0.264	84.1	430000	16.20	31270	0.88
47.029	106	0.264	84.1	430000	16.20	31460	0.89
47.030	106	0.264	84.1	430000	8.70	28810	0.89
47.031	106	0.264	84.1	430000	8.70	28810	0.89
47.032	106	0.264	84.1	345000	22.50	27390	0.91
47.033	106	0.264	84.1	345000	22.50	27390	0.91
47.034	106	0.264	84.1	345000	16.30	25590	0.90
47.035	106	0.264	84.1	345000	16.30	25590	0.90
47.036	106	0.264	84.1	345000	9.30	24150	0.92
47.037	106	0.264	84.1	345000	9.30	24150	0.92
48.001	106	0.264	42.0	1720000	23.10	107240	0.19
48.002	106	0.264	42.0	1720000	23.10	107240	0.19
48.003	106	0.264	42.0	1720000	15.00	96150	0.24
48.004	106	0.264	42.0	1720000	15.00	96150	0.24
48.005	106	0.264	42.0	1720000	7.30	84770	0.28
48.006	106	0.264	42.0	1720000	7.30	84770	0.28
48.007	106	0.264	42.0	1720000	14.60	94210	0.23
48.008	106	0.264	42.0	1720000	14.60	94210	0.23
48.009	106	0.264	42.0	1720000	22.60	104830	0.19
48.010	106	0.264	42.0	1720000	22.60	104830	0.19
48.011	106	0.264	42.0	1720000	18.90	100900	0.21
48.012	106	0.264	42.0	1720000	18.90	100900	0.21
48.013	106	0.264	42.0	1720000	17.20	97220	0.22
48.014	106	0.264	42.0	1720000	17.20	97220	0.22
48.015	106	0.264	42.0	1720000	13.50	93450	0.24
48.016	106	0.264	42.0	1720000	13.50	93450	0.24
48.017	106	0.264	42.0	1720000	7.40	84770	0.28
48.018	106	0.264	42.0	1720000	7.40	84770	0.28
48.019	106	0.264	42.0	1380000	23.20	99350	0.26
48.020	106	0.264	42.0	1380000	23.20	99350	0.26
48.021	106	0.264	42.0	1380000	16.40	90820	0.29
48.022	106	0.264	42.0	1380000	16.40	90820	0.29
48.023	106	0.264	42.0	1380000	6.50	79500	0.35
48.024	106	0.264	42.0	1380000	6.50	79500	0.35
48.025	106	0.264	42.0	1380000	22.40	96750	0.26
48.026	106	0.264	42.0	1380000	22.40	96750	0.26
48.027	106	0.264	42.0	1380000	18.90	91740	0.27
48.028	106	0.264	42.0	1380000	18.90	91740	0.27
48.029	106	0.264	42.0	1380000	13.70	86600	0.30
48.030	106	0.264	42.0	1380000	13.70	86600	0.30
48.031	106	0.264	42.0	1380000	8.10	82290	0.35
48.032	106	0.264	42.0	1380000	8.10	82290	0.35
48.033	106	0.264	42.0	1380000	8.10	81880	0.34
48.034	106	0.264	42.0	1380000	8.10	81880	0.34
48.035	106	0.264	42.0	859000	21.90	81660	0.45
48.036	106	0.264	42.0	859000	21.90	81660	0.45
[illegible]	106	0.264	[illegible]	859000	14.50	73640	0.46

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BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY LB/HR.FT.^{2}	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX BTU/HR.FT^2	EXIT QUALITY
48.038	106	0.264	42.0	859000	14.50	73040	0.46
48.039	106	0.264	42.0	859000	7.40	63940	0.46
48.040	106	0.264	42.0	859000	7.40	63940	0.46
48.041	106	0.264	42.0	859000	22.70	84100	0.46
48.042	106	0.264	42.0	859000	22.70	84100	0.46
48.043	106	0.264	42.0	859000	18.70	80930	0.48
48.044	106	0.264	42.0	859000	18.70	80930	0.48
48.045	106	0.264	42.0	859000	14.60	78460	0.50
48.046	106	0.264	42.0	859000	14.60	78460	0.50
48.047	106	0.264	42.0	859000	7.20	70850	0.52
48.048	106	0.264	42.0	859000	7.20	70850	0.52
48.049	106	0.264	42.0	859000	7.10	71290	0.53
48.050	106	0.264	42.0	859000	7.10	71290	0.53
48.051	106	0.264	42.0	859000	6.90	70530	0.52
48.052	106	0.264	42.0	690000	21.50	73290	0.53
48.053	106	0.264	42.0	690000	21.50	74400	0.54
48.054	106	0.264	42.0	690000	16.20	67490	0.53
48.055	106	0.264	42.0	690000	16.20	67490	0.53
48.056	106	0.264	42.0	690000	9.20	59910	0.53
48.057	106	0.264	42.0	690000	9.20	59910	0.53
48.058	106	0.264	42.0	690000	24.10	79790	0.57
48.059	106	0.264	42.0	690000	24.10	79790	0.57
48.060	106	0.264	42.0	690000	20.30	75920	0.57
48.061	106	0.264	42.0	690000	20.30	75920	0.57
48.062	106	0.264	42.0	690000	15.30	72590	0.60
48.063	106	0.264	42.0	690000	15.30	72210	0.59
48.064	106	0.264	42.0	690000	9.00	67870	0.62
48.065	106	0.264	42.0	690000	9.00	67870	0.62
48.066	106	0.264	42.0	690000	8.70	67390	0.62
48.067	106	0.264	42.0	430000	23.70	59410	0.74
48.068	106	0.264	42.0	430000	23.70	59410	0.74
48.069	106	0.264	42.0	430000	16.50	56680	0.78
48.070	106	0.264	42.0	430000	16.50	56680	0.78
48.071	106	0.264	42.0	430000	8.30	54140	0.83
48.072	106	0.264	42.0	430000	8.30	54140	0.83
48.073	106	0.264	42.0	345000	23.80	51320	0.82
48.074	106	0.264	42.0	345000	23.80	51320	0.82
48.075	106	0.264	42.0	345000	14.50	50150	0.90
48.076	106	0.264	42.0	345000	14.50	50150	0.90
48.077	106	0.264	42.0	345000	14.00	50150	0.91
48.078	106	0.264	42.0	345000	7.60	47550	0.93
48.079	106	0.264	42.0	345000	7.60	47550	0.93
48.080	106	0.264	42.0	345000	7.30	47550	0.93
49.001	200	0.264	41.7	351000	28.90	51700	0.84
49.002	200	0.264	41.7	351000	28.90	51700	0.84
49.003	200	0.264	41.7	351000	20.60	48220	0.87
49.004	200	0.264	41.7	351000	20.60	48220	0.87
49.005	200	0.264	41.7	351000	15.70	46120	0.89
49.006	200	0.264	41.7	351000	15.70	46120	0.89
49.007	200	0.264	41.7	435000	29.40	60990	0.78
49.008	200	0.264	41.7	435000	29.40	60990	0.78
49.009	200	0.264	41.7	435000	18.00	55190	0.82
49.010	200	0.264	41.7	435000	18.00	55190	0.82
49.011	200	0.264	41.7	435000	11.00	48980	0.79
49.012	200	0.264	41.7	435000	11.00	48980	0.79
49.013	200	0.264	41.7	435000	21.80	54590	0.76
49.014	200	0.264	41.7	435000	21.80	54590	0.76
49.015	200	0.264	41.7	435000	27.30	58490	0.76
49.016	200	0.264	41.7	435000	27.30	58490	0.76
49.017	200	0.264	41.7	701000	27.70	71420	0.48
49.018	200	0.264	41.7	701000	27.70	71710	0.49
49.019	200	0.264	41.7	701000	20.00	66090	0.52
49.020	200	0.264	41.7	701000	20.00	66090	0.52
49.021	200	0.264	41.7	701000	11.20	59120	0.55
49.022	200	0.264	41.7	701000	11.00	58950	0.55
49.023	200	0.264	41.7	870000	27.30	75480	0.36
49.024	200	0.264	41.7	870000	27.30	75480	0.36
49.025	200	0.264	41.7	870000	19.10	69390	0.41
49.026	200	0.26[illegible]	41.7	870000	19.10	69390	0.41
49.027	200	[illegible]	41.7	870000	8.90	61310	0.47

APPENDIX 2. (CONTINUED) (1x)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY LB/HR.FT.^{2}	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX BTU/HR.FT^2	EXIT QUALITY
49.028	200	0.264	41.7	870000	8.90	60800	0.46
49.029	200	0.264	41.7	1403000	27.30	89490	0.17
49.030	200	0.264	41.7	1403000	25.50	87560	0.18
49.031	200	0.264	41.7	1403000	25.50	87560	0.18
49.032	200	0.264	41.7	1403000	17.70	79820	0.24
49.033	200	0.264	41.7	1403000	17.70	79820	0.24
49.034	200	0.264	41.7	1403000	17.20	80110	0.25
49.035	200	0.264	41.7	1403000	17.20	80110	0.25
49.036	200	0.264	41.7	1403000	6.90	67240	0.31
49.037	200	0.264	41.7	1403000	6.90	67240	0.31
49.038	200	0.264	41.7	1740000	29.30	98970	0.09
49.039	200	0.264	41.7	1740000	30.00	101180	0.09
49.040	200	0.264	41.7	1740000	30.00	101180	0.09
49.041	200	0.264	41.7	1740000	21.70	88060	0.14
49.042	200	0.264	41.7	1740000	21.70	88060	0.14
49.043	200	0.264	41.7	1740000	9.80	72460	0.22
49.044	200	0.264	41.7	1740000	9.80	72460	0.22
50.001	200	0.264	20.8	1740000	25.70	143380	0.00
50.002	200	0.264	20.8	1740000	25.70	143380	0.00
50.003	200	0.264	20.8	1740000	25.70	134530	-0.02
50.004	200	0.264	20.8	1740000	25.70	134530	-0.02
50.005	200	0.264	20.8	1740000	22.30	133900	0.03
50.006	200	0.264	20.8	1740000	22.30	133900	0.03
50.007	200	0.264	20.8	1740000	19.00	125090	0.05
50.008	200	0.264	20.8	1740000	19.00	126070	0.05
50.009	200	0.264	20.8	1740000	15.60	115890	0.07
50.010	200	0.264	20.8	1740000	15.60	115890	0.07
50.011	200	0.264	20.8	1740000	10.60	102390	0.10
50.012	200	0.264	20.8	1740000	10.60	102390	0.10
50.013	200	0.264	20.8	1740000	9.50	99630	0.11
50.014	200	0.264	20.8	1740000	9.50	99630	0.11
50.015	200	0.264	20.8	1403000	28.20	137260	0.03
50.016	200	0.264	20.8	1403000	28.20	137260	0.03
50.017	200	0.264	20.8	1403000	25.80	131110	0.05
50.018	200	0.264	20.8	1403000	25.80	131110	0.05
50.019	200	0.264	20.8	1403000	22.00	124360	0.08
50.020	200	0.264	20.8	1403000	22.00	124360	0.08
50.021	200	0.264	20.8	1403000	18.50	116430	0.10
50.022	200	0.264	20.8	1403000	18.50	116430	0.10
50.023	200	0.264	20.8	1403000	14.10	112090	0.15
50.024	200	0.264	20.8	1403000	14.10	112090	0.15
50.025	200	0.264	20.8	1403000	10.80	101950	0.16
50.026	200	0.264	20.8	1403000	10.80	101950	0.16
50.027	200	0.264	20.8	1403000	8.10	97160	0.18
50.028	200	0.264	20.8	1403000	8.10	97160	0.18
50.029	200	0.264	20.8	870000	28.20	120240	0.20
50.030	200	0.264	20.8	870000	28.20	120240	0.20
50.031	200	0.264	20.8	870000	22.40	112790	0.24
50.032	200	0.264	20.8	870000	22.40	112000	0.24
50.033	200	0.264	20.8	870000	14.50	101120	0.29
50.034	200	0.264	20.8	870000	14.50	100460	0.29
50.035	200	0.264	20.8	870000	8.40	92120	0.33
50.036	200	0.264	20.8	870000	8.40	92120	0.33
50.037	200	0.264	20.8	701000	29.00	113230	0.29
50.038	200	0.264	20.8	701000	29.00	113230	0.29
50.039	200	0.264	20.8	701000	21.10	103750	0.34
50.040	200	0.264	20.8	701000	21.10	103750	0.34
50.041	200	0.264	20.8	701000	15.90	98020	0.37
50.042	200	0.264	20.8	701000	15.90	98400	0.37
50.043	200	0.264	20.8	701000	7.00	88160	0.43
50.044	200	0.264	20.8	701000	7.00	88160	0.43
50.045	200	0.264	20.8	435000	27.40	97410	0.57
50.048	200	0.264	20.8	435000	19.20	90820	0.61
50.049	200	0.264	20.8	435000	14.10	87210	0.65
50.050	200	0.264	20.8	435000	7.90	81440	0.67
50.051	200	0.264	20.8	435000	7.90	81440	0.67
50.052	200		20.8	351000	25.30	88700	0.72
50.053	200	0.264	20.8	351000	25.30	88700	0.72

APPENDIX 2. (CONTINUED) (x)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
50.054	200	0.264	20.8	351000	21.20	86570	0.74
50.055	200	0.264	20.8	351000	21.20	86570	0.74
50.056	200	0.264	20.8	351000	14.30	79660	0.75
50.057	200	0.264	20.8	351000	14.30	79660	0.75
50.058	200	0.264	20.8	351000	14.30	80010	0.76
50.059	200	0.264	20.8	351000	11.00	76810	0.76
50.060	200	0.264	20.8	351000	11.00	76810	0.76
51.001	106	0.264	21.0	1720000	23.50	148860	0.05
51.002	106	0.264	21.0	1720000	23.50	149430	0.05
51.003	106	0.264	21.0	1720000	19.20	136910	0.07
51.004	106	0.264	21.0	1720000	19.20	136910	0.07
51.005	106	0.264	21.0	1720000	13.70	127720	0.11
51.006	106	0.264	21.0	1720000	13.70	127720	0.11
51.007	106	0.264	21.0	1720000	7.60	114250	0.16
51.008	106	0.264	21.0	1720000	7.60	114940	0.16
51.009	106	0.264	21.0	1380000	23.10	140330	0.11
51.010	106	0.264	21.0	1380000	23.10	140330	0.11
51.011	106	0.264	21.0	1380000	19.60	132540	0.13
51.012	106	0.264	21.0	1380000	19.60	132540	0.13
51.013	106	0.264	21.0	1380000	14.20	121280	0.16
51.014	106	0.264	21.0	1380000	14.20	121280	0.16
51.015	106	0.264	21.0	1380000	5.50	108480	0.23
51.016	106	0.264	21.0	1380000	5.50	108480	0.23
51.017	106	0.264	21.0	1380000	5.50	107910	0.22
51.018	106	0.264	21.0	1380000	5.50	107910	0.22
51.019	106	0.264	21.0	1380000	7.90	112190	0.21
51.020	106	0.264	21.0	1380000	7.90	112190	0.21
51.021	106	0.264	21.0	859000	22.80	129300	0.29
51.022	106	0.264	21.0	859000	22.80	129300	0.29
51.023	106	0.264	21.0	859000	19.00	127720	0.33
51.024	106	0.264	21.0	859000	19.00	126360	0.32
51.025	106	0.264	21.0	859000	14.10	123630	0.37
51.026	106	0.264	21.0	859000	14.10	123000	0.36
52.001	200	0.633	97.8	870000	26.50	61720	0.23
52.002	200	0.633	97.8	870000	26.40	61440	0.23
52.003	200	0.633	97.8	870000	26.40	61440	0.23
52.004	200	0.633	97.8	870000	19.00	56140	0.27
52.005	200	0.633	97.8	870000	19.00	56010	0.27
52.006	200	0.633	97.8	870000	12.10	51350	0.32
52.007	200	0.633	97.8	870000	12.10	51350	0.32
52.008	200	0.633	97.8	870000	7.30	47840	0.35
52.009	200	0.633	97.8	870000	7.30	47580	0.35
52.010	200	0.633	97.8	701000	26.20	57850	0.33
52.011	200	0.633	97.8	701000	26.20	57789	0.33
52.012	200	0.633	97.8	701000	19.70	52780	0.35
52.013	200	0.633	97.8	701000	19.70	53098	0.36
52.014	200	0.633	97.8	701000	19.70	53098	0.36
52.015	200	0.633	97.8	701000	11.90	48440	0.41
52.016	200	0.633	97.8	701000	11.90	48440	0.41
52.017	200	0.633	97.8	701000	6.50	44540	0.43
52.018	200	0.633	97.8	701000	6.50	44540	0.43
52.019	200	0.633	97.8	435000	25.80	47740	0.55
52.020	200	0.633	97.8	435000	25.80	47960	0.56
52.021	200	0.633	97.8	435000	21.00	45740	0.58
52.022	200	0.633	97.8	435000	21.00	45870	0.58
52.023	200	0.633	97.8	435000	15.30	42620	0.60
52.024	200	0.633	97.8	435000	15.30	42730	0.60
52.025	200	0.633	97.8	435000	5.80	37790	0.63
52.026	200	0.633	97.8	435000	5.80	37790	0.63
52.027	200	0.633	97.8	351000	26.20	43560	0.66
52.028	200	0.633	97.8	351000	26.20	43560	0.66
52.029	200	0.633	97.8	351000	20.50	40880	0.68
52.030	200	0.633	97.8	351000	20.50	40990	0.68
52.031	200	0.633	97.8	351000	11.90	37180	0.70
52.032	200	0.633	97.8	351000	11.90	36960	0.70
52.033	200	0.633	97.8	351000	5.20	34110	0.72
52.034	200	0.633	97.8	351000	5.20	34000	0.72

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APPENDIX 2. (CONTINUED) (xi)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
52.035	200	0.633	97.8	859000	23.60	69340	0.35
52.036	200	0.633	97.8	859000	23.60	69340	0.35
52.037	200	0.633	97.8	859000	19.10	65760	0.37
52.038	200	0.633	97.8	859000	19.10	65760	0.37
52.039	200	0.633	97.8	859000	12.70	60780	0.41
52.040	200	0.633	97.8	859000	12.70	60780	0.41
52.041	200	0.633	97.8	859000	6.60	55650	0.44
52.042	200	0.633	97.8	859000	6.60	55980	0.44
52.043	200	0.633	97.8	690000	23.10	64985	0.46
52.044	200	0.633	97.8	690000	23.10	64836	0.46
52.045	200	0.633	97.8	690000	18.10	61300	0.48
52.046	200	0.633	97.8	690000	18.10	61300	0.48
52.047	200	0.633	97.8	690000	12.90	57240	0.50
52.048	200	0.633	97.8	690000	12.90	57240	0.50
52.049	200	0.633	97.8	690000	5.10	51427	0.54
52.050	200	0.633	97.8	690000	5.10	51576	0.54
52.051	200	0.633	97.8	430000	23.50	54258	0.72
52.052	200	0.633	97.8	430000	23.50	54258	0.72
52.053	200	0.633	97.8	430000	16.90	50780	0.74
52.054	200	0.633	97.8	430000	16.90	50780	0.74
52.055	200	0.633	97.8	430000	12.40	47845	0.74
52.056	200	0.633	97.8	430000	12.40	48155	0.75
52.057	200	0.633	97.8	430000	7.30	44215	0.74
52.058	200	0.633	97.8	430000	7.30	44339	0.74
52.059	200	0.633	97.8	345000	17.80	45390	0.84
52.060	200	0.633	97.8	345000	17.80	45390	0.84
52.061	200	0.633	97.8	345000	21.60	47530	0.84
52.062	200	0.633	97.8	345000	21.60	47530	0.84
52.063	200	0.633	97.8	345000	7.00	40040	0.85
52.064	200	0.633	97.8	345000	7.00	40627	0.87
52.065	200	0.633	97.8	345000	7.00	40390	0.86
52.066	200	0.633	97.8	1720000	22.00	98397	0.18
52.067	200	0.633	97.8	1720000	22.00	98397	0.18
52.068	200	0.633	97.8	1720000	17.50	92250	0.21
52.069	200	0.633	97.8	1720000	17.50	91390	0.20
52.070	200	0.633	97.8	1720000	11.70	82410	0.24
52.071	200	0.633	97.8	1720000	11.70	82550	0.24
52.072	200	0.633	97.8	1720000	6.60	76110	0.27
52.073	200	0.633	97.8	1720000	6.60	76020	0.27
52.074	200	0.633	97.8	1380000	6.90	71930	0.33
52.075	200	0.633	97.8	1380000	6.90	71710	0.33
52.076	200	0.633	97.8	1380000	10.70	75097	0.30
52.077	200	0.633	97.8	1380000	10.70	75097	0.30
52.078	200	0.633	97.8	1380000	14.50	79410	0.28
52.079	200	0.633	97.8	1380000	14.50	79410	0.28
52.080	200	0.633	97.8	1380000	22.50	90920	0.24
52.081	200	0.633	97.8	1380000	22.50	90920	0.24
52.082	200	0.633	97.8	1380000	18.60	86450	0.26
52.083	200	0.633	97.8	1380000	18.60	86130	0.26
52.084	200	0.633	97.8	1740000	25.60	88320	0.08
52.085	200	0.633	97.8	1740000	25.60	88630	0.08
52.086	200	0.633	97.8	1740000	25.50	89520	0.08
52.087	200	0.633	97.8	1740000	25.50	88440	0.08
52.088	200	0.633	97.8	1740000	19.40	76680	0.10
52.089	200	0.633	97.8	1740000	19.40	76020	0.10
52.090	200	0.633	97.8	1740000	13.80	65520	0.12
52.091	200	0.633	97.8	1740000	13.80	65810	0.13
52.092	200	0.633	97.8	1740000	9.20	59280	0.16
52.093	200	0.633	97.8	1740000	9.20	59280	0.16
52.094	200	0.633	97.8	1740000	8.60	58300	0.16
52.095	200	0.633	97.8	1740000	8.60	58490	0.16
52.096	200	0.633	97.8	1403000	25.30	79760	0.13
52.097	200	0.633	97.8	1403000	25.30	80070	0.13
52.098	200	0.633	97.8	1403000	20.50	72340	0.15
52.099	200	0.633	97.8	1403000	20.50	72340	0.15
52.100	200	0.633	97.8	1403000	14.80	64790	0.18
52.101	200	0.633	97.8	1403000	14.80	64790	0.18
52.102	200	0.633	97.8	1403000	14.80	64920	0.18
52.103	200	0.633	97.8	1403000	8.90	58490	0.22
52.104	200	0.633	97.8	1403000	8.90	58490	0.22

APPENDIX 2. (CONTINUED) (xii)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
53.001	106	0.633	125.0	859000	23.10	59089	0.36
53.002	106	0.633	125.0	859000	23.10	59089	0.36
53.003	106	0.633	125.0	859000	23.10	59140	0.36
53.004	106	0.633	125.0	859000	17.80	55345	0.38
53.005	106	0.633	125.0	859000	17.80	55345	0.38
53.006	106	0.633	125.0	859000	12.40	51260	0.40
53.007	106	0.633	125.0	859000	12.40	51260	0.40
53.008	106	0.633	125.0	859000	5.50	46170	0.43
53.009	106	0.633	125.0	859000	5.50	46170	0.43
53.010	106	0.633	125.0	690000	22.50	53976	0.45
53.011	106	0.633	125.0	690000	22.50	53976	0.45
53.012	106	0.633	125.0	690000	17.40	50750	0.47
53.013	106	0.633	125.0	690000	17.40	50560	0.47
53.014	106	0.633	125.0	690000	12.80	47550	0.48
53.015	106	0.633	125.0	690000	12.80	47550	0.48
53.016	106	0.633	125.0	690000	5.00	42770	0.51
53.017	106	0.633	125.0	690000	5.00	42770	0.51
53.018	106	0.633	125.0	430000	22.70	43359	0.66
53.019	106	0.633	125.0	430000	22.70	43359	0.66
53.020	106	0.633	125.0	430000	16.10	40569	0.68
53.021	106	0.633	125.0	430000	16.10	40569	0.68
53.022	106	0.633	125.0	430000	11.30	38270	0.68
53.023	106	0.633	125.0	430000	11.30	38270	0.68
53.024	106	0.633	125.0	430000	5.20	35420	0.69
53.025	106	0.633	125.0	430000	5.20	35320	0.69
53.026	106	0.633	125.0	345000	23.10	38477	0.75
53.027	106	0.633	125.0	345000	23.10	38278	0.75
53.028	106	0.633	125.0	345000	17.30	36198	0.76
53.029	106	0.633	125.0	345000	17.30	36198	0.76
53.030	106	0.633	125.0	345000	11.60	33992	0.77
53.031	106	0.633	125.0	345000	11.60	33992	0.77
53.032	106	0.633	125.0	345000	4.30	30940	0.77
53.033	106	0.633	125.0	345000	4.30	30980	0.77
53.034	106	0.633	125.0	345000	11.50	34130	0.77
53.035	106	0.633	125.0	345000	11.50	34130	0.77
53.036	106	0.633	125.0	345000	2.30	30000	0.77
53.037	106	0.633	125.0	345000	2.30	30000	0.77
53.038	106	0.633	125.0	345000	22.80	38179	0.75
53.039	106	0.633	125.0	345000	22.80	38477	0.75
53.040	106	0.633	125.0	870000	25.90	53770	0.26
53.041	106	0.633	125.0	870000	25.90	53770	0.26
53.042	106	0.633	125.0	870000	19.50	49350	0.29
53.043	106	0.633	125.0	870000	19.50	49350	0.29
53.044	106	0.633	125.0	870000	14.10	45330	0.31
53.045	106	0.633	125.0	870000	14.10	45330	0.31
53.046	106	0.633	125.0	870000	14.10	45398	0.31
53.047	106	0.633	125.0	870000	8.50	41435	0.34
53.048	106	0.633	125.0	870000	8.50	41226	0.33
53.049	106	0.633	125.0	701000	27.20	49075	0.32
53.050	106	0.633	125.0	701000	27.20	49075	0.32
53.051	106	0.633	125.0	701000	27.20	49300	0.33
53.052	106	0.633	125.0	701000	25.60	48340	0.33
53.053	106	0.633	125.0	701000	25.60	48340	0.33
53.054	106	0.633	125.0	701000	20.00	44960	0.35
53.055	106	0.633	125.0	701000	20.00	44910	0.35
53.056	106	0.633	125.0	701000	13.80	40920	0.37
53.057	106	0.633	125.0	701000	13.80	40920	0.37
53.058	106	0.633	125.0	701000	5.00	34930	0.40
53.059	106	0.633	125.0	701000	5.00	34930	0.40
53.060	106	0.633	125.0	435000	26.60	39120	0.51
53.061	106	0.633	125.0	435000	26.60	39320	0.52
53.062	106	0.633	125.0	435000	19.50	36230	0.54
53.063	106	0.633	125.0	435000	19.50	36230	0.54
53.064	106	0.633	125.0	435000	14.00	33690	0.55
53.065	106	0.633	125.0	435000	14.00	33690	0.55
53.066	106	0.633	125.0	435000	7.90	30960	0.56
53.067	106	0.633	125.0	435000	7.90	30960	0.56
53.068	106	0.633	125.0		26.00	34310	0.59
53.069	106	0.633	125.0	[illegible]	[illegible]	[illegible]	0.60

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
53.070	106	0.633	125.0	351000	18.50	32110	0.62
53.071	106	0.633	125.0	351000	18.50	32110	0.62
53.072	106	0.633	125.0	351000	11.60	29360	0.63
53.073	106	0.633	125.0	351000	11.60	29280	0.63
53.074	106	0.633	125.0	351000	13.10	30030	0.63
53.075	106	0.633	125.0	351000	13.10	30030	0.63
53.076	106	0.633	125.0	351000	6.40	27510	0.64
53.077	106	0.633	125.0	351000	6.40	27510	0.64
53.078	106	0.633	125.0	1720000	22.00	87130	0.21
53.079	106	0.633	125.0	1720000	22.00	86538	0.21
53.080	106	0.633	125.0	1720000	22.00	86538	0.21
53.081	106	0.633	125.0	1720000	18.00	81040	0.22
53.082	106	0.633	125.0	1720000	18.00	81399	0.22
53.083	106	0.633	125.0	1720000	12.10	75053	0.26
53.084	106	0.633	125.0	1720000	12.10	74520	0.26
53.085	106	0.633	125.0	1720000	12.10	74520	0.26
53.086	106	0.633	125.0	1720000	6.50	67930	0.29
53.087	106	0.633	125.0	1720000	6.50	68060	0.29
53.088	106	0.633	125.0	1380000	22.30	81550	0.28
53.089	106	0.633	125.0	1380000	22.20	80886	0.28
53.090	106	0.633	125.0	1380000	17.60	76140	0.30
53.091	106	0.633	125.0	1380000	17.60	75858	0.30
53.092	106	0.633	125.0	1380000	12.10	70170	0.32
53.093	106	0.633	125.0	1380000	12.10	70170	0.32
53.094	106	0.633	125.0	1380000	6.60	64380	0.35
53.095	106	0.633	125.0	1380000	6.60	64450	0.35
53.096	106	0.633	125.0	1740000	27.80	78200	0.09
53.097	106	0.633	125.0	1740000	27.80	78200	0.09
53.098	106	0.633	125.0	1740000	27.80	78140	0.09
53.099	106	0.633	125.0	1740000	19.60	65700	0.12
53.100	106	0.633	125.0	1740000	19.60	65700	0.12
53.101	106	0.633	125.0	1740000	14.40	52200	0.11
53.102	106	0.633	125.0	1740000	14.40	59279	0.14
53.103	106	0.633	125.0	1740000	7.90	54930	0.20
53.104	106	0.633	125.0	1740000	7.90	55345	0.20
53.105	106	0.633	125.0	1740000	7.90	55345	0.20
53.106	106	0.633	125.0	1403000	24.00	67226	0.16
53.107	106	0.633	125.0	1403000	24.00	67226	0.16
53.108	106	0.633	125.0	1403000	19.20	62195	0.18
53.109	106	0.633	125.0	1403000	19.20	62195	0.18
53.110	106	0.633	125.0	1403000	13.20	57567	0.22
53.111	106	0.633	125.0	1403000	13.20	57460	0.22
53.112	106	0.633	125.0	1403000	13.20	57460	0.22
53.113	106	0.633	125.0	1403000	7.30	52736	0.26
53.114	106	0.633	125.0	1403000	7.30	52736	0.26
53.115	106	0.633	125.0	1403000	9.00	53785	0.25
53.116	106	0.633	125.0	1403000	9.00	53785	0.25
54.001	200	0.633	48.9	870000	26.20	96780	0.11
54.002	200	0.633	48.9	870000	26.20	97310	0.11
54.003	200	0.633	48.9	870000	19.40	87430	0.15
54.004	200	0.633	48.9	870000	19.40	87430	0.15
54.005	200	0.633	48.9	870000	13.40	79030	0.19
54.006	200	0.633	48.9	870000	13.40	79030	0.19
54.007	200	0.633	48.9	870000	7.40	70786	0.23
54.008	200	0.633	48.9	870000	7.40	70786	0.23
54.009	200	0.633	48.9	701000	25.70	90090	0.18
54.010	200	0.633	48.9	701000	25.70	90090	0.18
54.011	200	0.633	48.9	701000	19.40	82660	0.22
54.012	200	0.633	48.9	701000	19.40	82390	0.22
54.013	200	0.633	48.9	701000	13.10	75290	0.26
54.014	200	0.633	48.9	701000	13.10	75540	0.27
54.015	200	0.633	48.9	701000	6.00	66470	0.31
54.016	200	0.633	48.9	701000	6.00	66470	0.31
54.017	200	0.633	48.9	701000	6.90	68090	0.30
54.018	200	0.633	48.9	701000	6.90	68570	0.31
54.019	200	0.633	48.9	435000	25.90	77400	0.38
54.020	200	0.633	48.9	435000	25.90	77250	0.38
54.021	200	33	48.9	435000	20.50	72560	0.41
54.022	200		48.9	435000	20.50	72940	0.41
54. 23	200		48.9	435000	15.00	69660	0.44

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APPENDIX 2. (CONTINUED) (xiv)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY $LB/HR.FT.^2$	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX $BTU/HR.FT^2$	EXIT QUALITY
54.024	200	0.633	48.9	435000	15.00	68660	0.44
54.025	200	0.633	48.9	435000	7.80	63070	0.49
54.026	200	0.633	48.9	435000	7.80	63070	0.49
54.027	200	0.633	48.9	351000	25.40	71720	0.50
54.028	200	0.633	48.9	351000	25.40	71720	0.50
54.029	200	0.633	48.9	351000	25.40	71850	0.50
54.030	200	0.633	48.9	351000	25.40	71850	0.50
54.031	200	0.633	48.9	351000	20.00	67900	0.52
54.032	200	0.633	48.9	351000	20.00	67900	0.52
54.033	200	0.633	48.9	351000	13.90	64256	0.56
54.034	200	0.633	48.9	351000	13.90	64540	0.56
54.035	200	0.633	48.9	351000	6.60	59310	0.60
54.036	200	0.633	48.9	351000	6.60	59370	0.60
54.037	200	0.633	48.9	859000	23.60	103080	0.18
54.038	200	0.633	48.9	859000	23.60	102710	0.18
54.039	200	0.633	48.9	859000	18.60	96430	0.21
54.040	200	0.633	48.9	859000	18.60	96560	0.21
54.041	200	0.633	48.9	859000	12.20	87240	0.25
54.042	200	0.633	48.9	859000	12.20	87240	0.25
54.043	200	0.633	48.9	859000	5.60	79535	0.30
54.044	200	0.633	48.9	859000	5.60	79535	0.30
54.045	200	0.633	48.9	859000	23.40	103470	0.18
54.046	200	0.633	48.9	859000	23.40	103470	0.18
54.047	200	0.633	48.9	859000	18.50	96430	0.21
54.048	200	0.633	48.9	859000	18.50	96430	0.21
54.049	200	0.633	48.9	859000	12.30	87970	0.25
54.050	200	0.633	48.9	859000	12.30	87970	0.25
54.051	200	0.633	48.9	859000	6.20	80580	0.30
54.052	200	0.633	48.9	859000	6.20	80640	0.30
54.053	200	0.633	48.9	690000	22.20	95640	0.27
54.054	200	0.633	48.9	690000	22.20	95640	0.27
54.055	200	0.633	48.9	690000	22.20	95480	0.27
54.056	200	0.633	48.9	690000	22.20	95480	0.27
54.057	200	0.633	48.9	690000	17.80	90916	0.30
54.058	200	0.633	48.9	690000	17.80	90567	0.30
54.059	200	0.633	48.9	690000	13.10	88030	0.35
54.060	200	0.633	48.9	690000	13.10	88030	0.35
54.061	200	0.633	48.9	690000	12.90	87207	0.34
54.062	200	0.633	48.9	690000	6.20	80900	0.40
54.063	200	0.633	48.9	690000	6.20	80900	0.40
54.064	200	0.633	48.9	430000	22.90	86126	0.53
54.065	200	0.633	48.9	430000	22.90	88126	0.53
54.066	200	0.633	48.9	430000	18.00	84576	0.56
54.067	200	0.633	48.9	430000	18.00	84576	0.56
54.068	200	0.633	48.9	430000	13.80	81340	0.59
54.069	200	0.633	48.9	430000	13.80	81500	0.59
54.070	200	0.633	48.9	430000	5.60	74240	0.63
54.071	200	0.633	48.9	430000	5.50	74685	0.63
54.072	200	0.633	48.9	345000	22.60	82420	0.67
54.073	200	0.633	48.9	345000	22.60	82420	0.67
54.074	200	0.633	48.9	345000	18.20	80550	0.71
54.075	200	0.633	48.9	345000	18.20	80550	0.71
54.076	200	0.633	48.9	345000	12.20	75950	0.73
54.077	200	0.633	48.9	345000	12.20	76240	0.74
54.078	200	0.633	48.9	345000	6.00	70850	0.76
54.079	200	0.633	48.9	345000	6.00	71515	0.76
54.080	200	0.633	48.9	345000	6.00	71110	0.76
54.081	200	0.633	48.9	345000	22.50	83310	0.69
54.082	200	0.633	48.9	345000	22.50	83310	0.69
54.083	200	0.633	48.9	1740000	22.10	125360	0.00
54.084	200	0.633	48.9	1740000	22.10	125360	0.00
54.085	200	0.633	48.9	1740000	18.30	111060	0.02
54.086	200	0.633	48.9	1740000	18.30	111060	0.02
54.087	200	0.633	48.9	1740000	13.60	95290	0.04
54.088	200	0.633	48.9	1740000	13.60	95290	0.04
54.089	200	0.633	48.9	1740000	8.10	77205	0.07
54.090	200	0.633	48.9	1740000	8.10	77000	0.07
54.091	200	0.633	48.9	1403000	5.10	68870	0.13
54.092	200	0.633	48.9	1403000	5.10	68818	0.13
54.093	200	0.633	[illegible]	1403000	10.50	80486	0.10
54.094	200	[illegible]	[illegible]	1403000	10.50	79630	0.09
[illegible]	200	[illegible]	[illegible]	[illegible]	16.70	[illegible]	[illegible]

APPENDIX 2. (CONTINUED) (xv)

BURNOUT DATA FOR FREON 21 IN UNIFORMLY HEATED ROUND TUBES

RUN NUMBER	INLET PRESSURE P.S.I.A.	INTERNAL DIAMETER INCHES	HEATED LENGTH INCHES	MASS VELOCITY LB/HR.FT.^{2}	INLET SUBCOOLING BTU/LB.	BURNOUT HEAT FLUX BTU/HR.FT^2	EXIT QUALITY
54.096	200	0.633	48.9	1403000	16.70	96050	0.06
54.097	200	0.633	48.9	1403000	21.40	109796	0.04
54.098	200	0.633	48.9	1403000	21.40	109796	0.04
54.099	200	0.633	48.9	1720000	4.90	92406	0.15
54.100	200	0.633	48.9	1720000	4.90	91708	0.15
54.101	200	0.633	48.9	1720000	8.20	97620	0.12
54.102	200	0.633	48.9	1720000	8.20	97256	0.12
54.103	200	0.633	48.9	1720000	12.40	106310	0.09
54.104	200	0.633	48.9	1720000	12.20	103370	0.08
54.105	200	0.633	48.9	1720000	12.20	103370	0.08
54.106	200	0.633	48.9	1720000	16.80	104640	0.03
54.107	200	0.633	48.9	1720000	16.80	104946	0.03
54.108	200	0.633	48.9	1380000	4.50	87514	0.20
54.109	200	0.633	48.9	1380000	4.50	87514	0.20
54.110	200	0.633	48.9	1380000	8.30	95030	0.17
54.111	200	0.633	48.9	1380000	8.30	95030	0.17
54.112	200	0.633	48.9	1380000	11.90	99690	0.14
54.113	200	0.633	48.9	1380000	15.40	106310	0.11

18

CARBON DIOXIDE CHF DATA
ROTEM & HAUPTMAN (1970)

Run No	G (lbm/hr-ft²)	Φ (Btu/hr-ft²)	P_i (psia)	ΔP (psid)	$\Delta H_i/\lambda$	W	X	L_b (in)	W_b	X_b
1	1.30	1.18	279	8	0.12	0.40	4.31	31.87	0.39	5.05
2	1.77	1.24	279	13	0.10	0.30	5.88	31.13	0.30	6.97
3	1.84	1.29	280	13	0.11	0.29	6.12	30.03	0.29	7.42
4	1.36	1.20	280	9	0.12	0.38	4.50	31.64	0.38	5.29
5	1.40	1.18	281	8	0.12	0.36	4.65	31.14	0.36	5.52
6	1.31	1.19	281	8	0.12	0.40	4.36	31.91	0.40	5.10
7	2.01	1.28	282	13	0.11	0.25	6.68	28.91	0.25	8.28
8	1.93	1.27	283	14	0.10	0.28	6.40	30.47	0.27	7.69
9	1.84	1.24	283	14	0.09	0.29	6.10	31.87	0.29	7.13
10	1.83	1.23	284	14	0.09	0.30	6.09	31.80	0.29	7.14
11	1.44	1.25	285	10	0.12	0.37	4.77	31.51	0.37	5.62
12	1.04	1.04	285	5	0.10	0.46	3.46	34.25	0.47	3.88
13	1.72	1.29	286	12	0.12	0.31	5.70	29.92	0.31	6.92
14	2.09	1.27	293	17	0.09	0.25	5.95	30.81	0.26	8.29
15	1.29	1.16	294	8	0.11	0.41	4.28	32.75	0.41	4.93
16	1.11	1.03	297	4	0.11	0.42	3.67	33.02	0.42	4.21
17	2.20	1.27	299	17	0.09	0.24	7.29	30.34	0.24	8.78
18	2.25	1.25	304	17	0.09	0.23	7.47	29.96	0.23	9.07
19	0.68	1.01	305	4	0.12	0.74	2.27	35.76	0.73	2.48
20	1.01	1.02	310	4	0.12	0.47	3.35	33.06	0.46	3.84
21	2.45	1.28	312	19	0.09	0.21	8.16	29.21	0.21	10.05
22	2.45	1.27	314	20	0.08	0.22	8.12	30.58	0.22	9.74
23	2.42	1.28	315	19	0.08	0.23	8.03	30.79	0.23	9.59
24	1.28	1.17	316	8	0.12	0.41	4.25	32.25	0.41	4.93
25	0.87	1.02	317	4	0.12	0.57	2.88	34.37	0.57	3.22
26	2.52	1.25	318	19	0.08	0.21	8.37	30.15	0.21	10.12
27	3.15	1.30	320	16	0.14	0.11	10.45	17.61	0.10	17.35
28	2.65	1.26	323	19	0.08	0.20	8.78	29.68	0.20	10.72
29	3.14	1.40	324	20	0.14	0.12	10.42	19.40	0.12	16.35
30	3.17	1.34	325	16	0.14	0.11	10.52	18.23	0.11	17.12
31	3.14	1.34	328	15	0.14	0.11	10.42	13.45	0.11	16.93
32	3.17	1.37	328	16	0.14	0.11	10.52	18.80	0.12	16.80
33	2.59	1.25	331	12	0.12	0.16	8.61	24.09	0.17	11.88
34	3.22	1.34	331	15	0.14	0.10	10.70	17.89	0.11	17.61
35	2.77	1.25	332	21	0.08	0.19	9.19	29.13	0.19	11.34
36	3.03	1.44	333	19	0.15	0.13	10.07	19.37	0.13	15.80

Run No	G $\frac{lbm}{hr-ft^2}$	Φ ($\frac{Btu}{hr-ft^2}$)	P_i (Psia)	ΔP psid	$\frac{\Delta H_i}{\lambda}$	W	X	L_b (in)	W_b	X_b
37	3.17	1.44	333	19	0.15	0.11	10.52	18.47	0.12	16.99
38	3.57	1.41	334	15	0.16	0.08	11.84	13.14	0.07	23.37
39	3.03	1.35	335	15	0.15	0.12	10.05	17.95	0.11	16.50
40	1.49	1.18	336	7	0.13	0.33	4.95	30.06	0.34	6.00
41	3.60	1.37	340	15	0.16	0.07	11.96	12.32	0.07	24.51
42	1.63	1.22	343	8	0.14	0.31	5.41	28.57	0.31	6.75
43	3.27	1.46	343	19	0.16	0.10	10.86	16.68	0.11	18.62
44	3.35	1.45	348	19	0.15	0.10	11.13	17.50	0.11	18.55
45	3.35	1.49	349	19	0.17	0.10	11.13	15.11	0.10	20.22
46	0.99	1.02	349	4	0.14	0.48	3.27	32.24	0.48	3.80
47	3.29	1.39	353	14	0.16	0.09	10.91	15.42	0.09	19.59
48	3.67	1.41	359	14	0.16	0.07	12.17	13.14	0.07	24.01
49	0.95	1.01	360	4	0.15	0.50	3.15	31.91	0.49	3.68
50	2.05	1.36	378		0.17	0.24	6.81	18.43	0.14	11.01
51	1.06	1.04	378	4	0.16	0.44	3.52	30.56	0.44	4.22
52	1.67	1.22	380		0.18	0.27	5.55	19.22	0.15	8.76
53	3.65	1.40	382	19	0.15	0.09	12.11	15.33	0.09	21.82
54	2.21	1.32	384		0.19	0.18	7.35	12.55	0.08	14.82
55	3.98	1.53	384	16	0.18	0.06	13.21	10.18	0.06	30.31
56	3.51	1.35	384	18	0.14	0.10	11.64	17.30	0.10	19.54
57	1.96	1.33	388		0.19	0.24	5.51	15.28	0.12	11.32
58	3.28	1.49	390		0.20	0.08	10.89	1.55	0.01	75.72
59	2.05	1.32	392		0.19	0.21	6.80	14.80	0.10	12.51
60	1.56	1.23	392		0.19	0.30	5.19	19.61	0.17	8.10
61	3.21	1.18	393	17	0.14	0.09	10.67	15.30	0.09	18.54
62	4.17	1.56	394	16	0.19	0.05	13.85	7.93	0.04	36.82
63	1.71	1.15	395	9	0.17	0.25	5.69	24.76	0.25	7.73
64	3.24	1.34	396	17	0.16	0.10	10.75	15.98	0.10	18.91
65	3.53	1.55	400		0.22	0.06	11.73			
66	4.31	1.58	400		0.19	0.05	14.31			
67	2.29	1.33	400		0.19	0.19	7.62	11.99	0.08	15.87
68	3.32	1.35	401	17	0.15	0.10	11.01	17.22	0.11	18.53
69	3.34	1.27	401	18	0.13	0.11	11.09	18.96	0.11	17.63
70	1.67	1.22	402		0.19	0.27	5.56	17.97	0.14	9.12
71	3.41	1.39	402	17	0.16	0.09	11.32	15.62	0.10	20.17
72	3.02	1.49	403	10	0.22	0.09	10.01	12.17	0.09	20.67

Run No	G $\frac{lbm}{hr-ft^2}$	Φ $\frac{Btu}{hr-ft^2}$	P_i (Psia)	ΔP psid	$\frac{\Delta H_i}{\lambda}$	W	X	L_b in	W_b	X_b
73	3.48	1.55	406		0.22	0.07	11.56			
74	2.22	1.29	408		0.20	0.17	7.36	10.54	0.07	16.54
75	3.01	1.45	410		0.21	0.09	9.99	2.21	0.01	56.40
76	3.12	1.55	410		0.22	0.10	10.34	1.45	0.01	74.97
77	3.76	1.36	411	17	0.16	0.07	12.46	12.72	0.07	25.07
78	3.46	1.52	413	16	0.20	0.08	11.47	11.88	0.08	24.03
79	3.26	1.48	418	10	0.22	0.07	10.83	10.07	0.07	25.02
80	3.57	1.31	418	17	0.15	0.09	11.86	14.92	0.08	21.71
81	3.34	1.62	420		0.22	0.09	11.09	0.59	0.00	136.26
82	3.63	1.58	420		0.23	0.05	12.05			
83	3.33	1.49	420		0.23	0.05	11.06			
84	3.44	1.55	420		0.22	0.07	11.43			
85	4.03	1.63	420	16	0.20	0.06	13.37	9.44	0.06	32.09
86	3.53	1.40	421	17	0.17	0.09	11.72	13.76	0.08	22.51
87	2.14	1.22	422		0.19	0.17	7.10	11.39	0.07	15.25
88	3.50	1.50	422		0.21	0.05	11.63			
89	3.29	1.49	425		0.22	0.07	10.91			
90	2.98	1.38	426	13	0.18	0.12	9.90	16.52	0.12	17.08
91	2.13	1.26	428		0.22	0.15	7.08	7.83	0.05	18.96
92	3.29	1.49	428		0.22	0.07	10.92			
93	2.41	1.26	428	8	0.1[illegible]	0.14	8.00	18.18	0.15	13.04
94	1.24	0.98	428	4	0.17	0.34	4.12	27.69	0.34	5.24
95	1.61	1.15	431	6	0.19	0.27	5.33	24.56	0.27	7.28
96	4.25	1.78	434		0.19	0.08	14.16	0.26	0.00	285.45
97	3.39	1.30	434	16	0.15	0.09	11.26	16.61	0.10	19.36
98	3.13	1.49	435		0.23	0.08	10.38			
99	3.79	1.46	435	17	0.17	0.08	12.57	13.33	0.08	24.61
100	3.30	1.52	436		0.22	0.08	10.94			
101	1.21	0.98	437	3	0.18	0.35	4.03	27.39	0.35	5.16
102	2.39	1.30	437	9	0.17	0.18	7.94	21.64	0.18	11.67
103	3.40	1.35	437	17	0.16	0.10	11.30	15.86	0.10	19.96
104	2.37	1.28	438		0.22	0.13	7.86	4.60	0.03	28.83
105	1.73	1.14	439	5	0.20	0.23	5.74	22.36	0.23	8.27
106	2.83	1.47	439		0.19	0.15	9.39	8.49	0.05	24.00
107	4.22	1.74	440		0.20	0.07	14.02			
108	3.39	1.61	440		0.24	0.07	11.26			

Run No	G $\left(\frac{lbm}{hr-ft^2}\right)$	Φ $\left(\frac{Btu}{hr-ft^2}\right)$	P_i (Psia)	ΔP (psid)	$\frac{\Delta H_i}{\lambda}$	W	X	L_b (in)	W_b	X_b
109	2.50	1.29	440	9	0.19	0.14	8.31	18.06	0.15	13.59
110	4.13	1.70	440	12	0.23	0.03	13.70	5.99	0.04	43.01
111	2.44	1.28	442		0.22	0.12	8.11	3.44	0.02	35.29
112	3.29	1.58	442		0.23	0.08	10.93			
113	3.46	1.54	446		0.22	0.07	11.48			
114	3.64	1.74	448		0.25	0.07	12.07			
115	2.52	1.82	449	9	0.20	0.28	8.37	24.12	0.28	11.54
116	3.58	1.44	449	17	0.17	0.10	11.89	14.93	0.10	21.76
117	3.24	1.45	450		0.23	0.06	10.76			
118	2.13	1.28	450		0.24	0.15	7.07	5.44	0.04	23.50
119	3.17	1.47	453		0.20	0.10	10.53	2.49	0.01	55.44
120	3.45	1.58	454		0.24	0.07	11.45			
121	1.21	1.00	456	3	0.20	0.35	4.03	26.33	0.34	5.28
122	2.55	1.30	456	9	0.20	0.14	8.45	17.01	0.14	14.33
123	1.33	1.02	456	3	0.21	0.30	4.41	24.41	0.30	6.03
124	3.45	1.38	458	16	0.17	0.10	11.46	14.95	0.10	20.96
125	0.54	0.75	458	2	0.20	0.74	1.78	32.72	0.74	2.05
126	3.47	1.55	460		0.21	0.08	11.53			
127	2.51	1.31	460		0.24	0.10	8.35			
128	1.94	1.14	460		0.22	0.17	6.45	7.53	0.05	17.67
129	3.37	1.52	460		0.21	0.09	11.20			
130	2.52	1.25	462		0.23	0.10	8.36			
131	2.47	1.28	465	9	0.20	0.15	8.18	17.71	0.15	13.55
132	3.25	1.40	469	13	0.20	0.09	10.78	12.96	0.09	21.46
133	3.86	1.66	473	12	0.25	0.04	12.82	5.71	0.04	41.38
134	3.51	1.60	480		0.26	0.05	11.64			
135	3.77	1.52	480		0.23	0.04	12.52			
136	2.52	1.29	480	7	0.23	0.12	8.35	14.23	0.12	15.72
137	3.46	1.57	482	9	0.27	0.04	11.49	5.28	0.04	38.86
138	3.52	1.50	482	14	0.21	0.08	11.67	11.64	0.08	24.73
139	3.37	1.34	483		0.16	0.11	11.19	5.21	0.02	38.13
140	4.11	1.78	484		0.26	0.03	13.63			
141	3.29	1.45	485	13	0.21	0.09	10.94	12.54	0.09	22.19
142	1.27	1.02	487	3	0.23	0.31	4.22	24.13	0.32	5.82
143	3.62	1.51	489	13	0.21	0.07	12.01	11.07	0.08	26.22
144	2.46	1.27	491	8	0.21	0.15	8.17	17.06	0.15	13.82

Run No	G $\left(\frac{lbm}{hr-ft^2}\right)$	Φ $\left(\frac{Btu}{hr-ft^2}\right)$	P_i (Psia)	ΔP (psid)	$\frac{\Delta H_i}{\lambda}$	W	X	L_b in)	W_b	X_b
145	3.45	1.45	493	16	0.18	0.10	11.44	15.70	0.11	20.34
146	2.15	1.14	495		0.25	0.12	7.13			
147	2.32	1.05	496		0.17	0.14	7.70	7.54	0.04	21.08
148	3.44	1.54	496		0.22	0.09	11.42			
149	3.32	1.55	500		0.25	0.07	11.01			
150	3.62	1.56	500	14	0.21	0.09	12.02	12.40	0.09	24.54
151	0.83	0.79	501	1	0.26	0.40	2.75	25.25	0.40	3.69
152	0.96	0.79	501	1	0.25	0.33	3.17	23.55	0.33	4.44
153	0.84	0.77	504	1	0.25	0.39	2.77	25.42	0.39	3.71
154	3.49	1.49	508		0.21	0.09	11.59			
155	2.42	1.31	509	7	0.26	0.12	8.03	13.17	0.12	15.83
156	3.31	1.52	510		0.27	0.05	10.99			
157	3.59	1.52	525		0.21	0.10	11.93			
158	3.55	1.43	527		0.19	0.09	11.79			
159	3.38	1.50	527	12	0.24	0.08	11.23	10.00	0.08	26.05
160	0.88	0.30	529	4	0.27	0.38	2.92	24.23	0.38	4.01
161	3.51	1.48	532	15	0.21	0.10	11.64	12.83	0.09	23.29
162	3.43	1.49	535	15	0.21	0.10	11.39	13.68	0.10	21.96
163	3.49	1.58	540		0.27	0.06	11.58			
164	3.49	1.72	540	13	0.28	0.07	11.59	8.84	0.08	28.88
165	3.60	1.48	542	15	0.21	0.09	11.94	12.30	0.09	24.52
166	3.37	1.55	544		0.29	0.04	11.19			
167	3.86	1.52	545		0.29	0.01	12.83			
168	2.91	1.52	546	9	0.28	0.10	9.67	11.02	0.10	21.19
169	3.74	1.53	585		0.24	0.08	12.40			
170	3.55	1.68	620		0.35	0.02	11.77			
171	2.88	1.64	629	8	0.36	0.09	9.58	8.53	0.09	24.38
172	1.74	1.07	630		0.28	0.21	5.77	0.18	0.00	141.31
173	2.06	1.16	646		0.33	0.13	6.84			
174	3.03	1.59	690		0.32	0.16	10.04			
175	1.73	1.05	691	2	0.38	0.14	5.75	11.37	0.14	12.37
176	2.67	1.49	700		0.48	0.0	8.86			
177	2.11	1.06	757	1	0.46	0.02	7.01	1.25	0.01	55.42

POTASSIUM CHF DATA, HOFFMANN & KRAKOVIAK (1964)

Table 1. Summary of Results on Potassium Boiling (Continued)

Run No.	10^{-5} × Inlet Mass Flow	Inlet Fluid Temperature	Exit Fluid Temperature	Exit Quality	Boiler ΔP	Heat Flux Q/A (fluid)	Heat Balance		ΔT_{sat}
Series A‡	(lb/hr·ft²)	(°F)	(°F)	(wt % vapor)	(psi)	(Btu/hr·ft²)	$\frac{Q_{electric}}{Q_{fluid}}$	$\frac{Q_{thru\ copper}}{Q_{fluid}}$	$(T_{v,1} - T_{sat})$
23	1.421	1424.4	1394.5	19.4	3.9	106,920	1.120	0.8588	14.34
24	1.126	1418.9	1392.8	24.3	3.6	107,740	1.028	0.7853	12.50
25	1.143	1448.6	1403.0	31.7	5.4	145,690	1.080	0.9790	19.57
26	1.226	1442.6	1401.6	37.2	4.8	146,200	1.086	1.0691	16.35
27	1.782	1461.1	1382.3	35.4	8.6	197,220	1.117	1.0638	39.68
28	1.578	1460.7	1386.5	40.5	7.8	201,600	1.092	1.0821	35.75
29	1.844	1466.4	1386.7	36.8	8.9	292,590	1.085	0.9834	40.72
30	2.115	1479.0	1397.3	32.2	9.6	290,020	1.097	1.0044	41.12
31	1.467	1472.1	1402.0	46.5	7.7	297,350	1.095	1.0201	36.43
32	1.147	1465.9	1402.6	58.7	6.7	296,430	1.0953	1.0177	34.77
33	0.9367	1460.0*	1402.0*	73.4	6.5	304,960	1.0647		
35	2.06	1447.4	1415.7	17.1	3.7	174,000	1.000	0.92	
36	2.05	1481.9	1401.9	34.2	8.3	343,200	1.06	0.98	45.2
37	1.54	1463.7	1393.5	45.5	6.9	349,500	1.04	0.98	39.8
38	1.27	1450.6	1388.0	53.8	6.1	345,100	1.05	0.98	47.1
39	1.20	1462.4	1395.8	57.5	4.9	347,100	1.05	0.98	55.5
40	2.08	1484.1	1405.3	34.2	8.7	346,900	1.06	0.99	43.4
41	1.81	1472.8	1394.4	39.9	7.7	357,000	1.03	0.95	41.1
Series B**									
6.2	0.37	1401.5	1404.7	32.5	1.9	31,890	1.22		11.9
6.3	0.37	1404.3	1390.9	34.3	2.0	32,970	1.18		13.3
6.4	0.21	1378.1	1354.6	60.8	1.8	33,060	1.18		15.7
6.5	0.15	1361.2	1363.6	81.3	1.6	32,370	1.21		13.8
7.1	0.29	1373.0	1369.5	48.9	2.2	37,630	1.18		22.7
7.2	0.29	1365.5	1348.7	49.5	2.5	37,630	1.19		26.0
7.3	0.28	1395.1	1365.3	51.2	2.3	37,970	1.18		22.1

‡High-flux boiler (0.325-in.-ID).

*Estimated.

**Low-flux boiler (0.87-in.-ID).

APPENDIX B

Listing of Computer Programs used to Select Water CHF

Data from CHF Data Bank

Computer Program used to Check Energy Balance.

The Program reads in the conditions at the inlet and exit of the tube. Then, using a heat balance equation, the program calculates the quality at the exit of the tube. If the difference between the calculated and experimental quality is less than 2% then the point is selected; otherwise it is discarded.

```
HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH

      PROGRAM CHFREAD     74/74    OPT=1,ROUND= A/ S/ M/ D,-DS      FTN 5.1+564         85-06-10  16.47.14        PAGE     1
   DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,PL=5000
   FTN5,LO=A/M/R/S.

              PROGRAM CHFREAD( INPUT, OUTPUT, TAPE2=OUTPUT, TAPE5, TAPE4,
          .                    TAPE6 )
          C
          C============================================================
          C============================================================
          C
          C         THIS PROGRAM WILL READ IN CRITICAL HEAT FLUX
          C     EXPERIMENTAL DATA WHICH WAS OBTAINED FROM VARIOUS
          C     REFERENCES OVER THE PAST SEVERAL YEARS.
          C
          C
          C------------------------------------------------------------
          C
          C                             VARIABLES
          C     CHF      CRITICAL HEAT FLUX                     KW/M**2
          C     DHIN     INLET SUBCOOLING                       KJ/KG
          C     DHY      WETTED DIAMETER                        M
          C     G        MASS FLUX                              KG/M**2/S
          C     HTL      HEATED LENGTH                          M
          C     IREFNO   REFERENCE SOURCE                       ----
          C     IRUN     RUN NUMBER                             ----
          C     P        PRESSURE                               KPA
          C     X        QUALITY                                ----
          C
          C
          C-------------------------------------------------------------
          C
          C     INPUT STRUCTURE OF DISC FILE ( TAPE5 )
          C
          C                REFERENCE CARD - CONTAINS CHARACTER DATA
          C                DATA CARD(S)    - IRUN,DHY,HTL,P,G,X,DHIN,CHF
          C                -EOF MARKER-
          C                REFERENCE CARD
          C                DATA CARD(S)
          C                -EOF MARKER-
          C                               ETC......
          C            NOTE!  TWO CONSECUTIVE -EOF MARKERS- INDICATE
          C                   END OF INFORMATION
          C
          C=============================================================
          C=============================================================
          C
                INTEGER IREFNO(8)
                COMMON/PROP/VF,VG,VL,HFG,HF,HG,HL,UF,UG,UL,
               .           AKF,AKG,AKL,CPF,CPG,CPL,SF,SG,SL,
               .           RHOF,RHOG,RHOL,PRF,PRG,PRL,PSAT,TSAT,
               .           VFG,UFG

          C     -----------------
          C     INITIALIZE COUNTER
          C     -----------------

                N = 0
                  IGOOD=0
                  IBAD=0
```

```
C       -------------------------
C       READ IN CHF DATA FROM DISC
C       -------------------------

  21       CONTINUE
C      ----------------------------------------------
C      CHECK FOR -EOF MARKER- FLAG WHICH IS SET BY FTN5
C      ----------------------------------------------
       A = EOF(5)


       READ (5,END=900) ( IREFNO(I),I=1,8 )
       WRITE(2,200)
       WRITE(2,210) ( IREFNO(I),I=1,8 )
       WRITE(2,220)

  31   CONTINUE
       READ(5,END=21)  IRUN,DHY,HTL,P,G,X,DHIN,CHF
         N=N+1
         IF(N.GT.10082) GO TO 900
         AF=(3.1416/4.)*DHY**2.
         AH=3.1416*HTL*DHY
         CALL PROPER( P, 1.0 )
         XBAL=((CHF*AH)/(G*AF)-DHIN)/HFG
         IF(XBAL.LE.1.0) GO TO 20
          IBAD=IBAD+1
          GO TO 10
  20      IF((XBAL.GT.X-0.02).AND.(XBAL.LT.X+0.02)) GO TO 30
          IBAD=IBAD+1
          GO TO 10
  30      IGOOD=IGOOD+1
               WRITE( 6 ) IRUN,DHY,HTL,P,G,X,DHIN,CHF
               WRITE(2,230) IRUN,DHY,HTL,P,G,X,DHIN,CHF
  10      CONTINUE
            GO TO 31
  900    CONTINUE

          WRITE(2,211)  N,IGOOD,IBAD
C       ----------------
C       FORMAT STATEMENTS
C       ----------------
  200  FORMAT(1H1,//)
  210  FORMAT(8A10)
  220  FORMAT(/,3X,*IRUN*,7X,*DHY*,7X,*HTL  *,6X,*P*,9X,*G*,9X,*X*,
      .         7X,*DHIN*,7X,*CHF*,/)
  230  FORMAT(1X,A7,2X,E9.3,4X,F5.3,3X,F6.0,3X,F7.1,4X,F5.3,4X,
      .         F6.0,4X,F7.1)
  211   FORMAT(11X,*  NUMBER OF RECORD READ = *,I11,//,11X,
     * *  NUMBER OF GOOD RECORD = *,I10,//,10X,
     *     *   NUMBER OF BAD RECORD = *,I10)
       STOP
       END
```

Computer Program used to Selected Water CHF Data from CHF Data Bank

Intervals of pressure, mass flux and quality are read in. The points satisfying the heat balance from the previous program are also read in. Only one point belonging to the same interval of pressure, mass flux and quality is selected.

```
      PROGRAM FROG(INPUT,OUTPUT,TAPE6,TAPE2=OUTPUT,TAPE5=INPUT
     *                  ,TAPE10)
      COMMON/NAME2/ NINT1,NINT2,NINT3,RVAL(3,11)
       READ(5,*) NINT1,NINT2,NINT3
      DO 10 I=1,3
      DO 20 J=1,11
      RVAL(I,J)=0.
   20 CONTINUE
   10 CONTINUE
      NPNT1=NINT1+1
      NPNT2=NINT2+1
      NPNT3=NINT3+1
       READ(5,*) (RVAL(1,J),J=1,NPNT1)
      READ(5,*) (RVAL(2,J),J=1,NPNT2)
      READ(5,*) (RVAL(3,J),J=1,NPNT3)
      CALL RECO
      STOP
      END
```

```
              SUBROUTINE ERRSTR
              COMMON /NAME1/ ARMS(10,10,10),AVGERR(10,10,10),NDATA(10,10,10)
              COMMON /NAME2/ NINT1,NINT2,NINT3,RVAL(3,11)
              COMMON/NAME3/ NRUN,DHY,HL,RP,G,XE,DHIN,CHF,IWRITE
        C
              DO 10 I=1,NINT1
              IF( RP .LE. RVAL(1,I+1) ) GO TO 20
           10 CONTINUE
           20 CONTINUE
              DO 30 J=1,NINT2
              IF( G .LE. RVAL(2,J+1) ) GO TO 40
           30 CONTINUE
           40 CONTINUE
              DO 50 K=1,NINT3
              IF( XE .LE. RVAL(3,K+1) ) GO TO 60
           50 CONTINUE
           60 CONTINUE
        C
              NDATA(I,J,K)=NDATA(I,J,K)+1
              IF( NDATA(I,J,K) .GT. 1 ) GO TO 70
             WRITE(10,*) RP,DHY,HL,G,DHIN,CHF
             WRITE(2,303) RP,DHY,HL,G,DHIN,CHF
          303  FORMAT(4X,F10.3,2X,F10.6,2X,F10.4,2X,F10.2,5X,F10.2,
            1 (X,F10.2,/)
              IWRITE=IWRITE+1
           70 CONTINUE
              RETURN
              END
```

```
      C
            SUBROUTINE REDO
            COMMON /NAME1/ ARMS(10,10,10),AVGERR(10,10,10),NDATA(10,10,10)
            COMMON /NAME2/ NINT1,NINT2,NINT3,RVAL(3,11)
            COMMON/NAME3/ NRUN,DHY,Z,RP,G,XE,DHIN,CHF,IWRITE
      C
            DO 91 I1=1,10
            DO 91 I2=1,10
            DO 91 I3=1,10
            ARMS(I1,I2,I3)=0.
            AVGERR(I1,I2,I3)=0.
            NDATA(I1,I2,I3)=0
        91  CONTINUE
           ICOUNT=0
            IWRITE=0
             NZ=0
             NWW=0
              NUMB=0
             NZZ=1
            WRITE(2,604)
       604  FORMAT(//,5X,*  PRESSURE   DIAMETER    LENGTH      MASS FLUX
          *INLET SUBCOOLING      CHF *,/)
            WRITE(2,605)
       605  FORMAT(5X,*    KPA              M              M              KG/M2/S
          *  KJ/KG            KW/M2   *,//)
       10  CONTINUE
            READ(6) NRUN,DHY,Z,RP,G,XE,DHIN,CHF
             NZ=NZ+1
       100  FORMAT(1X,A1,2X,F9.3,4X,F5.3,3X,F6.0,3X,F7.1,3X,F6.3,6X,
          *       F6.0,2X,F7.1)
            IF(EOF(6)) 33,48
       48     CONTINUE
               IF(NZ.GT.1) GO TO 54
               NUMB =ABS(XE*100) +NZZ
               NUMB=1
       54      CONTINUE
               IF(NUMB.NE.NZ) GO TO 10
               NWW=NWW+NZ
               NZ=0
            CALL ERRSTR
            ICOUNT=ICOUNT+1
            GO TO 10
       33      CONTINUE
               NZZ=NZZ+1
                IF(NZZ.GT.10) GO TO 20
               REWIND 6
               WRITE(2,73) NZZ
       73      FORMAT(5X,* NB OF > TAPE 6 REWIND    *,I10)
               GO TO 10
       20    CONTINUE
               WRITE(2,67) NZZ,NWW
       67      FORMAT(5X,* NB OF > CHFDT9K READ =*,I10,
          *             5X,* TOTAL NB OF DT READ =*,I10)
           WRITE(2,50) ICOUNT,IWRITE
       50   FORMAT(5X,*NUMBER OF RECORD READ   *,I10,
          *         5X,*NUMBER OF RECORD WRITTEN   *,I10)
           RETURN
```



```
1
```

A P P E N D I X   C

Experimental Water CHF Data Selected from CHF Data Bank for:

- Weisman & Pei's model
- Katto's Correlation
- The Non-Dimensional Table

WATER CHF DATA SELECTED FOR WEISMAN'S MODEL

PRESSURE KPA	DIAMETER M	LENGTH M	MASS FLUX KG/M2/S	INLET SUBCOOLING KJ/KG	CHF KW/M2
8000.000	.010000	1.0000	739.00	905.00	2753.00
8000.000	.010000	1.0000	1331.00	881.00	3648.00
8000.000	.010000	1.0000	2011.00	898.00	4592.00
7900.000	.010000	1.0000	2777.00	882.00	5479.00
10000.000	.010000	1.0000	308.00	974.00	1499.00
10000.000	.010000	1.0000	943.00	863.00	2787.00
10000.000	.010000	1.0000	1519.00	905.00	3862.00
10000.000	.010000	1.0000	1952.00	862.00	4170.00
10000.000	.010000	1.0000	2541.00	822.00	4712.00
14000.000	.010000	1.0000	980.00	720.00	1976.00
14000.000	.010000	1.0000	1478.00	736.00	2648.00
14000.000	.010000	1.0000	2561.00	695.00	3801.00
14000.000	.010000	1.0000	766.00	776.00	1833.00
14000.000	.010000	1.0000	412.00	920.00	1440.00
20000.000	.010000	1.0000	394.00	1390.00	1191.00
20000.000	.010000	1.0000	375.00	1392.00	1308.00
20000.000	.010000	1.0000	299.00	1384.00	1140.00
20000.000	.010000	1.0000	403.00	1404.00	1357.00
7498.000	.007000	.9800	3043.00	314.00	3137.00
6992.000	.007000	.9800	3008.00	197.00	3133.00
3330.000	.007000	.9800	2985.00	229.00	2511.00
9829.000	.007000	.9800	2914.00	64.00	2193.00
10234.000	.007000	.5600	3518.00	98.00	2456.00
2168.000	.007000	.5600	2886.00	82.00	5148.00
2148.000	.007000	.5600	2885.00	146.00	5279.00
6895.000	.012800	1.9300	2712.00	392.00	2401.00
10343.000	.012800	1.9300	9343.00	163.00	3527.00
5171.000	.012800	1.9300	9478.00	81.00	2940.00
5171.000	.012800	1.9300	5587.00	346.00	3413.00
6895.000	.006220	.9100	7472.00	113.00	3776.00
6895.000	.006220	.9100	13085.00	129.00	4322.00
10343.000	.006220	.9100	7566.00	271.00	4407.00

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10446.000	.011200	3.6600	7824.00	155.00	2492.00
10446.000	.011200	2.5600	9045.00	144.00	2776.00
10446.000	.011200	3.6600	7824.00	97.00	2524.00
5998.000	.011200	1.7900	9424.00	10.00	2839.00
103.000	.001020	.0400	698.00	319.00	4480.00
103.000	.001020	.0400	900.00	319.00	4627.00
103.000	.001020	.0400	1776.00	319.00	5899.00
103.000	.001020	.0400	2780.00	319.00	7508.00
103.000	.001020	.0400	5641.00	319.00	14700.00
2137.000	.001140	.1100	6509.00	500.00	7319.00
2137.000	.001140	.1100	8543.00	283.00	5836.00
2137.000	.001140	.1100	13696.00	463.00	14574.00
3448.000	.005740	.6200	5248.00	803.00	8581.00
3561.000	.005740	.6200	10441.00	199.00	5268.00
6895.000	.003630	.0800	1315.00	576.00	7981.00
6895.000	.003630	.0800	2388.00	560.00	10631.00
6895.000	.003630	.0800	6156.00	356.00	13281.00
6895.000	.010300	.7600	5695.00	294.00	4874.00
6895.000	.010300	.7600	8977.00	176.00	4637.00
6895.000	.012800	1.9300	13696.00	282.00	6025.00
6895.000	.023600	.6100	1912.00	490.00	4827.00
10343.000	.010300	.7600	3946.00	567.00	5732.00
10343.000	.010300	.7600	5546.00	337.00	5069.00
10343.000	.010300	.7600	5912.00	454.00	6451.00
10343.000	.010300	.7600	9275.00	337.00	7224.00
10343.000	.010300	.7600	9628.00	454.00	8912.00
13790.000	.001910	.1500	3634.00	387.00	4416.00
13790.000	.003630	.0800	2102.00	437.00	7003.00
13790.000	.003630	.0800	2712.00	479.00	6593.00
13790.000	.003630	.0800	5790.00	58.00	5016.00
13790.000	.003630	.0800	7634.00	409.00	12681.00
13790.000	.003630	.0800	10143.00	401.00	12713.00
13790.000	.004570	.3000	2522.00	47.00	2082.00

13790.000	.004750	.3200	5790.00	204.00	4196.00
13790.000	.004750	.3200	10523.00	822.00	12902.00
13790.000	.005740	.6200	10563.00	343.00	7192.00
15514.000	.001910	.1500	2875.00	600.00	5394.00
15514.000	.001910	.1500	2929.00	459.00	4164.00
15514.000	.001910	.1500	3024.00	812.00	6562.00
17238.000	.001910	.1500	2183.00	824.00	4763.00
3040.000	.009980	.4000	1234.00	890.00	6842.00
12000.000	.010000	1.0000	1849.00	894.00	3430.00
14000.000	.010000	2.0000	5708.00	75.00	1949.00
16000.000	.010000	2.0000	2732.00	89.00	1123.00
16000.000	.010000	2.0000	3566.00	96.00	1397.00
16000.000	.010000	2.0000	5720.00	93.00	2018.00
3000.000	.010000	3.0000	6357.00	366.00	3795.00
16000.000	.010000	3.0000	6198.00	602.00	3261.00
18000.000	.010000	3.0000	6849.00	610.00	3463.00
18000.000	.010000	3.0000	5845.00	176.00	1903.00
20000.000	.010000	3.0000	6102.00	656.00	2916.00
5000.000	.010000	4.9660	5530.00	457.00	2438.00
7000.000	.010000	4.9660	5996.00	101.00	1663.00
14000.000	.010000	4.9660	2571.00	123.00	565.00
14000.000	.010000	4.9660	6174.00	132.00	1370.00
272.000	.006600	0.0000	5669.30	242.00	6524.00
265.000	.006600	0.0000	5455.90	311.00	5800.00
374.000	.006500	0.0000	11734.80	226.00	10015.00
410.000	.006100	0.0000	10241.30	231.00	9316.00
468.000	.013200	0.0000	304.80	233.00	2692.00

WATER CHF DATA SELECTED FOR KATTO'S CORRELATION

PRESSURE KPA	DIAMETER M	LENGTH M	MASS FLUX KG/M2/S	INLET SUBCOOLING KJ/KG	CHF KW/M2
9000.000	.010000	1.0000	799.00	905.00	2753.00
9000.000	.010000	1.0000	1331.00	881.00	3648.00
9000.000	.010000	1.0000	2011.00	898.00	4592.00
9000.000	.010000	1.0000	1720.00	911.00	4304.00
10000.000	.010000	1.0000	308.00	974.00	1499.00
10000.000	.010000	1.0000	522.00	1078.00	2211.00
10000.000	.010000	1.0000	343.00	863.00	2787.00
10000.000	.010000	1.0000	677.00	894.00	2352.00
14000.000	.010000	1.0000	980.00	720.00	1976.00
14000.000	.010000	1.0000	1022.00	735.00	2073.00
14000.000	.010000	1.0000	1513.00	725.00	2682.00
14000.000	.010000	1.0000	2098.00	688.00	3249.00
14000.000	.010000	1.0000	766.00	776.00	1833.00
14000.000	.010000	1.0000	624.00	860.00	1702.00
14000.000	.010000	1.0000	412.00	920.00	1440.00
14000.000	.010000	2.0000	1103.00	1085.00	1673.00
14000.000	.010000	2.0000	836.00	1102.00	1465.00
14000.000	.010000	2.0000	701.00	1151.00	1302.00
20000.000	.010000	1.0000	304.00	1390.00	1191.00
20000.000	.010000	1.0000	375.00	1392.00	1308.00
20000.000	.010000	1.0000	299.00	1384.00	1140.00
6890.000	.007000	.9800	2481.00	177.00	2870.00
7194.000	.007000	.9800	2469.00	16.00	2427.00
7498.000	.007000	.9800	3043.00	314.00	3137.00
6992.000	.007000	.9800	3008.00	197.00	3133.00
7042.000	.007000	.9800	3003.00	159.00	2977.00
7600.000	.007000	.9800	2983.00	92.00	2251.00
5992.000	.007000	.9800	3578.00	208.00	3146.00
10031.000	.007000	.9800	2295.00	9.00	1937.00
10234.000	.007000	.9800	2319.00	56.00	1281.00
6890.000	.007000	.5600	2233.00	-239.00	2548.00

10234.000	.007000	.5600	3518.00	98.00	2456.00
10234.000	.007000	.5600	3510.00	87.00	2437.00
2168.000	.007000	.5600	2886.00	82.00	5148.00
2148.000	.007000	.5600	2886.00	146.00	5279.00
1925.000	.007000	.5600	2886.00	167.00	5356.00
2533.000	.007000	.5600	3274.00	136.00	5177.00
7041.000	.005980	4.8000	1113.00	-1057.00	125.60
6972.000	.005980	4.8000	1124.90	-873.00	175.80
6972.000	.005980	4.8000	1124.90	-488.00	271.10
6972.000	.005980	4.8000	2134.80	-1211.00	109.20
6986.000	.005980	4.8000	2202.80	-1055.00	141.00
7028.000	.005980	4.8000	2190.90	72.00	544.30
7037.000	.005980	4.8000	2979.10	-1004.00	166.70
6977.000	.005980	4.0050	3006.00	-986.00	205.50
7049.000	.005980	3.2030	2198.80	-1166.00	150.60
6895.000	.012800	1.9300	1939.00	288.00	2243.00
6895.000	.012800	1.9300	1953.00	389.00	2426.00
6895.000	.012800	1.9300	2712.00	392.00	2401.00
6274.000	.012850	1.9300	1898.00	93.00	1631.00
6895.000	.012800	1.9300	1329.00	395.00	2174.00
6895.000	.012800	1.9300	1478.00	932.00	2937.00
10343.000	.012800	1.9300	1370.00	185.00	1404.00
10343.000	.012800	1.9300	5316.00	160.00	2208.00
10343.000	.012800	1.9300	9343.00	163.00	3527.00
10343.000	.012800	1.9300	1966.00	465.00	2009.00
5171.000	.012800	1.9300	1370.00	63.00	1975.00
5171.000	.012800	1.9300	5492.00	85.00	2741.00
5171.000	.012800	1.9300	5424.00	207.00	2845.00
5171.000	.012800	1.9300	3810.00	305.00	2953.00
5171.000	.012800	1.9300	9478.00	81.00	2940.00
6895.000	.012800	1.9300	1790.00	1060.00	3451.00
6895.000	.006220	.9100	13035.00	129.00	4322.00
10343.000	.006220	.9100	5180.00	226.00	3145.00

6895.000	.012800	.9100	976.00	96.00	2549.00
6895.000	.012800	.9100	976.00	303.00	2880.00
10446.000	.011200	3.6600	7824.00	155.00	2492.00
10445.000	.011200	3.6600	7824.00	97.00	2524.00
10446.000	.011200	3.6600	6522.00	30.00	2019.00
6998.000	.011200	1.7900	9424.00	10.00	2839.00
13790.000	.010400	1.7500	1763.00	42.00	823.00
8263.000	.010600	.7600	1451.00	667.00	3943.00
6895.000	.010600	.7600	1478.00	715.00	4385.00
8274.000	.010600	.3800	732.00	691.00	5552.00
6895.000	.010600	.3800	719.00	912.00	5552.00
103.000	.001020	.0400	693.00	319.00	4480.00
103.000	.001020	.0400	990.00	319.00	4827.00
103.000	.001020	.0400	1370.00	319.00	5457.00
103.000	.001020	.0400	1776.00	319.00	5899.00
103.000	.001020	.0400	2780.00	319.00	7508.00
103.000	.001020	.0400	3756.00	319.00	9716.00
103.000	.001020	.0400	5641.00	319.00	14700.00
103.000	.001020	.0500	399.00	319.00	2981.00
103.000	.001020	.0500	885.00	319.00	4133.00
103.000	.001020	.0500	1790.00	319.00	5552.00
103.000	.001700	.0400	1300.00	319.00	6940.00
103.000	.003050	.1500	49.00	323.00	473.00
103.000	.023900	.2000	30.00	354.00	782.00
690.000	.004570	.2400	13.00	343.00	148.00
2137.000	.001140	.1100	3715.00	37.00	6088.00
2137.000	.001140	.1100	4312.00	405.00	4858.00
2137.000	.001140	.1100	5180.00	171.00	7319.00
2137.000	.001140	.1100	6129.00	7.00	2432.00
2137.000	.001140	.1100	7933.00	241.00	4448.00
2137.000	.001140	.1100	13696.00	463.00	14574.00
1758.000	.003050	.1500	57.00	778.00	233.00
[illegible]	[illegible]	.1500	148.00	768.00	1590.00

3448.000	.003050	.1500	60.00	119.00	470.00
3448.000	.003050	.1500	148.00	318.00	1397.00
3448.000	.003630	.0800	1492.00	467.00	8360.00
3634.000	.004580	.2300	1275.00	29.00	5741.00
3689.000	.004580	.2300	1383.00	457.00	6909.00
3758.000	.004580	.2300	2766.00	421.00	8013.00
3896.000	.005590	.2200	1017.00	35.00	7335.00
3896.000	.005590	.2200	1898.00	74.00	7151.00
3827.000	.005590	.4300	1939.00	51.00	4934.00
3896.000	.005590	.8600	2061.00	184.00	3259.00
3758.000	.005590	1.7300	1017.00	22.00	1286.00
3930.000	.010800	.4300	963.00	19.00	4798.00
3861.000	.010800	.4300	1885.00	37.00	5134.00
3861.000	.010800	.8600	814.00	37.00	3251.00
5033.000	.005590	.4300	1844.00	30.00	4261.00
6695.000	.004570	.2400	97.00	898.00	957.00
7205.000	.004580	.2300	1166.00	18.00	4069.00
7274.000	.004580	.2300	1302.00	356.00	4763.00
6895.000	.004580	.2400	39.00	1084.00	470.00
7067.000	.005590	.2200	1776.00	55.00	4644.00
7102.000	.005590	.4300	1017.00	38.00	3325.00
6861.000	.005590	.8600	949.00	356.00	2509.00
6861.000	.005590	1.3600	963.00	23.00	1381.00
7033.000	.009350	1.3600	4068.00	374.00	3283.00
7274.000	.010800	.8600	881.00	32.00	2392.00
6895.000	.012400	.6100	692.00	272.00	3533.00
6895.000	.012400	.6100	746.00	689.00	4259.00
6895.000	.023600	.6100	666.00	490.00	4133.00
6895.000	.023600	.6100	328.00	185.00	3502.00
6895.000	.023600	.6100	949.00	401.00	4006.00
10343.000	.004580	.2400	40.00	1029.00	423.00
10343.000	.004580	.2400	41.00	844.00	379.00
11101.000	.009350	1.5200	1017.00	167.00	1117.00

13790.000	.003630	.0800	10143.00	401.00	12713.00
13790.000	.004750	.3200	521.00	393.00	852.00
13790.000	.004750	.3200	335.00	130.00	1808.00
15514.000	.001910	.1500	2034.00	500.00	3060.00
15514.000	.001910	.1500	3324.00	812.00	6562.00
17238.000	.001910	.1500	1939.00	511.00	2839.00
18272.000	.003090	.1500	793.00	373.00	1117.00
1910.000	.003940	1.0400	1041.00	625.00	1789.00
1675.000	.003940	1.0400	1041.00	595.00	1798.00
1386.000	.003940	1.0400	1128.00	554.00	1808.00
1696.000	.003940	1.0400	987.00	613.00	1779.00
1579.000	.003940	1.0400	805.00	625.00	1571.00
1145.000	.003940	1.0400	913.00	544.00	1564.00
1156.000	.003940	2.0800	1323.00	531.00	1032.00
3558.000	.003940	2.0800	922.00	784.00	997.00
1875.000	.003940	2.0800	713.00	632.00	776.00
1531.000	.003940	2.0800	736.00	588.00	773.00
507.000	.003940	2.0800	942.00	461.00	782.00
655.000	.003940	2.0800	1001.00	424.00	782.00
3013.000	.003940	2.0800	1562.00	786.00	1432.00
1083.000	.003940	3.1200	1182.00	496.00	656.00
1965.000	.003940	3.1200	914.00	650.00	653.00
576.000	.003940	3.1200	1231.00	473.00	662.00
1482.000	.003940	3.1200	525.00	589.00	420.00
1110.000	.003940	3.1200	553.00	528.00	423.00
1048.000	.007770	1.0400	256.00	430.00	991.00
1365.000	.007770	2.0800	877.00	318.00	1199.00
1186.000	.007770	2.0800	968.00	282.00	1205.00
993.000	.007770	2.0800	744.00	238.00	984.00
807.000	.007770	2.0800	838.00	181.00	965.00
696.000	.007770	2.0800	1079.00	162.00	968.00
1089.000	.007770	3.1200	1337.00	234.00	861.00
1855.000	.009960	1.0000	715.00	541.00	2994.00

1634.000	.009960	1.0000	717.00	513.00	2962.00
1937.000	.009960	1.0000	1540.00	363.00	3943.00
1675.000	.009960	1.0000	1573.00	326.00	3962.00
1958.000	.009960	1.0000	1418.00	386.00	3953.00
1669.000	.009960	1.0000	1479.00	344.00	3905.00
1986.000	.009960	1.0000	1021.00	444.00	3511.00
2627.000	.009980	.6000	644.00	623.00	4287.00
1841.000	.009980	.6000	869.00	538.00	4505.00
1538.000	.009980	.6000	946.00	486.00	4524.00
1063.000	.009980	.6000	1365.00	355.00	4521.00
1710.000	.009980	.6000	755.00	509.00	4293.00
3068.000	.009980	.6000	971.00	587.00	4934.00
1510.000	.009980	.6000	1325.00	422.00	4909.00
2930.000	.009980	.6000	1243.00	553.00	5155.00
1944.000	.010000	2.2500	1599.00	307.00	2016.00
1675.000	.010000	2.5000	1584.00	283.00	1760.00
1177.000	.003940	3.1200	1094.00	-50.00	661.00
971.000	.009960	.9600	426.00	1640.00	1948.00
3040.000	.009980	.4000	916.00	666.00	6036.00
3040.000	.009980	.4000	733.00	691.00	5713.00
3040.000	.009980	.4000	1565.00	890.00	7477.00
2059.000	.009980	.4000	648.00	802.00	5147.00
2059.000	.009980	.4000	316.00	802.00	5791.00
1353.000	.013100	2.0000	743.00	1171.00	2029.00
1079.000	.013000	.6000	590.00	679.00	4055.00
1030.000	.010000	2.0000	1617.00	600.00	2519.00
1079.000	.010000	2.0000	2075.00	559.00	2944.00
1961.000	.020100	2.4300	1728.00	328.00	2786.00
1147.000	.006070	1.0000	1531.00	546.00	3249.00
7944.000	.009980	1.0000	238.00	821.00	1280.00
7012.000	.009980	2.5000	799.00	796.00	1430.00
5001.000	.003930	1.5000	1577.00	840.00	1958.00
16000.000	.010000	1.0000	279.00	1183.00	1261.00

16000.000	.010000	1.0000	309.00	1201.00	1264.00
16000.000	.010000	1.0000	773.00	1155.00	2479.00
16000.000	.010000	1.0000	1068.00	1112.00	2902.00
8000.000	.010000	2.0000	5025.00	354.00	2753.00
16000.000	.010000	2.0000	156.00	1126.00	393.00
16000.000	.010000	2.0000	1014.00	1072.00	1505.00
16000.000	.010000	2.0000	812.00	769.00	1020.00
9000.000	.010000	2.0000	5825.00	64.00	1888.00
16000.000	.010000	2.0000	1168.00	98.00	629.00
16000.000	.010000	2.0000	1721.00	98.00	756.00
16000.000	.010000	2.0000	2205.00	99.00	670.00
16000.000	.010000	2.0000	2268.00	108.00	990.00
16000.000	.010000	2.0000	3170.00	77.00	1247.00
16000.000	.010000	2.0000	3566.00	96.00	1397.00
16000.000	.010000	2.0000	5720.00	93.00	2018.00
18000.000	.010000	2.0000	777.00	145.00	466.00
9000.000	.010000	2.0000	1512.00	77.00	1256.00
3000.000	.010000	3.0000	5459.00	96.00	2571.00
16000.000	.010000	3.0000	1564.00	606.00	1047.00
16000.000	.010000	3.0000	5325.00	599.00	2991.00
13000.000	.010000	3.0000	5845.00	176.00	1903.00
20000.000	.010000	3.0000	1029.00	185.00	383.00
20000.000	.010000	3.0000	1521.00	209.00	579.00
20000.000	.010000	3.0000	2097.00	201.00	796.00
7000.000	.010000	4.9660	5499.00	100.00	1567.00
10000.000	.010000	4.9660	7566.00	502.00	2300.00
10000.000	.010000	4.9660	5474.00	112.00	1398.00
12000.000	.010000	4.9660	3176.00	115.00	755.00
13000.000	.010000	4.9660	3232.00	176.00	803.00
374.000	.006100	0.0000	12649.20	147.00	7422.00
291.000	.011600	0.0000	9906.00	109.00	7434.00
408.000	.013200	0.0000	304.80	46.00	1556.00
1585.000	.084400	0.0000	39.60	381.00	4790.00

374.000	.006100	0.0000	12649.20	147.00	7422.00
291.000	.011600	0.0000	9306.00	100.00	7434.00
408.000	.013200	0.0000	304.80	46.00	1556.00
408.000	.013200	0.0000	1219.20	116.00	3245.00
1685.000	.084400	0.0000	39.60	381.00	4790.00
1939.000	.003600	0.0000	3109.00	220.00	10745.00
3401.000	.092400	0.0000	304.80	72.00	5618.00
100.000	.004000	.3960	1644.50	317.00	5236.00
100.000	.004800	.4780	2392.00	319.00	6434.00

WATER CHF DATA SELECTED FOR THE NON-DIMENSIONAL CHF TABLE

PRESSURE KPA	DIAMETER M	LENGTH M	MASS FLUX KG/M2/S	INLET SUBCOOLING KJ/KG	CHF KW/M2
8000.000	.010000	1.0000	799.00	905.00	2753.00
8000.000	.010000	1.0000	1331.00	881.00	3648.00
8000.000	.010000	1.0000	1076.00	934.00	3366.00
8000.000	.010000	1.0000	2011.00	898.00	4592.00
8000.000	.010000	1.0000	1720.00	911.00	4304.00
7900.000	.010000	1.0000	2777.00	882.00	5479.00
10000.000	.010000	1.0000	308.00	974.00	1499.00
10000.000	.010000	1.0000	522.00	1078.00	2211.00
10000.000	.010000	1.0000	943.00	863.00	2787.00
10000.000	.010000	1.0000	1952.00	862.00	4170.00
10000.000	.010000	1.0000	282.00	908.00	1389.00
14000.000	.010000	1.0000	980.00	720.00	1976.00
14000.000	.010000	1.0000	1022.00	735.00	2073.00
14000.000	.010000	1.0000	1478.00	736.00	2648.00
14000.000	.010000	1.0000	1513.00	725.00	2682.00
14000.000	.010000	1.0000	2088.00	688.00	3249.00
14000.000	.010000	1.0000	766.00	776.00	1833.00
14000.000	.010000	1.0000	624.00	860.00	1702.00
14000.000	.010000	1.0000	412.00	920.00	1440.00
14000.000	.010000	2.0000	1516.00	1077.00	2113.00
20000.000	.010000	1.0000	304.00	1390.00	1191.00
20000.000	.010000	1.0000	283.00	1391.00	1133.00
20000.000	.010000	1.0000	375.00	1392.00	1308.00
20000.000	.010000	1.0000	403.00	1404.00	1357.00
6890.000	.007000	.9800	2481.00	177.00	2870.00
7194.000	.007000	.9800	2469.00	16.00	2427.00
7498.000	.007000	.9800	3043.00	314.00	3137.00
6992.000	.007000	.9800	3008.00	197.00	3133.00
7600.000	.007000	.9800	2983.00	92.00	2251.00
10031.000	.007000	.9800	2295.00	9.00	1937.00
9829.000	.007000	.9800	3461.00	210.00	2576.00
10234.000	.007000	.9800	2319.00	56.00	1281.00

6992.000	.007000	.9800	3205.00	27.00	1219.00
6890.000	.007000	.5600	2377.00	15.00	3290.00
10234.000	.007000	.5600	2891.00	50.00	2049.00
10234.000	.007000	.5600	3518.00	98.00	2456.00
2168.000	.007000	.5600	2886.00	82.00	5148.00
1925.000	.007000	.5600	2986.00	167.00	5356.00
2533.000	.007000	.5600	3274.00	136.00	5177.00
7041.000	.005980	4.8000	1113.00	-1057.00	125.60
6972.000	.005980	4.8000	1124.90	-873.00	175.80
6972.000	.005980	4.8000	1117.00	-112.00	348.40
6972.000	.005980	4.8000	2194.80	-1211.00	109.20
6986.000	.005980	4.8000	2210.80	-606.00	278.10
7007.000	.005980	4.8000	2979.10	-1004.00	166.70
7007.000	.005980	4.8000	2979.10	-859.00	189.70
6977.000	.005980	4.0050	3006.00	-986.00	205.50
6977.000	.005980	4.0050	3006.00	-693.00	287.50
6895.000	.012800	1.9300	1939.00	268.00	2243.00
6895.000	.012800	1.9300	2712.00	392.00	2401.00
3274.000	.012850	1.9300	1898.00	93.00	1631.00
6895.000	.012800	1.9300	1329.00	395.00	2174.00
6895.000	.012800	1.9300	1478.00	932.00	2937.00
10343.000	.012800	1.9300	1370.00	185.00	1404.00
10343.000	.012800	1.9300	1424.00	285.00	1555.00
10343.000	.012800	1.9300	5316.00	160.00	2206.00
10343.000	.012800	1.9300	9343.00	163.00	3527.00
10343.000	.012800	1.9300	1980.00	332.00	1773.00
5171.000	.012800	1.9300	1912.00	64.00	2221.00
5171.000	.012800	1.9300	5492.00	85.00	2741.00
5171.000	.012800	1.9300	9478.00	81.00	2940.00
6895.000	.012800	1.9300	1790.00	1060.00	3451.00
6895.000	.006220	.9100	5130.00	104.00	3129.00
6895.000	.006220	.9100	13085.00	129.00	4322.00
6895.000	.012800	.9100	976.00	96.00	2549.00

6895.000	.012800	.9100	1356.00	502.00	3379.00
10446.000	.011200	3.6600	7824.00	155.00	2492.00
10446.000	.011200	3.6600	6522.00	30.00	2019.00
10446.000	.011200	3.6600	6734.00	51.00	2284.00
13790.000	.010400	1.7500	678.00	37.00	587.00
13790.000	.010400	1.7500	949.00	53.00	672.00
8274.000	.010600	.3800	732.00	891.00	5552.00
8274.000	.010600	.3800	719.00	583.00	4448.00
6895.000	.010600	.3800	719.00	912.00	5552.00
6902.000	.010600	.3800	732.00	721.00	4858.00
103.000	.001020	.0400	698.00	319.00	4480.00
103.000	.001020	.0400	900.00	319.00	4827.00
103.000	.001020	.0400	1370.00	319.00	5457.00
103.000	.001020	.0400	1776.00	319.00	5899.00
103.000	.001020	.0400	2780.00	319.00	7508.00
103.000	.001020	.0400	3756.00	319.00	9716.00
103.000	.001020	.0400	5641.00	319.00	14700.00
103.000	.001020	.0500	399.00	319.00	2981.00
103.000	.001020	.0500	683.00	319.00	3786.00
103.000	.001020	.0500	1336.00	319.00	4858.00
103.000	.003050	.1500	57.00	316.00	596.00
2137.000	.001140	.1100	3715.00	37.00	6088.00
2137.000	.001140	.1100	4312.00	405.00	4858.00
2137.000	.001140	.1100	5180.00	171.00	7319.00
2137.000	.001140	.1100	6129.00	7.00	2432.00
2137.000	.001140	.1100	6509.00	500.00	7319.00
2137.000	.001140	.1100	7933.00	241.00	4448.00
2137.000	.001140	.1100	13696.00	463.00	14574.00
1758.000	.003050	.1500	57.00	778.00	233.00
1724.000	.003050	.1500	148.00	768.00	1590.00
3448.000	.003050	.1500	60.00	119.00	470.00
3448.000	.003050	.1500	258.00	466.00	2230.00
3448.000	.003630	.0800	1492.00	467.00	8360.00

3634.000	.004580	.2300	1275.00	29.00	5741.00
3716.000	.004580	.2300	1275.00	27.00	5741.00
3689.000	.004580	.2300	1410.00	556.00	7256.00
4034.000	.004580	.2300	2631.00	268.00	6530.00
3896.000	.005590	.2200	1898.00	74.00	7151.00
3827.000	.005590	.4300	1939.00	51.00	4934.00
3896.000	.005590	.4300	2020.00	355.00	6095.00
3827.000	.005590	.8600	1017.00	27.00	2366.00
3930.000	.005590	.8600	1939.00	48.00	2909.00
3896.000	.005590	1.7300	2034.00	182.00	1839.00
3861.000	.005740	.6200	10441.00	199.00	5268.00
3448.000	.010300	.7600	7553.00	78.00	4653.00
3930.000	.010800	.4300	963.00	19.00	4798.00
3861.000	.010800	.4300	4068.00	257.00	5469.00
3861.000	.010800	.8600	814.00	37.00	3251.00
5102.000	.005590	1.7300	3702.00	25.00	1924.00
6895.000	.003630	.0800	1315.00	576.00	7981.00
6895.000	.003630	.0800	2888.00	560.00	10631.00
6895.000	.003630	.0800	4041.00	526.00	11262.00
6895.000	.003630	.0800	6156.00	356.00	13281.00
6895.000	.004570	.2400	97.00	898.00	957.00
7205.000	.004580	.2300	1166.00	18.00	4069.00
7102.000	.005590	.4300	1017.00	38.00	3325.00
6861.000	.005590	.8600	949.00	356.00	2509.00
6895.000	.005590	.8600	1776.00	52.00	2355.00
7343.000	.005590	1.7300	3965.00	158.00	2020.00
6895.000	.010300	.7600	7553.00	294.00	5931.00
6895.000	.010300	.7900	10156.00	298.00	7445.00
6895.000	.010800	.6600	678.00	38.00	2334.00
6895.000	.010800	.8600	814.00	32.00	2403.00
7274.000	.010800	.8600	881.00	32.00	2392.00
6895.000	.012400	.6100	692.00	272.00	3533.00
6895.000	.012400	.6100	1668.00	562.00	4890.00

6895.000	.023600	.6100	928.00	185.00	3502.00
6895.000	.023600	.6100	959.00	482.00	4290.00
6895.000	.023600	.6100	969.00	87.00	3281.00
10343.000	.014580	.2400	40.00	1029.00	423.00
10998.000	.009350	.7600	4068.00	436.00	4992.00
10343.000	.010300	.7600	5546.00	337.00	5069.00
10343.000	.010300	.7600	7716.00	454.00	7806.00
13790.000	.003630	.0800	10143.00	401.00	12713.00
13790.000	.004750	.3200	521.00	393.00	852.00
13790.000	.004750	.3200	782.00	1303.00	3218.00
13790.000	.007720	.4600	689.00	1251.00	3155.00
15514.000	.001910	.1500	2034.00	500.00	3060.00
15514.000	.001910	.1500	2875.00	600.00	5394.00
15514.000	.001910	.1500	3024.00	812.00	6562.00
15514.000	.001910	.1500	3553.00	421.00	4700.00
17238.000	.001910	.1500	1339.00	511.00	2639.00
13272.000	.003000	.1500	793.00	373.00	1117.00
3661.000	.003940	1.0400	861.00	785.00	1760.00
1910.000	.003940	1.0400	1041.00	625.00	1789.00
1675.000	.003940	1.0400	1041.00	595.00	1798.00
1336.000	.003940	1.0400	937.00	613.00	1779.00
1827.000	.003940	1.0400	774.00	660.00	1571.00
1579.000	.003940	1.0400	895.00	625.00	1571.00
1145.000	.003940	1.0400	913.00	544.00	1584.00
1158.000	.003940	2.0800	1323.00	531.00	1032.00
931.000	.003940	2.0800	1414.00	490.00	997.00
1875.000	.003940	2.0800	713.00	632.00	776.00
1531.000	.003940	2.0800	736.00	588.00	773.00
1365.000	.003940	2.0800	759.00	564.00	776.00
1062.000	.003940	2.0800	785.00	514.00	782.00
807.000	.003940	2.0800	942.00	461.00	782.00
655.000	.003940	2.0800	1031.00	424.00	782.00
1413.000	.003940	3.1200	1020.00	575.00	659.00

1110.000	.003940	3.1200	553.00	528.00	423.00
1083.000	.007770	1.0400	403.00	359.00	1391.00
862.000	.007770	2.0800	1138.00	202.00	1215.00
1372.000	.007770	2.0800	593.00	326.00	975.00
772.000	.007770	2.0800	885.00	172.00	968.00
1400.000	.007770	3.1200	1083.00	294.00	852.00
1262.000	.009960	1.0000	907.00	420.00	3158.00
1041.000	.009960	1.0000	975.00	371.00	3164.00
1937.000	.009960	1.0000	1540.00	363.00	3943.00
1675.000	.009960	1.0000	1573.00	326.00	3962.00
1958.000	.009960	1.0000	1418.00	386.00	3953.00
1000.000	.009980	.6000	645.00	462.00	3833.00
1248.000	.009980	.6000	626.00	512.00	3883.00
1841.000	.009980	.6000	869.00	538.00	4505.00
1269.000	.009980	.6000	1161.00	416.00	4514.00
1158.000	.009980	.6000	1214.00	384.00	4521.00
2527.000	.009980	.6000	746.00	595.00	4511.00
1362.000	.009980	.6000	1170.00	468.00	4909.00
1177.000	.003940	3.1200	1094.00	-50.00	661.00
971.000	.009960	.9600	426.00	1640.00	1948.00
3043.000	.009980	.4000	916.00	886.00	6036.00
3040.000	.009980	.4000	733.00	891.00	5713.00
3040.000	.009980	.4000	1234.00	890.00	6842.00
3040.000	.009980	.4000	1565.00	890.00	7477.00
2059.000	.009980	.4000	816.00	892.00	5791.00
1353.000	.013100	2.0000	743.00	1171.00	2029.00
1079.000	.013000	.6000	590.00	679.00	4055.00
1030.000	.010000	2.0000	1617.00	600.00	2519.00
1079.000	.010000	2.0000	2075.00	559.00	2944.00
4021.000	.010000	1.0000	1693.00	926.00	4982.00
1961.000	.020100	2.4300	1728.00	328.00	2786.00
7159.000	.009980	2.5000	1832.00	514.00	2067.00
1128.000	.016010	1.0000	2153.00	488.00	3932.00

16000.000	.010000	1.0000	279.00	1183.00	1261.00
16000.000	.010000	1.0000	752.00	1168.00	2325.00
16000.000	.010000	1.0000	801.00	1158.00	2600.00
16000.000	.010000	1.0000	1068.00	1112.00	2902.00
8000.000	.010000	2.0000	5025.00	354.00	2753.00
16000.000	.010000	2.0000	156.00	1126.00	393.00
16000.000	.010000	2.0000	1014.00	1072.00	1505.00
16000.000	.010000	2.0000	1573.00	1017.00	2002.00
16000.000	.010000	2.0000	1073.00	790.00	1301.00
12000.000	.010000	2.0000	758.00	106.00	746.00
12000.000	.010000	2.0000	3640.00	82.00	1232.00
16000.000	.010000	2.0000	1168.00	98.00	629.00
16000.000	.010000	2.0000	1721.00	98.00	756.00
16000.000	.010000	2.0000	2205.00	99.00	870.00
16000.000	.010000	2.0000	3170.00	77.00	1247.00
16000.000	.010000	2.0000	5720.00	93.00	2018.00
18000.000	.010000	2.0000	777.00	145.00	466.00
18000.000	.010000	2.0000	1982.00	94.00	848.00
10000.000	.010000	3.0000	5578.00	112.00	1717.00
12000.000	.010000	3.0000	1532.00	126.00	719.00
16000.000	.010000	3.0000	5325.00	599.00	2991.00
18000.000	.010000	3.0000	6849.00	610.00	3463.00
18000.000	.010000	3.0000	2147.00	159.00	744.00
18000.000	.010000	3.0000	3189.00	173.00	1115.00
7000.000	.010000	4.9660	5499.00	100.00	1567.00
10000.000	.010000	4.9660	7568.00	592.00	2300.00
10000.000	.010000	4.9660	5474.00	112.00	1396.00
12000.000	.010000	4.9660	3176.00	115.00	755.00
16000.000	.010000	4.9660	775.00	572.00	404.00
16000.000	.010000	4.9660	5391.00	158.00	1241.00
279.000	.006600	0.0000	5852.20	123.00	4647.00
272.000	.006600	0.0000	4669.00	95.00	4669.00
272.000	.006600	0.0000	1676.40	151.00	3186.00

1939.000	.003600	0.0000	3109.00	220.00	10745.00
3401.000	.092400	0.0000	304.80	72.00	5618.00
100.000	.004000	.1980	2093.00	322.00	7002.00
100.000	.004000	.3960	1644.50	317.00	5236.00
100.000	.004800	.4780	2392.00	319.00	6434.00

A P P E N D I X   D

<u>Computer Program used to Predict CHF using Katto's Correlation</u>

The program reads in the conditions at the inlet of the tube. Then, it predicts the CHF using Katto's Correlation; equations (2.22) to (2.32).

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**************************************************************************************************
     PROGRAM KATTO       74/74    OPT=2,ROUND= A/ S/ M/ D,-DS      FTN 5.1+564          85-05-29  09.59.50          PAGE      1
   DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,PL=5000
   FTN5,OPT=2,LO=A/M/S/S.

                   PROGRAM KATTO(INPUT,OUTPUT,TAPE6=OUTPUT)
                   DIMENSION ICODE(1),IHTFS(1),IPHASE(1),TEMP(2),PROPS(22,20)
                 1,NATES(20),RTEMP(2,11,20),RPRESS(20),NAMESC(8,20),XVAR(1000),
                 1P(1000),C(1000),C(1000),DHIN(1000),CHFEXP(1000),PEI(1000)
                 1,XEXP(1000),X(1000),Y(1000),BAU(1000),TIN(1000),DETAP(1000)
      C
                   REAL L(1000),LCC(1000)
      C
                  COMMON/ SCALES / XMIN,XMAX,TICX,FXSCAL,YMIN,YMAX,TICY,FYSCAL
                  COMMON/ FORMAT / XL,YL,FTITLE(8),FSUBTIT(8),FXAXTIT(8),
                 1                 FYAXTIT(8),NSTVARS,STVARS
      C
      C            INITIALIZE CONSTANTS .
      C
                NCOMP=1
                TEMP(1)=200.
                TEMP(1)=TEMP(1)+273.
                TEMP(2)=400.
                TEMP(2)=TEMP(2)+273.
                IHTFS(1) =1
                MAXHOT=1
                NLP=6
                NTELE=8
                ITEL=1
                NLINE=64
                LINCT=25
                IFLAGX=0
                  SUM=0.
                  STOTAL=0.
                  SADD=0.
      C
      C             FLUID TYPE .
      C
                  ICODE(1)=434
      C
      C            READ THE NUMBER OF RUNS.
      C
                  READ*,NRNS
      C
      C                REAC THE SYSTEM PRESSURE (KPA),THE TUBE DIAMETER (M),THE
      C           TUBE LENGTH (M),THE MASS FLUX (KG/S/SQ-M),THE INLET SUBCOOLING
      C           (KJ/KG) AND CHF(KW/SQ-M)
      C
                  DO 830 I=1,32
           830     P(I)=200.
                  DO 831 I=33,38
           831     P(I)=106.
                  DO 832 I=39,115
           832     P(I)=200.
                  DO 833 I=116,186
           833     P(I)=106.
                  DO 834 I=187,205
           834     P(I)=200.
                   DO 835 I=206,268
           835     P(I)=106.
```

```
      DO 836 I=269,323
  836 P(I)=200.
      DO 837 I=324,337
  837 P(I)=106.
      DO 838 I=338,390
  838 P(I)=200.
      DO 839 I=391,450
  839 P(I)=106.
      DO 840 I=451,507
  840 P(I)=200.
      DO 730 I=1,38
  730 D(I)=0.324
      DO 731 I=39,186
  731 D(I)=0.424
      DO 732 I=187,337
  732 D(I)=0.264
      DO 733 I=338,507
  733 D(I)=0.633
      DO 991 I=1,NRNS
      READ*,L(I),G(I),DHIN(I),CHFEXP(I)
C
C       CHANGE UNITS TO SI .
C
        D(I)=D(I)*2.54/100.
        L(I)=L(I)*2.54/100.
        G(I)=G(I)*1.359/1000.
        DHIN(I)=DHIN(I)*2325.9
        CHFEXP(I)=CHFEXP(I)*3.15
       P(I)=P(I)*6.894
C
C
       MODE=0.
       IPHASE(1)=2
      LOD(I)=L(I)/D(I)
      IF(LOD(I).LT.50) C=0.25
      IF(LOD(I).GE.50.AND.LOD(I).LE.150) C=0.25+0.0009*(LOD(I)-50.)
      IF(LOD(I).GT.150) C=0.34
C
C        STATE VARIABLES .
C
       IPHASE(1)=2
       PRESS=P(I)*1000.
       MODE=1

     CALL HPROS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
    *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESO,
    *IFLAGX)
C
     HFG=PROPS(10,1)/WATES(1)
C
      ROL=PROPS(7,1)
     SIGMA=PROPS(11,1)
     MODE=0
     IPHASE(1)=1
     TEMP(1)=RTEMP(1,1,1)+2.
     CALL HPROS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
    *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESO,
```

```
     *IFLAGX)
      RCV=PROFS(5,1)
C
      SRGL=SIGMA*RCL/G(I)**2/L(I)
      RVRL=ROV/RCL
C
     B02=C*SRGL**0.043/LOD(I)
     B03=0.1*RVRL**0.133*SRGL**0.3333/(1+0.0031*LOD(I))
     B04=0.098*RVRL**0.133*SRGL**0.433*LOD(I)**0.27/(1+0.0031*LOD(I))
     B05=0.0384*RVRL**0.6*SRGL**0.173/(1+0.28*SRGL**0.233*LOD(I))
     B013=0.234*RVRL**0.513*SRGL**0.433*LOD(I)**0.27/(1+0.0031*LOD(I))
C
C
     ZK6=1.043/(4*C*SRGL**0.043)
     ZK7=5/6*(0.0124+1/LOD(I))/(RVRL**0.133*SRGL**0.333)
     ZK9=1.12*(1.52*SRGL**0.233+1/LOD(I))/(RVRL**0.6*SRGL**0.173)
C
     IF(RVRL.GE.0.15) GO TO 111
C
     IF(B02.LT.B03) B0=B02
     IF(B02.GT.B03.AND.B03.LT.B04) B0=B03
     IF(B02.GT.B03.AND.B03.GT.B04) B0=B04
C
     IF(ZK6.GT.ZK7) ZK=ZK6
     IF(ZK6.LT.ZK7) ZK=ZK7
C
      GO TO 222
 111 IF(B02.LT.B013) B0=B02
     IF(B02.GT.B013.AND.B013.GT.B05) B0=B013
     IF(B02.GT.B013.AND.B013.LT.B05) B0=B05
C
     IF(ZK6.GT.ZK7) ZK=ZK6
     IF(ZK6.LT.ZK7.AND.ZK7.LT.ZK9) ZK=ZK7
     IF(ZK6.LT.ZK7.AND.ZK7.GT.ZK9) ZK=ZK9
C
 222 CONTINUE
C
      QCO=B0*G(I)*HFG
      QC=QCO*(1+ZK*DHIN(I)/HFG)
C
      PEI(I)=QC/CHFEXP(I)
      XEXP(I)=4*CHFEXP(I)/G(I)/HFG*LOD(I)-DHIN(I)/HFG
C
      BAU(I)=(PEI(I)-1.)*(PEI(I)-1.)
      STOTAL=STOTAL+PEI(I)
      SADD=SADD+BAU(I)
      PRINT*,'            PRESSURE       DIAMETER    LENGTH    MASS FLUX
    * IN SUBCOOLING        CHFEXP        EXIT QUALITY    CHFPRED/CHFEXP'
C
     WRITE(6,10) P(I),D(I),L(I),G(I),DHIN(I),CHFEXP(I),XEXP(I),PEI(I)
  10 FORMAT(3X,5F14.3,F14.2,2F11.4/)
 351  CONTINUE
C       PLOT RESULTS .
C
      XL=5.0
      YL=5.0
      YMIN=0.4
```

A P P E N D I X E

Computer Program used to Predict CHF using Weisman & Pei's Model

The program reads in the conditions at the inlet of the tube. Then it assumes a CHF value. The program calculates the CHF based on the assumption that the CHF occurs when the vapor void fraction in the bubbly layer reaches 82%. If the assumed CHF value equals the predicted one within a preassigned tolerance, then, calculations stop. Otherwise a new CHF value is assumed and the process is repeated.

```
      PROGRAM ONBUNF     74/74   OPT=2,ROUND= A/ S/ M/ D,-DS     FTN 5.1+564          85-05-29  10.00.58        PAGE
   DO=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,PL=5000
   FTN5,OPT=2,LO=A/M/R/S.

C
C     **********   NOMENCLATURE   ************************
C
C       BAU      PEI**2.
C       BBDA11=  BUBBLE DIAMETER.
C       COFF1 =  COFFICIENT OF THE TURBULENT INTENSITY.
C       COFF2 =  COFFICIENT OF THE TURBULENT INTENSITY.
C       CONDSC=  LIQUID THERMAL CONDUCTIVITY.
C       CPLSC =  LIQUID HEAT CAPACITY.
C       CZ       NET VELOCITIES TRANSFER FROM BULK TO BUBLY LAYER.
C       DA       DIAMETER OF THE TUBE.
C       DENAVG=  GLOBAL DENSITY.
C       DENAVL=  LIQUID DENSITY.
C       DENFF =  SATURATED LIQUID DENSITY.
C       DENGF    DENFF-DENGG.
C       DENGG =  SATURATED STEAM DENSITY.
C       DENMSE=  LIQUID DENSITY AT CHF LOCATION.
C       DEN1  =  AVERAGE DENSITY OF THE BULK FLOW.
C       DEN2  =  AVERAGE DENSITY OF BUBBLY LAYER.
C       FHHM     FRICTION FACTOR.
C       FHHOM    FRICTION FACTOR.
C       G        MASS VELOCITY.
C       HAVG     GLOBAL ENTHALPY.
C       HAVGG    GLOBAL ENTHALPY.
C       HAVGL    LIQUID ENTHALPY.
C       HEATB    HEAT GOES TO GENERATE BUBBLES.
C       HEATEX=  EXPERIMENTAL CHF.
C       HEATC    CHF VALUE.
C       HFF      SATURATED LIQUID ENTHALPY.
C       HFG      LATENT HEAT FOR VAPORIZATION.
C       HGG      SATURATED STEAM ENTHALPY.
C       HIN      INLET ENTHALPY.
C       HMSE     LIQUID ENTHALPY AT CHF LOCATION.
C       HS       LENGTH OF THE SEGMENT.
C       H1    =  AVERAGE ENTHALPY OF THE BULK FLOW.
C       H1L      LIQUID ENTHALPY OF THE BULK FLOW.
C       H10      SINGLE PHASE HEAT TRANSFER COEFFICIENT.
C       LSU      CHF LOCATION.
C       W     -  MASS FLOW RATE.
C       P        PRESSURE OF THE SYSTEM.
C       PC       CRITICAL PRESSURE.
C       PEI      PREDICTED CHF/EXPERIMENTAL CHF.
C       PRNO     PRANDTL NUMBER.
C       R        TUBE RADIUS.
C       REFHOM=  REYNOLDS NUMBER.
C       RESC     REYNOLDS NUMBER.
C       S        BUBBLY LAYER THICKNESS.
C       SABD     SUMMATION OF BAU.
C       STOTAL=  SUMMATION OF PEI.
C       SUTN  =  LIQUID SURFACE TENSION.
C       SUTSC    LIQUID SURFACE TENSION.
C       TAVGL    LIQUID TEMPERATURE.
C       TI       TURBULENT INTENSITY.
C       TMSE     LIQUID TEMPERATURE AT CHF LOCATION.
C       TSATT    SATURATION TEMPERATURE.
```

```
      C       VISFSA= SATURATED LIQUID VISCOSITY.
      C       VISFSC= LIQUID VISCOSITY.
      C       VISFF   LIQUID VISCOSITY.
      C       VISGG = STEAM VISCOSITY.
      C       VISHOM= TWO-PHASE MIXTURE VISCOSITY.
      C       VOIDAG= GLOBAL VOID FRACTION.
      C       VOID1 - AVERAGE VOID FRACTION OF BULK FLOW.
      C       VOID2   AVERAGE VOID FRACTION OF BUBBLY LAYER.
      C       V1      BUBBLE GENERATION VELOCITY.
      C       XAVG  - GLOBAL QUALITY.
      C       XEQ     THERMODYNAMIC EQUILIBRIUM QUALITY.
      C       X1    = AVERAGE QUALITY OF BULK FLOW.
      C       X2    = AVERAGE QUALITY OF BUBBLY LAYER.
      C       Z       AXIAL LOCATION.
      C       ZZ    = AXIAL LOCATION.
      C
      C
             PROGRAM DNBUNF(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PLOT)
             REAL LSU,M
      C
      C             SET ARRAYS DIMENSIONS .
      C
             DIMENSION Z(2010),ZZ(2010),DEN1(1500),DENAVG(1500),DENAVL(1500)
            1,XAVG(1500),VOIDAG(1500),H1(1500),H1L(1500),HAVCL(1500),LOO(50)
            1,TAVGL(1500),HAVGG(1500),HAVC(1500),XEQ(1500),SLSU(50),GSI(50),
            1,HIN(50),PF(50),GG(50),DAA(50),HEATHW(50),PEI(50),XEQEX(1500)
            1,TIN(50),BAU(50),XVAR(50),ICODE(1),IHTFS(1),IPHASE(1),PSI(50)
            1,TEMP(2),PROPS(22,20),WATES(26),RTEMP(2,11,20),RPRESS(20),X(50)
            1,NAMESC(8,20),CPL1(1500),COND1(1500),SURTEN1(1500),VISF1(1500)
            1,HINSI(50),CHFSI(50),DSI(50),SLSI(50)
      C
               COMMON/ SCALES / XMIN,XMAX,TICX,FXSCAL,YMIN,YMAX,TICY,FYSCAL
               COMMON/ FORMAT / XL,YL,FTITLE(8),FSUBTIT(8),FXAXTIT(8),
            1                   FYAXTIT(8),NSTVARS,STVARS
      C
      C         FLUID CONSTANT .
      C
               FLUIDCT=458551.0
      C
      C      INITIALIZE CONSTANTS .
      C
              NCOMP=1
              TEMP(1)=230.+273.
              TEMP(2)=300.+273.
              IHTFS(1)=1
              MAXHOT=1
              NLF=6
              NTFLE=8
              ITEL=1
              NLINE=64
              LINCT=25
              IFLAGX=0
              VOIDGH=0.
              VOIDGW=0.
              HS=0.01
              N=2000.001
              N1=N-0.999
```

```
      C
      C        DIVIDE THE CHANNEL INTO SEGMENTS .
      C
            Z(1)=0.
            DO 1 I=1,N1
            Z(I+1)=Z(I)+HS
          1 CONTINUE
            ZZ(1)=0.5*HS
            DO 2 I=1,N1
            ZZ(I+1)=ZZ(I)+HS
         2  CONTINUE
      C
      C        READ THE NUMBER OF RUNS .
      C
            READ*,NRNS
      C
      C           READ THE SYSTEM PRESSURE (KPA),THE TUBE DIAMETER (M),
      C         THE TUBE LENGTH (M),THE MASS FLUX (KG/S/SQ-M),THE INLET
      C         ENTHALPY (KJ/KG) AND,CHF (KW/SQ-M) .
      C
            DO 991 II=1,NRNS
            READ*,PP(II),GG(II),HHIN(II),HEATWW(II)
              DAA(II)=0.505
              SLSU(II)=12.
             DSI(II)=DAA(II)*2.54/100.
             SLSI(II)=SLSU(II)*2.54/100.
             LOD(II)=SLSU(II)/DAA(II)
             PSI(II)=PP(II)*6.894757
             GSI(II)=GG(II)*1361.66
             HINSI(II)=HHIN(II)*2.3259
             CHFSI(II)=HEATWW(II)*3.158-03
      C
        991  CONTINUE
      C
      C          INITIALIZE VARIABLES .
      C
         777 SUM=0.
             STOTAL=0.
             SACD=0.
             ROUGH=0.00000
      C
      C         READ THEN PRINT TURBULENT INTENSITY COEFFICIENTS .
      C
             READ*,COFF1,COFF2,COFF3
             WRITE(6,7771) COFF1
             WRITE(6,7772) COFF2
             WRITE(6,7775) COFF3
      C
      C           START THE CALCULATIONS .
      C
             DO 99999 II=1,NRNS
      C
      C           PRINT THE INPUT DATA IN SI UNITS .
      C
              PRINT*,'  PRESS FLUXURE (KPA), DIAMETER (M), LENGTH (M),      MASS
           1 FLUX (MG/HR/SQ-M),      INLET ENTHALPY (KJ/KG),    CHF(MW/SQ-M)'
             WRITE(6,6712) PSI(II),DSI(II),SLSI(II),GSI(II),HINSI(II),CHFSI(II)
```

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```
 6712 FORMAT(1X,*PRESS=*,F10.2,3X,*DIAM=*,F10.5,3X,*LENGTH=*,F10.4,
     13X,*MASS FLUX=*,F15.4,3X,*IN ENTHALPY=*,F12.4,3X,*CHF=*,F12.4)

C
      PRESS=PSI(II)*1000.
C       CHANGE TO BRITISH UNITS  .
C
C
      DA=DAA(II)/12.
      P=FP(II)
      G=GG(II)*1000000.
      HEATEX=HEATWW(II)
      LSU=SLSU(II)/12.
      H=LSU*1.02
      NR=1.
      R=DA/2.
      NJT=1.0001
      VOIDF=0.8
      PC=3206.2
      PRATIO=P/PC
      PI=3.14159
      W=G*PI*R*R
      AGCC=4.1697*10.**8.
      DA=2.*R
      PI1=1.398942
      CON=0.707107
C
C       CALCULATE PROPERTIES AT SATURATION .
C
C
      ICODE(1)=51
      IPHASE(1)=2
      MODE=1
C
      CALL HPPCS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
     *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESC,
     *IFLAGX)
C
C       PRINT*,*WATE= *,WATES(1),*PRESS = *,RPRESS(1),*FLAG= *,IFLAGX
        HC=(PROPS(6,1)+PROPS(10,1))/WATES(1)+FLUIDCT
      PROPS(6,1)=PROPS(6,1)/WATES(1)+FLUIDCT
      PROPS(10,1)=PROPS(10,1)/WATES(1)
      PROPS(1,1)=0.0623*PROPS(1,1)
      PROPS(5,1)=0.0623*PROPS(5,1)
      PROPS(7,1)=0.0623*PROPS(7,1)
      PROPS(2,1)=2.39E-04*PROPS(2,1)
        PRINT*,************SIGMA      *,PROPS(3,1)
      PROPS(3,1)=2414*PROPS(3,1)
      VISGG=2414*PROPS(8,1)
      PROPS(4,1)=0.5719*PROPS(4,1)
      PROPS(6,1)=4.31E-04*PROPS(6,1)
      PROPS(10,1)=4.31E-04*PROPS(10,1)
      PROPS(9,1)=PROPS(6,1)+PROPS(10,1)
C
       HFF=PROPS(6,1)
       DENFF=PROPS(7,1)
       HGG=PROPS(9,1)
```

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```
       HFG=PROPS(10,1)
      VISFSA=PROPS(3,1)
       TSATT=(STEMP(1,1,1)-273.)*1.8+32.
        TIN(II)=TSATT-HHIN(II)/PROPS(2,1)
      MODE=0
      IPHASE(1)=1
      TEMP(1)=STEMP(1,1,1) +2.
      CALL HPPCS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
     *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESC,
     *IFLAGX)
      PROPS(5,1)=0.0623*PROPS(5,1)
       DENGG=PROPS(5,1)
      DENGF=DENFF-DENGG
   63 HIN=HFF-HHIN(II)
      HOUTEX=HEATEX*4.*LSU/G/DA+HIN
      XEOEX(II)=(HOUTEX-HFF)/HFG
      CFC=1.0
      HO=150.
      E3=1./DENGG
      E6=4./(G*DA*HFG)
      E7=DENGG*HFG
      E8=HFG/(1./DENGG-1./DENFF)*(DA/4.)
      E9=4./(G*DA)
      E11=E3-1./DENFF
      E12=DENGG/DENFF
      J1=H/HS+1.001
      K1=J1-0.999
      JA=LSL/HS+1.001
C     PRINT*,*   INPUT DATA IN BRITISH UNITS .*
C     PRINT*,*   PRESSURE (PSIA), RADIUS (FT), LENGTH (FT), MASS FLUX
C    1(MLB/HR/SQ-FT), INLET ENTHALPY (BTU/LB) *
C     WRITE(6,7779) P,R,LSL,G,HIN
 7779 FORMAT(1X,*PRESS=*,F10.2,10X,*RADIUS=*,F10.3,10X,*LENGTH=*,F10.8,
     110X,*MASS FLUX=*,F15.5,10X,*INLET ENTHALPY=*,F10.3)
RECORD LENGTH EXCEEDS 137 COLUMNS -- MAY EXCEED I/O DEVICE
 7771 FORMAT(////,1X,*COFF1=*,F10.5)
 7772 FORMAT(1X,*COFF2=*,F10.5)
 7773 FORMAT(1X,*COFF3=*,F10.5,//)
      HEATOR=6000000.
      HEATCL=100.
      DENEW=1000.
      HEATO=(HEATCL+HEATOR)/2.
      ZZH=ZZ(1)/2.
      HAVG(1)=HIN
   2+ DO 5 I=1,J1
      HAVG(I+1)=HAVG(I)+E9*(HS/6.)*(HEATO+HEATO+4.*HEATO)
    5 CONTINUE
      HAVGG(1)=HIN+E9*(0.5*HS/6.)*(HEATO+HEATO+4.*HEATO)
      DO 6 I=1,J1
      HAVGG(I+1)=HAVGG(I)+E9*(HS/6.)*(HEATO+HEATO+4.*HEATO)
    6 CONTINUE
      DO 75 I=1,J1
      TAVGL(I)=0.
      HAVGL(I)=0.
      DENAVL(I)=0.
      H1(I)=0.
      H1L(I)=0.
```

```
      DEN1(I)=0.
      DENAVG(I)=0.
      XEC(I)=0.
      XAVG(I)=0.
      VOIDAG(I)=0.
   75 CONTINUE
      J2=1.0001
      DELTAH=ES*(HS/6.)*(6.*HEATC)
      TAVGL(1)=TIN(II)
    9 DF=HAVG(J2)-HFF
      IF(DF.GE.0) GO TO 8
      IF(J2.GE.J1) GO TO 8
      IPHASE(1)=0
      MODE=0
       TEMP(1)=(TAVGL(J2)-32.)/1.8+273.
      TEMP(2)=TEMP(1)+2.
       CALL HPFDS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
     *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESC,
     *IFLAGX)
      CPL1(J2+1)=2.39E-04*PROPS(2,1)
      TAVGL(J2+1)=DELTAH/CPL1(J2+1)+TAVGL(J2)
      DENAVG(J2+1)=0.0623*PROPS(1,1)
      COND1(J2+1)=0.5719*PROPS(4,1)
      VISF1(J2+1)=2414*PROPS(3,1)
C
C          CALCULATE SURFACE TENSION .
C
       MODE=2
       IPHASE(1)=2
       CALL HPFDS(ICODE,NCOMP,IPHASE,TEMP,PRESS,MODE,IHTFS,MAXHOT,
     *NLF,NTELE,ITEL,NLINE,LINCT,PROPS,WATES,RTEMP,RPRESS,NAMESC,
     *IFLAGX)
       SURTEN1(J2+1)=PROPS(11,1)*2.2/32.17
      J2=J2+1.0001
      GO TO 9
    8 J3=J2
      DENAVG(1)=DENAVG(2)
      CPL1(1)=CPL1(2)
      COND1(1)=COND1(2)
      SURTEN1(1)=SURTEN1(2)
      VISF1(1)=VISF1(2)
      J5=1.0001
   12 CPLSC=CPL1(J5)
      CONDSC=COND1(J5)
      SUTSC=SURTEN1(J5)
      VISFSC=VISF1(J5)
      PRNO=VISFSC*CPLSC/CONDSC
      RESC=C*DA/VISFSC
      H1C=0.023*(RESC**0.8)*(PRNO**0.4)*CONDSC/DA
      FWHL=0.005
      FWHR=2.0
      FWHM=(FWHL+FWHR)/2.
 3515 SSH=1./SQRT(FWHM)
      RRH=-2.*ALOG10(ROUGH/(3.7*DA)+2.51/(RESC*SQRT(FWHM)))
      COSCOF=SSH-RRH
      IF(COSCOF.GE.0.0) GO TO 3555
      FWHR=FWHM
```

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```
      GO TO 3556
 3555 FWHL=FWHM
 3556 IF(ABS(DCSCCF).LT.0.100) GO TO 3557
      FWHM=(FWHL+FWHH)/2.
      GO TO 3505
 3557 YB=0.01* (SLTSC*AGCC*DENFF*DA/2.)**0.5/VISFSA
      IF(YB.LE.5.0) GO TO 3331
      IF(YB.GT.5.0.AND.YB.LE.30.0) GO TO 3332
      IF(YB.GT.30.0) GO TO 3333
 3331 ZAAA=G*(FWHM/8.)**0.5
      ADF1=(CPLSC*HEATC/H10)-(HEATC*PRNC*YB/ZAAA)
      ADF2=HFF-HAVG(J5)
      ADFF=ADF1-ADF2
      IF(ADFF.GE.0.) GO TO 11
      IF(J5.GE.J1) GO TO 11711
      GO TO 3339
 3332 ZAAA=G*(FWHM/8.)**0.5
      XXXXX=1.+PRNC*(YB/5.0-1.0)
      ADF1=(CPLSC*HEATC/H10)-(5.0*HEATC*(PRNC+ALOG(XXXXX))
     1/ZAAA)
      ADF2=HFF-HAVG(J5)
      ADFF=ADF1-ADF2
      IF(ADFF.GE.0.0) GO TO 11
      IF(J5.GE.J1) GO TO 11711
      GO TO 3339
 3333 ZAAA=G*(FWHM/8.)**0.5
      XXXXX=1.0+5.0*PRNC
      YYYYY=YB/30.0
      ADF1=(CPLSC*HEATC/H10)-(5.0*HEATC*(PRNC+ALOG(XXXXX)+0.5*ALOG
     1(YYYYY))/ZAAA)
      ADF2=HFF-HAVG(J5)
      ADFF=ADF1-ADF2
      IF(ADFF.GE.0.0) GO TO 11
      IF(J5.GE.J1) GO TO 11711
 3339 J5=J5+1.0351
      GO TO 12
 11   J6=J5
      IF(J6.GT.J4) GO TO 11711
      H1L(J6)=HAVG(J6)
      IF(H1L(J6).GE.HFF) H1L(J6)=100.
      DENAVL(J6)=DENAVG(J6)
      HAVGL(J6)=HAVG(J6)
      IF(HAVGL(J6).GE.HFF) HAVGL(J6)=HFF
      DENGLH=DENAVL(J6)
      DENGLW=DENAVL(J6)
      XAVG(J6)=0.
      VOIDAG(J6)=0.
      XAVGH=XAVG(J6)
      XAVGW=XAVG(J6)
      TAVGL1=TAVGL(J6)
      TAVGL2=TAVGL(J6)
      J7=J6
 33     RAT1=(HAVGL(J7)-H1L(J6))/(HFF-H1L(J6))
        IF(RAT1.LT.0.) RAT1=0.
        RAT2=E7/(E7+DENAVL(J7)*(HFF-HAVGL(J7)))
        ARGA1=HEATC*RAT1*RAT2
        ARGA2=HO*E8*VOIDAG(J7)*(TSATT-TAVGL(J7))
```

```
  100 HAVGL1=(HAVGG(J7)-HGG*XAVGH)/(1.-XAVGH)
      IF(HAVGL1.GE.HFF) HAVGL1=HFF
      CAT1=(HAVGL1-H1L(J6))/(HFF-H1L(J6))
      IF(CAT1.LT.0.) CAT1=0.
      CAT2=E7/(E7+DENGLH*(HFF-HAVGL1))
      ARGB1=HEATC*CAT1*CAT2
      ARGB2=HO*E8*VOIDGH*(TSATT-TAVGL1)
      J8=J7+1.0001
      HAVGL2=(HAVGG(J8)-HGG*XAVGW)/(1.-XAVGW)
      IF(HAVGL2.GE.HFF) HAVGL2=HFF
      TIGER1=(HAVGL2-H1L(J6))/(HFF-H1L(J6))
      IF(TIGER1.LT.0.) TIGER1=0.
      TIGER2=E7/(E7+DENGLW*(HFF-HAVGL2))
      ARGC1=HEATC*TIGER1*TIGER2
      ARGC2=HO*E8*VOIDGW*(TSATT-TAVGL2)
      XAVGN=E6*(HS/6.)*((ARGA1-ARGA2)+(ARGC1-ARGC2)+4.*(ARGB1-ARGB2
     1))+XAVG(J7)
      XAVGH=(XAVG(J7)+XAVGN)/2.
      XAVGW=XAVGN
      HAVGL1=(HAVGG(J7)-HGG*XAVGH)/(1.-XAVGH)
      IF(HAVGL1.GE.HFF) HAVGL1=HFF
      HAVGL2=(HAVGG(J8)-HGG*XAVGW)/(1.-XAVGW)
      IF(HAVGL2.GE.HFF) HAVGL2=HFF
      WHIN=(DENGG/DENGLW)*(1.-XAVGN)+XAVGN
      VOIDGW=XAVGN/WHIN
      VOIDGH=(VOIDAG(J7)+VOIDGW)/2.
       NB1=0
  713  NB1=NB1+1
       IF(HAVGL1.LE.HAVG(NB1)) GO TO 713
      NB2=0
  714  NB2=NB2+1
       IF(HAVGL2.LE.HAVG(NB2)) GO TO 714
       TAVGL1=TAVGL(NB1)
       TAVGL2=TAVGL(NB2)
       DENGLW=DENAVG(NB2)
      DENGLH=(DENAVL(J7)+DENGLW)/2.
      CFEXAM=XAVG(J8)/XAVGN
      IF(CFEXAM.GT.0.99.AND.CFEXAM.LT.1.01) GO TO 200
      XAVG(J8)=XAVGN
      GO TO 100
  200 DENAVL(J8)=DENGLW
      XAVG(J8)=XAVGN
      HAVGL(J8)=HAVGL2
      TAVGL(J8)=TAVGL2
      VOIDAG(J8)=VOIDGW
      DENGLH=DENAVL(J8)
      DENGLW=DENAVL(J8)
      XAVGH=XAVG(J8)
      XAVGW=XAVG(J8)
      TAVGL1=TAVGL(J8)
      TAVGL2=TAVGL(J8)
      VOIDGH=VOIDAG(J8)
      VOIDGW=VOIDAG(J8)
      IF(VOIDAG(J8).GE.0.82) GO TO 11311
      IF(J8.GE.J1) GO TO 22229
      J7=J7+1.0001
      GO TO 99
```

```
22229 VOID2=0.82
      DEN2=DENGG*VOID2+DENFF*(1.-VOID2)
      X2=VOID2*DENGG/DEN2
      HMSE=(HAVG(JA)-HGG*XAVG(JA))/(1.-XAVG(JA))
      IF(HMSE.GT.HFF) HMSE=HFF
       NB3=0
  715 NB3=NB3+1
      IF(HMSE.LE.HAVG(NB3)) GO TO 715
      TMSE=TAVGL(NB3)
      DENMSE=DENAVG(NB3)
      VISFF=VISF1(NB3)
      SUTN=SURTEN1(NB3)
      FWHCML=0.005
      FWHCMR=2.0
      REN1=(G*DA/VISFF)**COFF2
      VISHOM=VISFF*EXP(2.5*VOIDAG(JA)/(1.-39.*VOIDAG(JA)/64.))
      REFHOM=G*DA/VISHOM
      FWHCM=(FWHCML+FWHCMR)/2.
 6605 SSHS=1./SQRT(FWHCM)
      RRHS=-2.*ALOG10(ROUGH/(3.7*DA)+2.51/(REFHOM*SQRT(FWHCM)))
      DDDDDF=SSHS-RRHS
      IF(DDDDDF.GE.0.) GO TO 22225
      FWHCMR=FWHCM
      GO TO 22226
22225 FWHCML=FWHCM
22226 IF(ABS(DDDDDF).LT.0.100) GO TO 6606
      FWHCM=(FWHCML+FWHCMR)/2.
      GO TO 6605
 6606 WANG=(DENGG/DENMSE)*(1.-XAVG(JA))+XAVG(JA)
      DENAVG(JA)=DENGG/WANG
      BBDA11=0.015*((8.*SUTN*AGCC*DENAVG(JA)*DA/2)/(FWHCM*G*G))**0.5
      GRATIO=1./(G/2000000.)**0.3
      IF(G.LE.2000000.) GRATIO=1.0
      TT=COFF1*(G*DA/VISHOM)**(-0.1)*(BBDA11/DA)**COFF2*
     1(0.13483*GRATIO*DENFF/DENGG+(1.-0.13483*GRATIO))
      EAG1=(HMSE-H1L(J6))/(HFF-H1L(J6))
      IF(EAG1.LT.0.) EAG1=0.000001
      EAG2=E7/(E7+DENMSE*(HFF-HAVGL(JA)))
      HEATB=HEATC*EAG1
      V1=HEATB/E7
      W=G/DENMSE
      SIG=TT*(W+(G*E3-W)*XAVG(JA))
      WW=V1/SIG
      IF(WW.GE.17.5) WW=17.5
      C7=SIG*(FI1*EXP(-0.5*WW**2.)-0.5*WW*ERFC(WW*CCN))
      DXAVG=E6*(HEATC*EAG1*EAG2-HO*E8*VOIDAG(JA)*(TSATT-TAVGL(JA)))
      S=5.0*BBDA11
      E1=R*R/((R-S)*(R-S))
      E2=2.*(R-S/2.)*S/((R-S)*(R-S))
      E4=(R-S)/((R-S/2)*S)
      E5=R*R/((R-S)*(R-S/2.)*S)
      F10=(R-S/2.)*S*HFG
      DEN1(JA)=DENGG*E1/(DENGG/DENMSE+XAVG(JA)*(1.-DENGG/DENMSE))
     1-DEN2*E2
      VOID1=(DENMSE-DEN1(JA))/(DENMSE-DENGG)
      X1=VOID1*DENGG/DEN1(JA)
      TERM1=DEN1(JA)*C7*(X2-X1)*HFG*(R-S)/R
```

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```
      DFNEW=HEATE-TERM1
      IF(DFNEW.GT.0.) GO TO 11311
11711 HEATOL=HEATO
      GO TO 11511
11311 HEATOR=HEATO
11511 IF(ABS(DFNEW).LT.5000.) GO TO 56
      HEATO=(HEATOR+HEATOL)/2.
      IF(NJT.GE.15.) GO TO 56
      NJT=NJT+1.0001
      XEQ(JA)=(4.*HEATO*LSU)/(G*DA*HFG)-((HFF-HIN)/HFG)
      GO TO 24
 56     CONTINUE
      DFNEW=DFNEW*0.317
      HEATO=HEATO*0.317
      HEATB=HEATB*0.317
      TERM1=TERM1*0.317
      HEATEX=HEATEX*0.317
C     WRITE(6,55) JA,DFNEW,XEQ(JA)
 55   FORMAT(1X,*JA=*,I5,10X,*DFNEW=*,F15.8,10X,*XEQ(JA)=*,F15.8)
C     WRITE(6,57) HEATO,HEATE,TERM1
 57   FORMAT(1X,*HEATO=*,F15.2,10X,*HEATB=*,F15.2,10X,*TERM1=*,
     1F15.2)
C     WRITE(6,59799) XAVG(JA)
59799 FORMAT(1X,*XAVG(JA)=*,F15.9)
C     WRITE(6,3773) HEATEX
 3773 FORMAT(1X,*HEATEX=*,F15.1)
      PEI(II)=HEATO/HEATEX
C
        WRITE(6,118) XEQEX(II),PEI(II)
 118  FORMAT(2X,* EQUIL QUALITY =*,F18.5,5X,*CHFPRED/CHFEXP  =*,F12.6)
      BAU(II)=(PEI(II)-1.)*(PEI(II)-1.)
      STOTAL=STOTAL+PEI(II)
      SADD=SADD+BAU(II)
C     WRITE(6,6000) PEI(II),BAU(II),STOTAL,SADD
 6000 FORMAT(1X,*PEI(II)=*,F15.3,5X,*BAU(II)=*,F15.3,5X,*STOTAL=*
     1,F15.3,5X,*SADD=*,F15.3)
      FAN2=FAN2*6.23
      DEN1(JA)=DEN1(JA)*6.23
      DXAVG=DXAVG*6.23
      DENAVG(JA)=DENAVG(JA)*6.23
C     WRITE(6,58)X1,X2,DEN1(JA),FAN2,VCID1
 58   FORMAT(1X,*X1=*,F15.2,5X,*X2=*,F15.2,5X,*DEN1(JA)=*,
     1F15.2,*FAN2=*,F15.2,5X,*VCID1=*,F15.2)
 59   FORMAT(1X,*DXAVG=*,F15.2,5X,*DENAVG(JA)=*,F15.2,5X,*S=*,
     1E13.6,/////)
      S=S*2.54*12
C     WRITE(6,59) DXAVG,DENAVG(JA),S
C
20999 CONTINUE
C
C         PLOT RESULTS .
C
       XL=5.0
       YL=5.0
       YMIN=0.4
       YMAX=1.6
C
```

APPENDIX F

Computer Program used to Predict CHF using Non-Dimensional CHF Table

The program reads in the non-dimensional parameters (e.g. $\Delta H_{in}/\lambda$, ρ_f/ρ_g, Ψ, x etc.) of the CHF point. Then, it calculates the water equivalent dimensional parameters (P, G, X). The program calculates the CHF using the standard CHF table. Using an iterative technique it finds the intersection between the heat balance equation and the CHF table. This allows the error to be calculated assuming that only inlet conditions are known.

```
      PROGRAM CHFPRED(INPUT,OUTPUT,TAPE2=OUTPUT,TAPE5,TAPE7,PLOT)
C
C     ***************************************************************
C
C                    ****     VARIABLES     ****
C     AVGERR    AVERAGE RELATIVE ERROR
C     AF        FLOW AREA                                   M**2
C     AG        ACCELERATION DUE  TO GRAVITY                M/S**2
C     AH        HEATED AREA                                 M**2
C     CHF       CRITICAL HEAT FLUX                          KW/M**2
C     DHE       HEATED  DIAMETER                            M
C     DHIN      INLET SUBCOOLING                            KJ/KG
C     DHY       WETTED DIAMETER                             M
C     G         MASS FLUX                                   KG/M**2*S
C     HLIN      HEATED LENGTH                               M
C     ICCR      CORRELATION NUMBER
C     IN        NUMBER OF DATA POINTS IN EACH *GROUP*
C     IRUN      RUN NUMBER
C     KDHIN     INLET CONDITION PREDICTION SWITCH
C     N         NUMBER OF RECORDS READ FROM TAPE
C     PRED      PREDICTED HEAT FLUX                         KW/M**2
C     RERR      RELATIVE ERROR
C     RG        RANGE FOR MASS FLUX
C     RMS       ROOT MEAN SQUARE
C     RP        RANGE FOR PRESSURE
C     RX        RANGE FOR QUALITY
C     P         PRESSURE                                    KPA
C     TIN       INLET TEMPERATURE                           DEG. C
C     X         QUALITY
C
C     ***************************************************************
      DIMENSION RMS(6,8,9),AVGERR(6,8,9),IN(6,8,9),RX(7),
     +          RG(9),RP(10),RPP(10),PEI(1000),ZLOC(1000),ZBO(1000)
     !,ZRFRG(1000),ZPSI(1000),ZDHINP(1000),ZX(1000),X(1000),Y(1000)
      REAL REFNC(8),HLIN
       COMMON/ SCALES / XMIN,XMAX,TICX,FXSCAL,YMIN,YMAX,TICY,FYSCAL
       COMMON/ FORMAT / XL,YL,FTITLE(8),FSUBTIT(8),FXAXTIT(8),
     !                  FYAXTIT(8),NSTVARS,STVARS(10)
      COMMON/GEOM/AG
      COMMON/PROP/VF,VG,VL,HFG,HF,HG,HL,UF,UG,UL,
     ,      AKF,AKG,AKL,CPF,CPG,CPL,SF,SG,SL,
     ,      RHOF,RHOG,RHOL,PRF,PRG,PRL,PSAT,TSAT,
     ,      VFG,UFG
      COMMON/CK/ CK1,CK2,CK4

C                    **  DATA STATEMENTS  **

      DATA RX/-1.0,0.0,0.1,0.2,0.4,0.7,1.0/
      DATA RP/0.0,200.0,500.0,1000.0,2500.0,6000.0,8000.0,12000.0,
     *       16000.0,22000.0/
      DATA RG/0.0,40.0,100.0,400.0,1000.0,2000.0,3500.0,5500.0,
     *       10000.0/
      DATA RPP/0.1,0.2,0.5,1.0,2.5,6.0,8.0,12.0,16.0,22.0/

C                    **  INITIALIZE VARIABLES  **

      AG=9.81
```

249


```
      PI=3.14159
      ICCR=0
         NZ=0
         SUM=0.
         STOTAL=0.
         SADD=0.
         BAL=0.
          PEI2=0.
          BAU2=0.
          SADD2=0.
          STOTAL2=0.
          SUM2=0.
C
C   IF KCHIN=0 THEN ONLY CONSTANT QUALITY PREDICTIONS ARE MADE AND
C   THE SUMMARY TABLES ARE BASED ON THESE RESULTS. OTHERWISE BOTH
C   CONSTANT QUALITY AND INLET CONDITION PREDICTIONS ARE MADE AND
C   THE SUMMARY TABLES REPORT INLET CONDITION RESULTS.
C
      KDHIN=1
C
      N=0
      CALL PRESET(RMS,432,0.)
      CALL PRESET(AVGERR,432,0.)
      CALL PRESET(IN,432,0)
C
C
C       ***  INPUT SECTION  ***
C
          WRITE(2,405)
 405  FORMAT(/81X,*CONSTANT QUALITY*,6X,*INLET CONDITIONS*/
     +        3X,*IRUN*,7X,*DHY*,7X,*HLIN*,6X,*P*,9X,*G*,9X,*X*,
     +        7X,*DHIN*,7X,*CHF*,2(5X,*CHFPREC*,5X,*ERROR*)/)
 10   READ(5) IRUN,HLIN,CHY,XE,CHINP,PSI,RFRG,P0
          IF(XE.LT.-.15) GO TO 10
      IF(EOF(5)) 900,1


 1    CONTINUE
      CHF=DHY
      AF=(PI/4.)*CHY**2
      AH=PI*HLIN*CHY

C
          P=50.
 905    CONTINUE
         P=P+10.
      CALL PROPER(P,0)
        PRFRG=RHOF/RHOG
        DIFF=ABS(RFRG-PRFRG)
        IF(DIFF.LT..4) GO TO 874
        GO TO 905
 874    CONTINUE
         SIG=SIGMA(TSAT)
          DHIN=CHINP*HFG
        P2=P*1.02
        CALL PROPER(P2,0)
        RFRG2=RHOF/RHOG
```

```
          P3=P*0.98
          CALL PRCPER(P3,0)
          RFRG3=RHOF/RHOG
          GAMA=ABS((RFRG3-RFRG2)/(P*1000.*0.04))
          CALL PRCPER(P,0)
        G=PSI*(UG/UF)**0.125*(DHE*RHOF**0.5/GAMA**0.5/UF)**0.667
     1*(LF/CHE)
          CHF=E0*G*HFG
C
C     GET INITIAL PREDICTION (CONSTANT QUALITY)
C
        CALL PREDICT(XE,G,P,CHY,DHE,HLIN,CHIN,ICCR,PRECO)
          RERR0=PRECO/CHF-1.
         PEI2=RERR0+1.
         BAU2=(PEI2-1.)*(PEI2-1.)
         STOTAL2=STOTAL2+PEI2
         SADD2=SADD2+BAU2
        IF(KOHIN.EQ.0) GO TO 13
C
C     THROW OUT RECORDS WITH HEATED LENGTH = 0
C
        IF(HLIN.EQ.0.) GO TO 10
        CONST=(DHIN*G*AF)/AH
        SLG=(G*AF*HFG)/AH
        PREC=PRECO
C
C     ITERATIVELY SEARCH FOR CONSTANT INLET CONDITION PREDICTION
C
        CALL SEARCH(XE,G,P,DHY,DHE,HLIN,DHIN,ICOR,PRED,
     +              CHF,CONST,SLQ,IRUN)
        IF(PRED.EQ.-1.) GO TO 10
          NZ=NZ+1
          ZLOC(NZ)=HLIN/CHY
          ZBO(NZ)=EC
          ZRFRG(NZ)=RFRG
          ZPSI(NZ)=PSI
          ZCHINR(NZ)=CHINR
          ZX(NZ)=XE
            BOPRED=PREC/E/HFG
            RERR=BCPRED/BO-1.
          PEI(NZ)=RERR+1.
          BAU=(PEI(NZ)-1.)*(PEI(NZ)-1.)
          STOTAL=STOTAL+PEI(NZ)
          SADD=SADD+BAU
C     FIND WHICH ROWS THE DATA FITS WITH RESPECT TO
C     QUALITY, OUTLET PRESSURE, AND MASS FLUX SO THAT
C     THE OUTPUT TABLES CAN BE FILLED IN.
 13     DO 14 IX=1,6
 14     IF(XE.LE.RX(IX+1)) GO TO 15
 15     DO 16 IG=1,8
 16     IF(G.LE.RG(IG+1)) GO TO 17
 17     DO 18 IP=1,9
 18     IF(P.LE.RP(IP+1)) GO TO 20
```

```
      SUBROUTINE PREDICT (X,G,P,DHY,DHE,HLIN,DHIN,ICOR,Q)
C     ***********************************************************************
C
C     SUBROUTINE PREDICT IS USED TO EVALUATE CRITICAL HEAT FLUX VALUES
C     USING ONE OF THE FOLLOWING METHODS.
C
C        0. TABLE ACCESS (LINEAR INTERPOLATION)
C        1. TONG+S HIGH FLOW SUBCOOLED ONB CORRELATION
C        2. ZUBER+S CORRELATION
C        3. BABCOCK AND WILCOX COMPANY,B&W-2
C        4. MACBETH CORRELATION AS GIVEN BY ECCSA-1
C        5. RELAP4-MOD 7 CHF CORRELATION
C        6. HSU AND BECKER CORRELATION
C        7. BIASI CORRELATION
C        8. BOWRING CORRELATION
C        9. BOWRING+S BLOWDOWN DRYOUT CORRELATION
C       10. PESKOV CORRELATION
C       11. BECKER+S CORRELATION
C       12. VTI CORRELATION
C
C     ***********************************************************************


      REAL INTERP3
      COMMON/PROP/VF,VG,VL,HFG,HF,HG,HL,UF,UG,UL,
     .      AKF,AKG,AKL,CPF,CPG,CPL,SF,SG,SL,
     .      RHOF,RHOG,RHOL,PRF,PRG,PRL,PSAT,TSAT,
     .      VFG,UFG
      COMMON/TABLE/CHFEST(17,14,15)
      COMMON/CK/ CK1,CK2,CK4
      COMMON/ROWS/ PX(17),PP(15),PG(14),IX,IG,IP

*****************************************************************
*  THE FOLLOWING DATA STATEMENTS ARE USED ONLY BY TABLE ACCESS  *
*****************************************************************

      DATA PX/-.15,-.1,-.05,0.,.05,.1,.15,.2,.25,.3,.4,.5,
```

```
     +          .6,.7,.8,.9,1./
      DATA PG/0.,50.,100.,200.,300.,500.,750.,1000.,1500.,2000.,
     +          3000.,4000.,5000.,7500./
      DATA PF/100.,150.,200.,300.,450.,700.,1000.,1500.,2000.,
     +          3000.,4500.,7000.,10000.,15000.,20000./

      DATA (CHFEST(I, 1, 1),I=1,17) / 3930., 3430., 2045., 1200., 1000.,
     +                                 980.,  800.,  750.,  740.,  733.,  500.,
     +                                 500.,  450.,  356.,  212.,   89.,    0./
      DATA (CHFEST(I, 2, 1),I=1,17) / 4000., 3500., 2400., 1700., 1600.,
     +                                1500., 1250., 1200., 1150., 1108.,  873.,
     +                                 756.,  710.,  506.,  386.,  350.,    0./
      DATA (CHFEST(I, 3, 1),I=1,17) / 4800., 4200., 3100., 2200., 2100.,
     +                                2000., 1450., 1000.,  850.,  820.,  750.,
     +                                 727.,  700.,  667.,  493.,  330.,    0./
      DATA (CHFEST(I, 4, 1),I=1,17) / 5600., 4900., 3800., 2600., 2550.,
     +                                2500., 1500., 1400., 1350., 1300., 1200.,
     +                                1160., 1108.,  863.,  532.,  407.,    0./
      DATA (CHFEST(I, 5, 1),I=1,17) / 6400., 5600., 4500., 3000., 3000.,
     +                                3000., 2200., 2100., 2000., 1978., 1900.,
     +                                1774., 1443.,  827.,  620.,  450.,    0./
      DATA (CHFEST(I, 6, 1),I=1,17) / 7200., 6300., 5200., 3600., 3550.,
     +                                3500., 3450., 3350., 3300., 2466., 2354.,
     +                                2318., 1251.,  662.,  633.,  440.,    0./
      DATA (CHFEST(I, 7, 1),I=1,17) / 8000., 7000., 5900., 5500., 5000.,
     +                                4700., 4572., 4105., 3186., 2986., 2887.,
     +                                2394., 1308.,  905.,  730.,  400.,    0./
      DATA (CHFEST(I, 8, 1),I=1,17) / 8800., 7600., 6600., 4800., 4600.,
     +                                4400., 4200., 3552., 3536., 3400., 3319.,
     +                                2534., 1514., 1100.,  600.,  300.,    0./
      DATA (CHFEST(I, 9, 1),I=1,17) / 9600., 8200., 7000., 5500., 4800.,
     +                                4200., 4600., 4500., 4500., 4000., 3823.,
     +                                3266., 2200., 1100.,  600.,  300.,    0./
      DATA (CHFEST(I,10, 1),I=1,17) /10000., 8600., 7700., 5900., 5400.,
     +                                5300., 5260., 5100., 5050., 5000., 4900.,
     +                                4040., 2900., 1100.,  600.,  300.,    0./
      DATA (CHFEST(I,11, 1),I=1,17) /10500., 9400., 8400., 7300., 6500.,
     +                                6000., 5992., 5400., 5300., 5200., 5017.,
     +                                3500., 2700., 1100.,  600.,  300.,    0./
      DATA (CHFEST(I,12, 1),I=1,17) /11000.,10000., 9000., 6800., 6683.,
     +                                6500., 6100., 5300., 5000., 4600., 4000.,
     +                                3000., 2000., 1000.,  500.,  300.,    0./
      DATA (CHFEST(I,13, 1),I=1,17) /11500.,10600., 9500., 8356., 7951.,
     +                                7600., 7400., 5200., 4400., 3800., 3000.,
     +                                2500., 1500.,  900.,  500.,  300.,    0./
      DATA (CHFEST(I,14, 1),I=1,17) /12000.,11000.,10000., 9500., 9200.,
     +                                9000., 7500., 5000., 4000., 3000., 2200.,
     +                                2000., 1200.,  800.,  400.,  300.,    0./
      DATA (CHFEST(I, 1, 2),I=1,17) / 4000., 3500., 2400., 1350., 1200.,
     +                                1100.,  950.,  947.,  900.,  887.,  680.,
     +                                 600.,  560.,  377.,  236.,  111.,    0./
      DATA (CHFEST(I, 2, 2),I=1,17) / 4100., 3600., 2700., 1900., 1800.,
     +                                1700., 1500., 1400., 1390., 1265.,  984.,
     +                                 793.,  600.,  521.,  403.,  300.,    0./
      DATA (CHFEST(I, 3, 2),I=1,17) / 4800., 4200., 3200., 2400., 2200.,
     +                                2000., 1900., 1600., 1400., 1072.,  944.,
     +                                 920.,  900.,  890.,  680.,  450.,    0./
```

```
      DATA (CHFEST(I, 4, 2),I=1,17) / 5400., 4800., 3800., 2700., 3600.,
     +                                 2500., 2100., 1600., 1500., 1400., 1325.,
     +                                 1304., 1200., 1100., 1000.,  500.,    0./
      DATA (CHFEST(I, 5, 2),I=1,17) / 6000., 5400., 4400., 3000., 3000.,
     +                                 3000., 2700., 2400., 2200., 1700., 1650.,
     +                                 1600., 1500., 1400.,  800.,  500.,    0./
      DATA (CHFEST(I, 6, 2),I=1,17) / 6600., 6000., 5000., 3700., 3600.,
     +                                 3500., 3100., 2700., 2227., 1800., 1668.,
     +                                 1500., 1300., 1100.,  670.,  450.,    0./
      DATA (CHFEST(I, 7, 2),I=1,17) / 7200., 6600., 5600., 4300., 4150.,
     +                                 4000., 3500., 2200., 2000., 1900., 1800.,
     +                                 1700., 1500., 1170.,  650.,  400.,    0./
      DATA (CHFEST(I, 8, 2),I=1,17) / 7800., 7200., 6200., 5000., 4700.,
     +                                 4400., 3700., 3400., 3100., 2900., 2700.,
     +                                 2300., 2200., 1100.,  600.,  350.,    0./
      DATA (CHFEST(I, 9, 2),I=1,17) / 8400., 7600., 6800., 5500., 5200.,
     +                                 4800., 3800., 3600., 3400., 3100., 3000.,
     +                                 2800., 2500., 1100.,  550.,  300.,    0./
      DATA (CHFEST(I,10, 2),I=1,17) / 9000., 8200., 6000., 5500., 4988.,
     +                                 4529., 4135., 4000., 3900., 3700., 3500.,
     +                                 3400., 3000., 1000.,  550.,  300.,    0./
      DATA (CHFEST(I,11, 2),I=1,17) / 9600., 6240., 5800., 5600., 5400.,
     +                                 5200., 4600., 4100., 3800., 3300., 3250.,
     +                                 3200., 2500., 1000.,  500.,  300.,    0./
      DATA (CHFEST(I,12, 2),I=1,17) /10000., 6636., 6000., 5766., 5214.,
     +                                 5000., 4700., 4200., 3600., 2800., 2800.,
     +                                 2600., 2000., 1000.,  450.,  300.,    0./
      DATA (CHFEST(I,13, 2),I=1,17) /10500., 9900., 9100., 8901., 7254.,
     +                                 6500., 5700., 4000., 3100., 2600., 2300.,
     +                                 2000., 1500.,  900.,  450.,  300.,    0./
      DATA (CHFEST(I,14, 2),I=1,17) /11000.,10400., 9700., 9000., 8600.,
     +                                 8000., 6500., 5000., 3000., 2200., 1800.,
     +                                 1600., 1000.,  600.,  400.,  300.,    0./
      DATA (CHFEST(I, 1, 3),I=1,17) / 4820., 3700., 2774., 1450.,  277.,
     +                                  262.,  248.,  233.,  219.,  204.,  175.,
     +                                  146.,  117.,   87.,   58.,   29.,    0./
      DATA (CHFEST(I, 2, 3),I=1,17) / 4955., 4000., 3094., 2313., 1794.,
     +                                 1641., 1562., 1483., 1405., 1326., 1244.,
     +                                 1044.,  700.,  600.,  593.,  468.,    0./
      DATA (CHFEST(I, 3, 3),I=1,17) / 5000., 4100., 3200., 2600., 2300.,
     +                                 2100., 2000., 1900., 1300., 1200., 1085.,
     +                                  900.,  751.,  700.,  650.,  315.,    0./
      DATA (CHFEST(I, 4, 3),I=1,17) / 5200., 4300., 3400., 2800., 2500.,
     +                                 2300., 2150., 1400., 1350., 1325., 1300.,
     +                                 1250., 1200., 1142.,  800.,  315.,    0./
      DATA (CHFEST(I, 5, 3),I=1,17) / 5400., 4450., 3500., 3000., 2700.,
     +                                 2400., 2200., 2150., 2100., 2000., 1810.,
     +                                 1461., 1000.,  700.,  600.,  350.,    0./
      DATA (CHFEST(I, 6, 3),I=1,17) / 5600., 4650., 3700., 3150., 2900.,
     +                                 2500., 2250., 2100., 2000., 1800., 1649.,
     +                                 1500., 1100.,  800.,  450.,  300.,    0./
      DATA (CHFEST(I, 7, 3),I=1,17) / 5800., 4850., 3900., 3300., 3000.,
     +                                 2650., 2350., 2118., 2066., 1826., 1767.,
     +                                 1600., 1400.,  600.,  450.,  300.,    0./
      DATA (CHFEST(I, 8, 3),I=1,17) / 6000., 5000., 4000., 3400., 3000.,
     +                                 2600., 2350., 2140., 1958., 1800., 1700.,
     +                                 1600., 1000.,  600.,  450.,  300.,    0./
```

```
      DATA (CHFEST(I,12,15),I=1,17) / 2500., 2400., 2300., 2200., 2100.,
     +                               2000., 1800., 1517., 1410., 1246.,  983.,
     +                                649.,  189.,  182.,  178.,  143.,    0./
      DATA (CHFEST(I,13,15),I=1,17) / 3085., 2831., 2771., 2561., 2373.,
     +                               2350., 2180., 1927., 1689., 1405.,  940.,
     +                                700.,  268.,  253.,  250.,  214.,    0./
      DATA (CHFEST(I,14,15),I=1,17) / 3268., 2969., 2900., 2800., 2758.,
     +                               2500., 2412., 2164., 1950., 1557., 1016.,
     +                                750.,  339.,  325.,  321.,  256.,    0./

      ALPH = ALPHA( X )
      SIG=SIGMA(TSAT)

      GO TO (4000,4010,4020,4050,4120,4130,4140,4160,
     +       4170,4230,4250,4260,4270)  ICOR+1

C*****************************************************************
C*                                                               *
C*          THIS METHOD PREDICTS CRITICAL HEAT FLUX USING        *
C*    A  " TABLE APPROACH METHOD   ". THIS 3-D TABLE             *
C*    IS INDEXED BY QUALITY (X), MASS FLUX (G), & PRESSURE (P).  *
C*    THE ACTUAL RANGES THE TABLE ROWS COVER WITH RESPECT TO     *
C*    THE INDEXING QUANTITIES ARE DEFINED BY THE ARRAYS RX,      *
C*    RP AND RG. LINEAR INTERPOLATION IS CARRIED OUT BETWEEN     *
C*    POINTS IN THE TABLE. THE CHF PREDICTION IS MODIFIED BY     *
C*    THE CORRECTION FACTORS CK1, CK2, CK4.                      *
C*                                                               *
C*****************************************************************

 4000 IF(X.LT.1.) GO TO 6
         X=1.
         Q=0.
         RETURN
 6    CK1=CK2=CK4=1.
C
C   SEARCH FOR WHICH ROWS OF THE CHF TABLE THE DATA FITS
C   WITH RESPECT TO QUALITY, MASS FLUX, AND PRESSURE.
C
      DO 11 IX=1,15
 11   IF(X.LE.PX(IX+1)) GO TO 21

 21   DO 30 IG=1,12
 30   IF(G.LE.PG(IG+1)) GO TO 40

 40   DO 50 IP=1,13
 50   IF(P.LE.PP(IP+1)) GO TO 60

C     DIAMETER CORRECTION FACTOR
 60   IF(DHY.LE.0.016) GO TO 70
         CK1=.7937
         GO TO 90
 70   IF(DHY.GE.0.002) GO TO 80
         CK1=1.5874
         GO TO 90
 80   CONTINUE
         CK1=(.008/DHE)**.3333
```

```
C     BUNDLE CORRECTION FACTOR *** SET TO 1 FOR TUBE DATA  ***
 90   CONTINUE
C     IF ( DHE .NE. DHY )
C    .          CK2 = AMIN1( 0.8, 0.8*EXP( -0.5 * X**0.3333 ) )

C     HEATED LENGTH FACTOR
      ALPH = ALPHA( X )
C    ***  SET CK4 TO 1 TEMPORARILY  ***
C
C     CK4 = EXP( DHY / HTL * EXP( 2. * ALPH ) )

C
C   EXTRAPOLATION FOR PRESSURES OVER 20 MPA.
C
      IF(P.LE.20000.) GO TO 100
         CALL PROPER(20000.,0.)
         SIG=SIGMA(TSAT)
         A=SQRT(RHOG)*HFG*(SIG*(RHOF-RHOG))**.25
         CALL PROPER(P,0.)
         SIG=SIGMA(TSAT)
         B=SQRT(RHOG)*HFG*(SIG*(RHOF-RHOG))**.25

         Q=INTERP3(X,G,20000.)*(B/A)

         RETURN
 100  CONTINUE

      Q=INTERP3(X,G,P)*CK1*CK2*CK4

      RETURN
```

```
      SUBROUTINE PROFER(PRESS,TEMP)
C**********************************************************************
C*                                                                    *
C*     SUBROUTINE PROFER IS USED TO CALCULATE THE                     *
C*     THERMODYNAMIC AND HEAT TRANSPORT PROPERTIES                    *
C*     OF LIGHT WATER AND STEAM FOR SUBCOOLED,                        *
C*     SATURATED, AND SUPERHEATED CONDITIONS.                         *
C*                                                                    *
C*     A VALUE OF PRESSURE (KPA) AND A VALUE OF                       *
C*     TEMPERATURE (C) IN SI UNITS ARE PASSED INTO                    *
C*     THE SUBROUTINE PROPER.                                         *
C*     SINCE POLSAW REQUIRES BRITISH UNITS, THE                       *
C*     INPUT VALUES MUST BE CONVERTED. ALL PROPER-                    *
C*     TIES RETURNED FROM POLSAW ARE IN BRITISH                       *
C*     UNITS. THE PROPERTIES ARE CONVERTED TO SI                      *
C*     UNITS AND ARE PASSED TO OTHER PARTS OF THE                     *
C*     PROGRAM VIA COMMON BLOCK PROP.                                 *
C*                                                                    *
C**********************************************************************

C**********************************************************************
C*                                                                    *
C*  VARIABLE         DEFINITION                          UNITS        *
C*  --------         ----------                          -----        *
C*                                                                    *
C*  AKF              THERMAL CONDUCTIVITY OF                          *
C*                   SATURATED LIQUID.                   KW/M/C       *
C*  AKG              THERMAL CONDUCTIVITY OF                          *
C*                   SATURATED VAPOUR.                   KW/M/C/      *
C*  AKL              THERMAL CONDUCTIVITY OF                          *
C*                   SUBCOOL OR SUPERHEAT WATER.         KW/M/C       *
C*  CPF              SPECIFIC HEAT OF                                 *
C*                   SATURATED LIQUID.                   KJ/KG/C      *
C*  CPG              SPECIFIC HEAT OF                                 *
C*                   SATURATED VAPOUR.                   KJ/KG/C      *
C*  CPL              SPECIFIC HEAT OF                                 *
C*                   SUBCOOL OR SUPERHEAT WATER          KJ/KG/C      *
C*  HF               ENTHALPY OF SAT. LIQ.               KJ/KG        *
C*  HG               ENTHALPY OF SAT. VAP.               KJ/KG        *
C*  HL               ENTHALPY OF SUBCOOL                              *
C*                   OR SUPERHEAT WATER.                 KJ/KG        *
C*  HFG              LATENT ENTHALPY                     KJ/KG        *
C*  PRF              PRANDT NUMBER                       NON DIM.     *
C*  PRG              PRANDT NUMBER                       NON DIM.     *
C*  PRL              PRANDT NUMBER                       NON DIM.     *
C*  RHOF             DENSITY OF SAT LIQ.                 KG/M3        *
C*  RHOG             DENSITY OF SAT VAP.                 KG/M3        *
C*  RHOL             DENSITY OF SUBCOOL                               *
C*                   OR SUPERHEAT WATER.                 KG/M3        *
C*  SF               ENTROPY OF SAT. LIQ.                KJ/KG/C      *
C*  SG               ENTROPY OF SAT. VAP.                KJ/KG/C      *
C*  SL               ENTROPY OF SUBCOOL                               *
C*                   OR SUPERHEAT WATER.                 KJ/KG/C      *
C*  UF               DYNAMIC VISCOSITY OF                             *
C*                   SATURATED LIQUID.                                *
C*  UG               DYNAMIC VISCOSITY OF                             *
```

```
*                       SATURATED VAPOUR.                               *
*  UL                   DYNAMIC VISCOSITY OF                            *
*                       SUBCOOL OR SUPERHEAT WATER.                     *
*  VF                   SPECIFIC VOLUME OF                              *
*                       SATURATED LIQUID.                 M3/KG         *
*  VG                   SPECIFIC VOLUME OF                              *
*                       SATURATED VAPOUR.                 M3/KG         *
*  VL                   SPECIFIC VOLUME OF                              *
*                       SUBCOOL OR SUPERHEAT WATER.       M3/KG         *
*  PRESS                PRESSURE PASSED INTO                            *
*                       SUBROUTINE PROPER.                KPA           *
*  P                    PRESSURE USED BY                                *
*                       SUBROUTINE POLSAW.                PSIA          *
*  TEMP                 TEMPERATURE PASSED INTO                         *
*                       SUBROUTINE PROPER.                C             *
*  T                    TEMPERATURE USED BY                             *
*                       SUBROUTINE POLSAW.                F             *
*  PSAT                 SATURATION PRESSURE.              KPA           *
*  TSAT                 SATURATION TEMPERATURE.           C             *
*                                                                       *
*************************************************************************

      REAL K,R(13)
      COMMON/L120/K(148)
      COMMON/PROP/VF,VG,VL,HFG,HF,HG,HL,UF,UG,UL,
     .            AKF,AKG,AKL,CPF,CPG,CPL,SF,SG,SL,
     .            RHOF,RHOG,RHOL,PRF,PRG,PRL,PSAT,TSAT,
     .            VFG,UFG

      P   PRESS/6.894757
      T = TEMP*1.8 + 32.

*************************************************************************
*     IF THE PRESSAMURE (PRESS) PASSED INTO PROPER                          *
*     EQUALS 0.0 THEN SATURATION PROPERTIES AS A                        *
*     FUNCTION OF TEMPERATURE HAVE BEEN REQUESTED.                      *
*     IF THE PRESSURE IS NOT EQUAL TO 0.0 THEN                          *
*     SATURATION PROPERTIES AS A FUNCTION OF                            *
*     PRESSURE ARE CALCULATED.                                          *
*************************************************************************

      IF(PRESS .EQ. 0.0) CALL POLSAW(0.0,T,K,R,1)
      IF(PRESS .NE. 0.0) CALL POLSAW(P,0.0,K,R,1)

      VF = R(1) * .062428
      VG   R(7) * .062428
      VFG = VG - VF
      HFG   (R(8)-R(2)) * 2.3255
      HF = R(2) * 2.3255
      HG = R(8) * 2.3255
      UF   R(3) * 1.488164
      UG   R(9) * 1.488164
      UFG = UF - UG
      AKF - R(4) * .001730735
      AKG - R(10) * .001730735
      CPF   R(5) * 4.1868
      CPG = R(11) * 4.1868
```

```
          SF = R(6) * 4.1868
          SG = R(12) * 4.1868
          RHOF = 1.0/R(1) * 16.018
          RHOG = 1.0/R(7) * 16.018
          PRF = R(5) * R(3) * 3600./R(4)
          PRG = R(11) * R(9) * 3600./R(10)
          IF(PRESS .EQ. 0.0) PSAT = R(13) * 6.894757
          IF(PRESS .NE. 0.0) TSAT = (R(13) - 32.) / 1.8

    ***************************************************************
    *     IF THE TEMPERATURE(TEMP) OR THE PRESSURE(PRESS)         *
    *     PASSED INTO PROPER EQUALS 0.0 THEN ONLY THE             *
    *     SATURATED VALUES HAVE BEEN REQUESTED.                   *
    ***************************************************************

          IF(TEMP .EQ. 0.0  .OR. PRESS .EQ. 0.0) RETURN

    ***************************************************************
    *     CALCULATE THE SUBCOOLED WATER OR SUPERHEATED STEAM      *
    *     PROPERTIES.                                             *
    ***************************************************************

          CALL POLSAW(P,T,K,R,1)
          VL = R(1) * .062428
          HL = R(2) * 2.3255
          UL = R(3) * 1.488164
          AKL = R(4) * .001730735
          CPL = R(5) * 4.1868
          SL = R(6) * 4.1868
          RHOL = 1.0/R(1) * 16.01846
          PRL = R(5) * R(3) * 3600./R(4)
          PSAT = R(13) * 6.894757

          RETURN
          END
```

```
      REAL FUNCTION INTERP3(X,G,P)
C**************************************************
C
C   CARRIES OUT LINEAR INTERPOLATION BETWEEN POINTS
C   IN THE TABLE *CHFEST*. INTERPOLATION IS DONE WITH
C   RESPECT TO MASS FLUX, QUALITY AND PRESSURE.
C
C**************************************************

      REAL INTERP
      COMMON/TABLE/ CHFEST(17,14,15)
      COMMON/ROWS/ PX(17),PP(15),PG(14),IX,IG,IP

      PARAM=(P-PP(IP))/(PP(IP+1)-PP(IP))

      C1=INTERP(CHFEST(IX,IG,IP),CHFEST(IX,IG,IP+1),PARAM)
      C2=INTERP(CHFEST(IX,IG+1,IP),CHFEST(IX,IG+1,IP+1),PARAM)
      C3=INTERP(CHFEST(IX+1,IG,IP),CHFEST(IX+1,IG,IP+1),PARAM)
      C4=INTERP(CHFEST(IX+1,IG+1,IP),CHFEST(IX+1,IG+1,IP+1),PARAM)

      PARAM=(G-PG(IG))/(PG(IG+1)-PG(IG))

      C5=INTERP(C1,C2,PARAM)
      C6=INTERP(C3,C4,PARAM)

      PARAM=(X-PX(IX))/(PX(IX+1)-PX(IX))

      INTERP3=INTERP(C5,C6,PARAM)

      RETURN
      END
```

```
FUNCTION ALPHA       74/74    OPT=0 ROUND=+-*/ TRACE   PMDMP    FTN 4.8+498

      FUNCTION ALPHA( X )

      COMMON/PROP/VF,VG,VL,HFG,HF,HG,HL,UF,UG,UL,
     .       AKF,AKG,AKL,CPF,CPG,CPL,SF,SG,SL,
     .       RHOF,RHOG,RHOL,PRF,PRG,PRL,PSAT,TSAT,
     .       VFG,UFG

      IF ( X .LE. 0.0 ) ALPHA = 0.000001

      IF ( X .GE. 1.0 ) ALPHA = 0.999999

      IF ( X .GT. 0.0  .AND. X .LT. 1.0 )
     .       ALPHA = X / ( X + RHOG / RHOF * ( 1.0 - X ) )

      RETURN
      END
```

```
FUNCTION INTERP       74/74    OPT=0 ROUND=+-*/ TRACE   PMDMP    FTN 4.8+498

      REAL FUNCTION INTERP(A1,A2,P)

C*********************************************
C
C   LINEAR INTERPOLATION WITH PARAMETER 0<=P<=1
C
C       P = 0   RETURNS A1
C       P = 1   RETURNS A2
C
C*********************************************

      INTERP=A1+(A2-A1)*P

      RETURN
      END
```

```
FUNCTION SIGMA       74/74    OPT=0 ROUND=+-*/ TRACE   PMDMP    FTN 4.8+498          85

      FUNCTION SIGMA(TEMP)

C     **************************************************************
C
C     THIS FUNCTION CALCULATES SURFACE TENSION AT A GIVEN SATURATION
C     TEMPERATURE.
C
C     **************************************************************

      DIMENSION A(5)
      DATA A/1.160936807E-01,1.121404688E-03,-5.752805180E-06,
     .        1.286274650E-08,-1.149719290E-11/

      B=0.83
      TC=647.3
      T=TEMP+273.

      SIGMA=A(1)*(TC-T)**2/(1.0+B*(TC-T))

      DO 10 I=2,5
   10 SIGMA=SIGMA + A(I)*(TC-T)**I

      SIGMA=SIGMA/1000.
      RETURN
```

```
FUNCTION HORNER      74/74    OPT=0 ROUND=+-*/ TRACE  PMDMP   FTN 4.8+498

              FUNCTION HORNER(A,X,N)
C
C    EVALUATE A POLYNOMIAL P(X) OF DEGREE N USING HORNER+S RULE.
C    THIS SAVES TIME BY NESTING MULTIPLICATIONS INSTEAD OF FINDING
C    P(X) ONE TERM AT A TIME.
C
C    ARRAY OF POLYNOMIAL COEFFICIENTS:
      DIMENSION A(10)

      HORNER=A(N+1)
      I=N
    5 HORNER=HORNER*X+A(I)
      I=I-1
      IF(I.GT.0) GO TO 5
      RETURN
      END
```

```
      SUBROUTINE SEARCH(X,G,P,DHY,DHE,HLIN,DHIN,ICOR,PRED,CHF,
     +                  CONST,SLQ,IRUN)
C
C
C   ITERATIVE METHOD OF FINDING INTERSECTION OF PREDICTED AND EXPERIMENT
C   LINES. BINARY SEARCH IS USED. VARIABLE NAMES DIFFERING ONLY IN THEIR
C   SUFFIXES *1* OR *2* REPRESENT THE SAME QUANTITY ON OPPOSITE SIDES
C   OF THE INTERSECTION.
C
C   FIRST, FIND INTERVAL X1,X2 WHICH STRADDLES THE INTERSECTION.
C
      ITER=0
      X1=X
      Q1=CHF
      PRED1=PRED
      IF(PRED1.GT.Q1) GO TO 701
  700    Q2=Q1
         X2=X1
         PRED2=PRED1
         X1=X2-.1
         Q1=X1*SLQ+CONST
         CALL PREDICT(X1,G,P,DHY,DHE,HLIN,DHIN,ICOR,PRED1)
         ITER=ITER+1
         IF(ITER.GE.50) GO TO 705
         IF(PRED1.GT.Q1) GO TO 702
         GO TO 700
  701 CONTINUE
         X2=X1+.1
         Q2=X2*SLQ+CONST
         CALL PREDICT(X2,G,P,DHY,DHE,HLIN,DHIN,ICOR,PRED2)
         ITER=ITER+1
         IF(ITER.GE.50) GO TO 705
         IF(PRED2.LT.Q2) GO TO 702
         X1=X2
         Q1=Q2
         PRED1=PRED2
         GO TO 701

  702 CONTINUE
C
C    BINARY SEARCH
C
  703 XMEAN=(X1+X2)/2.
      QMEAN=(Q1+Q2)/2.
      CALL PREDICT(XMEAN,G,P,DHY,DHE,HLIN,DHIN,ICOR,PRED)
      IF(ABS((PRED/QMEAN)-1.).LT.0.002) RETURN
      ITER=ITER+1
      IF(ITER.GE.50) GO TO 705
      IF(PRED.GT.QMEAN) GO TO 704
         X2=XMEAN
         Q2=QMEAN
         GO TO 703
  704 CONTINUE
         X1=XMEAN
         Q1=QMEAN
         GO TO 703
C
```

```
      C   GUARD AGAINST INFINITE LOOPS ARISING FROM NON-CONVERGENT
      C   CASES (IE . LINES DON*T INTERSECT).  RETURN PRED=-1
      C
  705 WRITE(2,710) IRUN,ITER
  710 FORMAT(1X,A6,≠ **** IGNORED. INLET CONDITIONS SOLUTION NON-≠,
     + ≠CONVERGENT AFTER ≠,I3,≠ ITERATIONS≠)
      PRED=-1.
      RETURN
      END
```

A P P E N D I X G

Results from testing Weisman & Pei's model with experimental CHF data of

Freon-113, Freon-11, Nitrogen, Freon-12 and Water

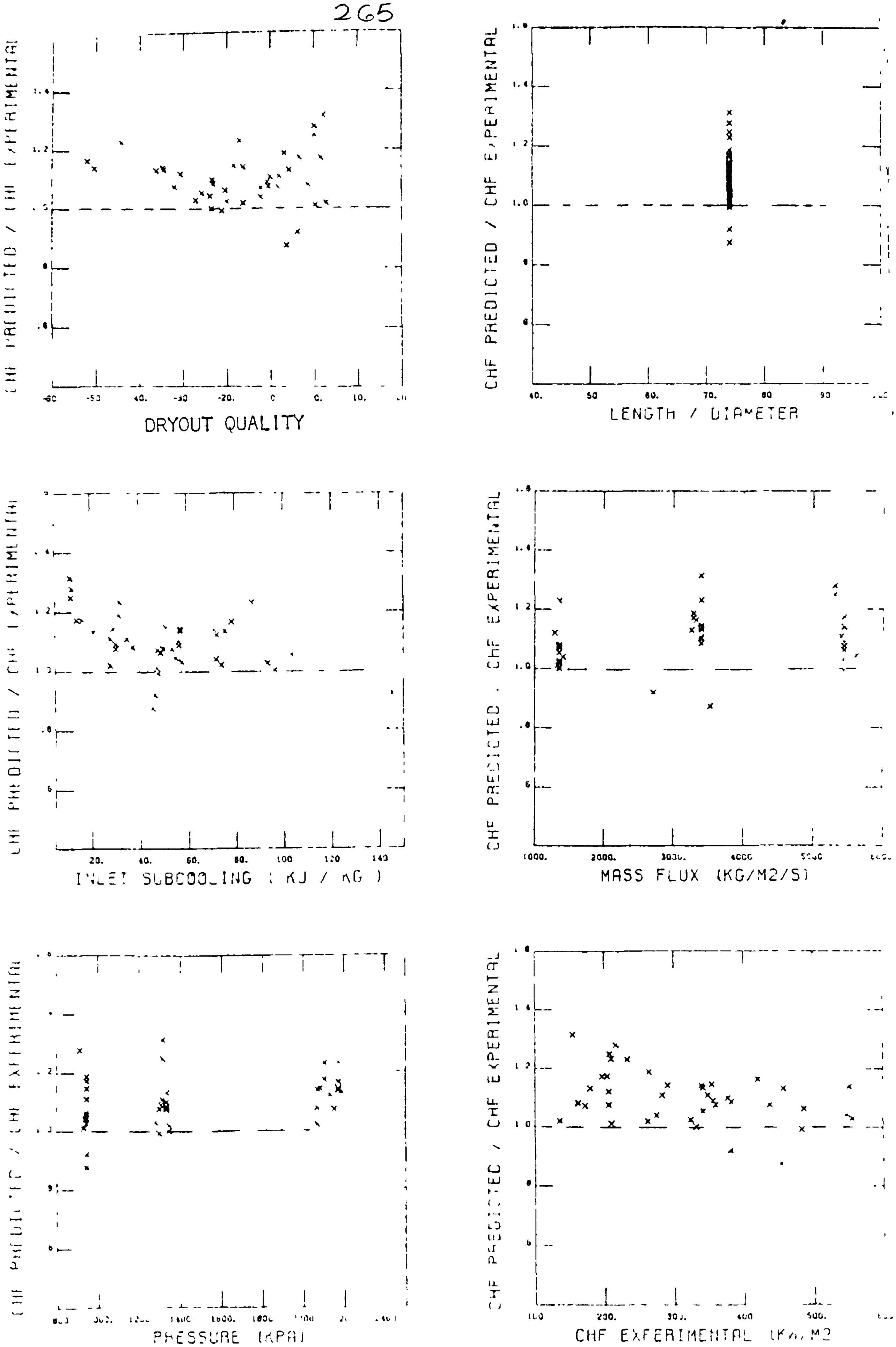

FIGURE 1. WEISMAN & PEI'S MODEL CHF PREDICTIONS FOR FREON-113

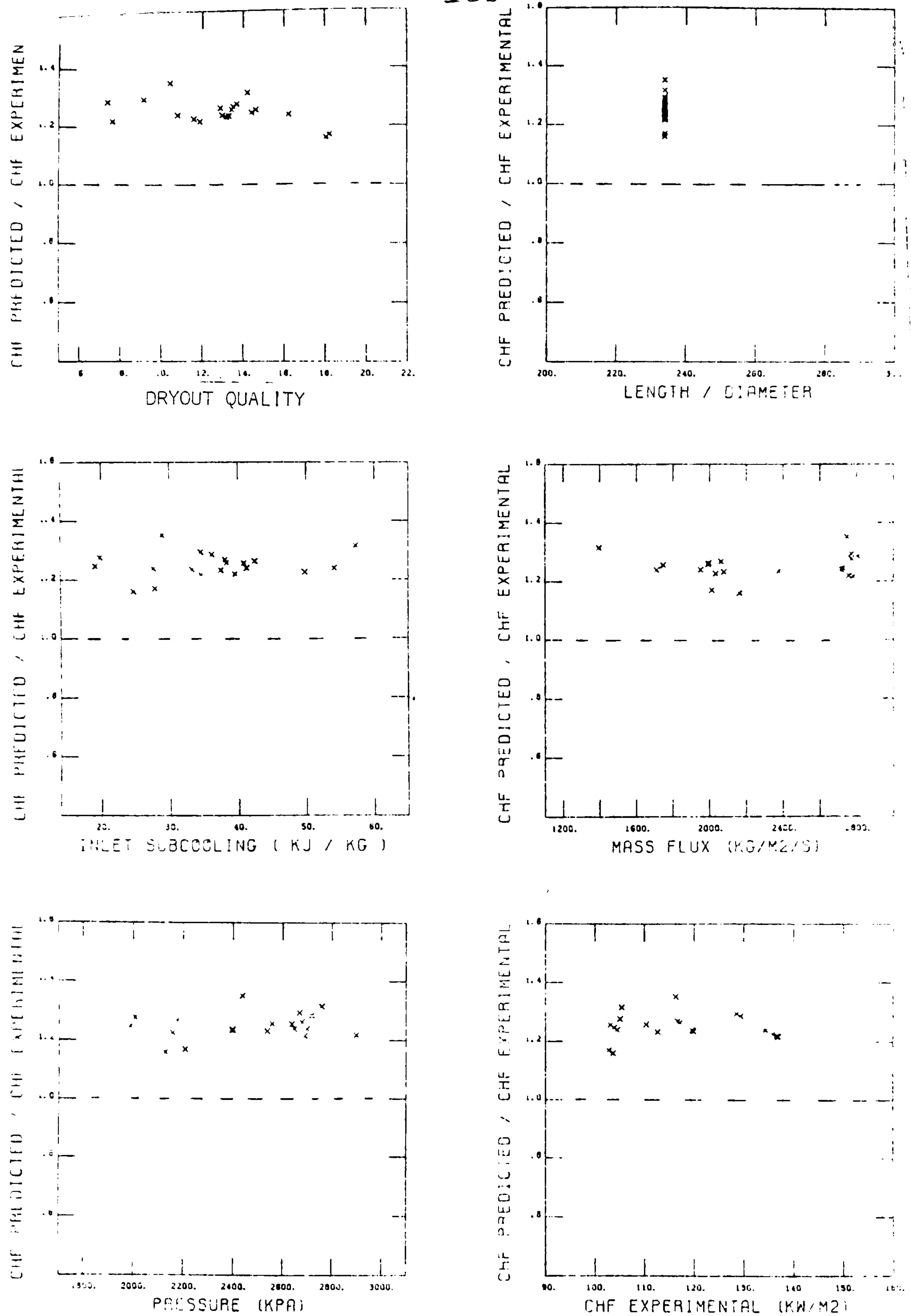

FIGURE 2. WEISMAN & PEI'S MODEL CHF PREDICTIONS FOR FREON-11

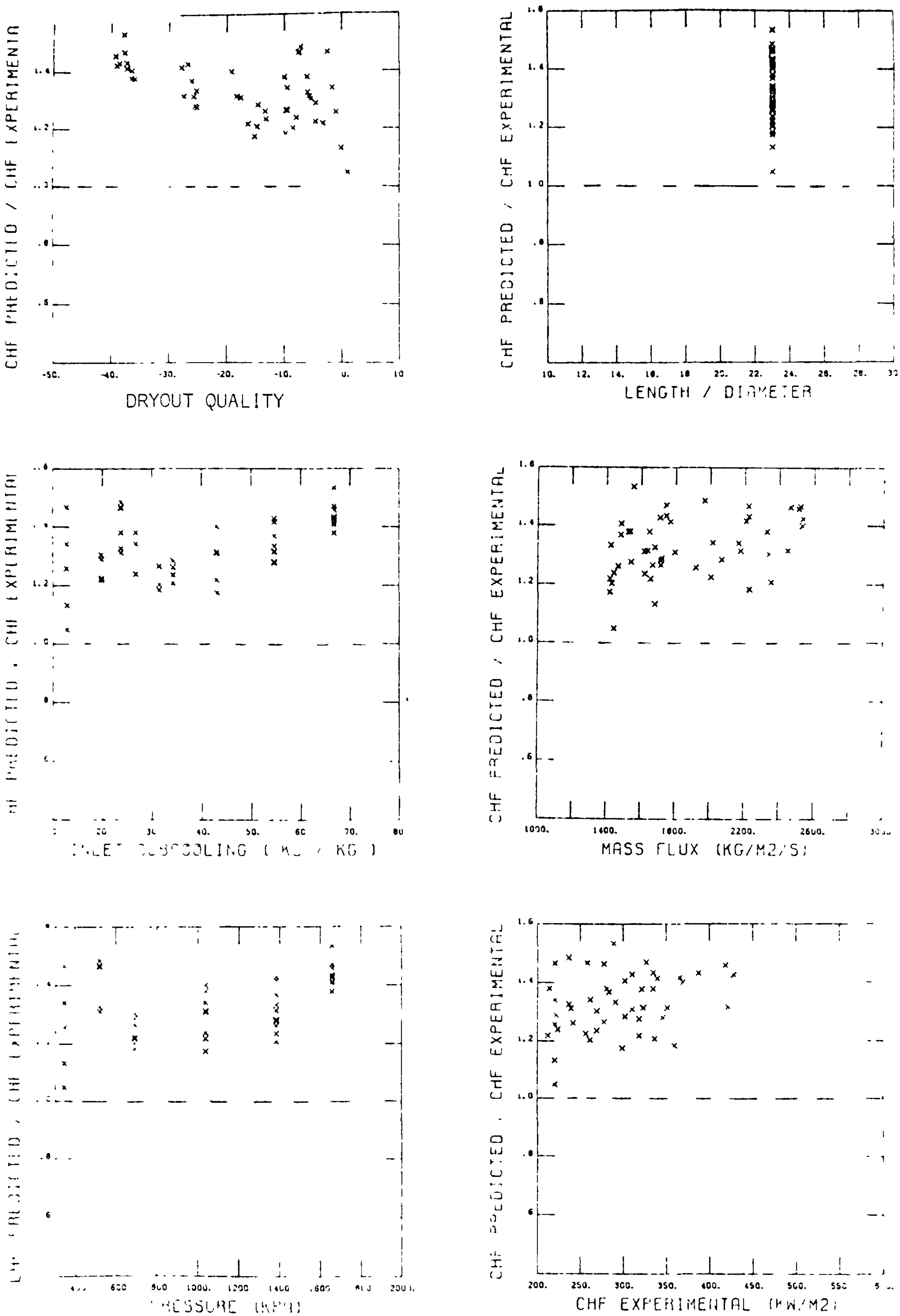

FIGURE 3. WEISMAN & PEI'S MODEL CHF PREDICTIONS FOR NITROGEN

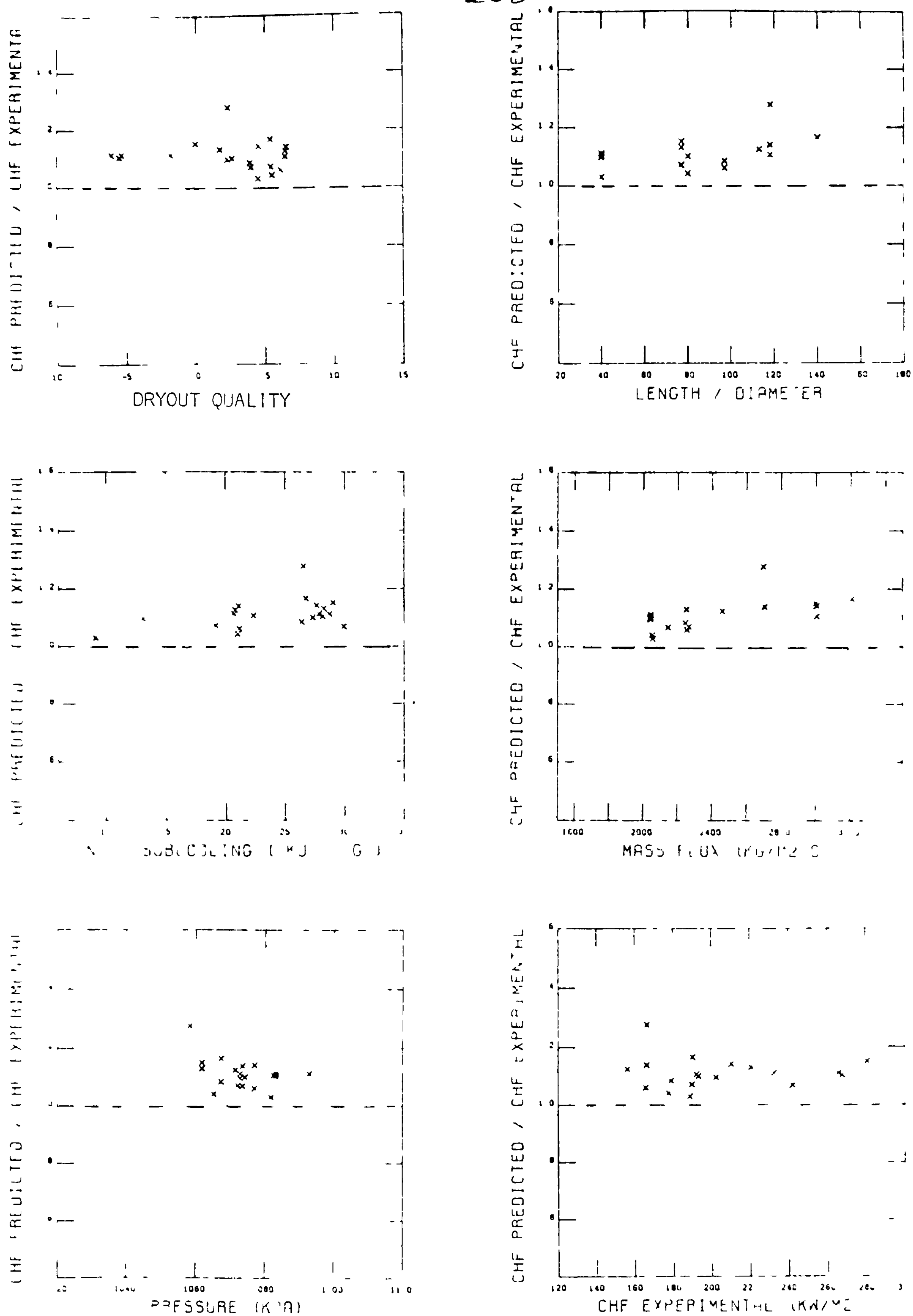

FIGURE 4. WEISMAN & PEI'S MODEL CHF PREDICTIONS FOR FREON-12

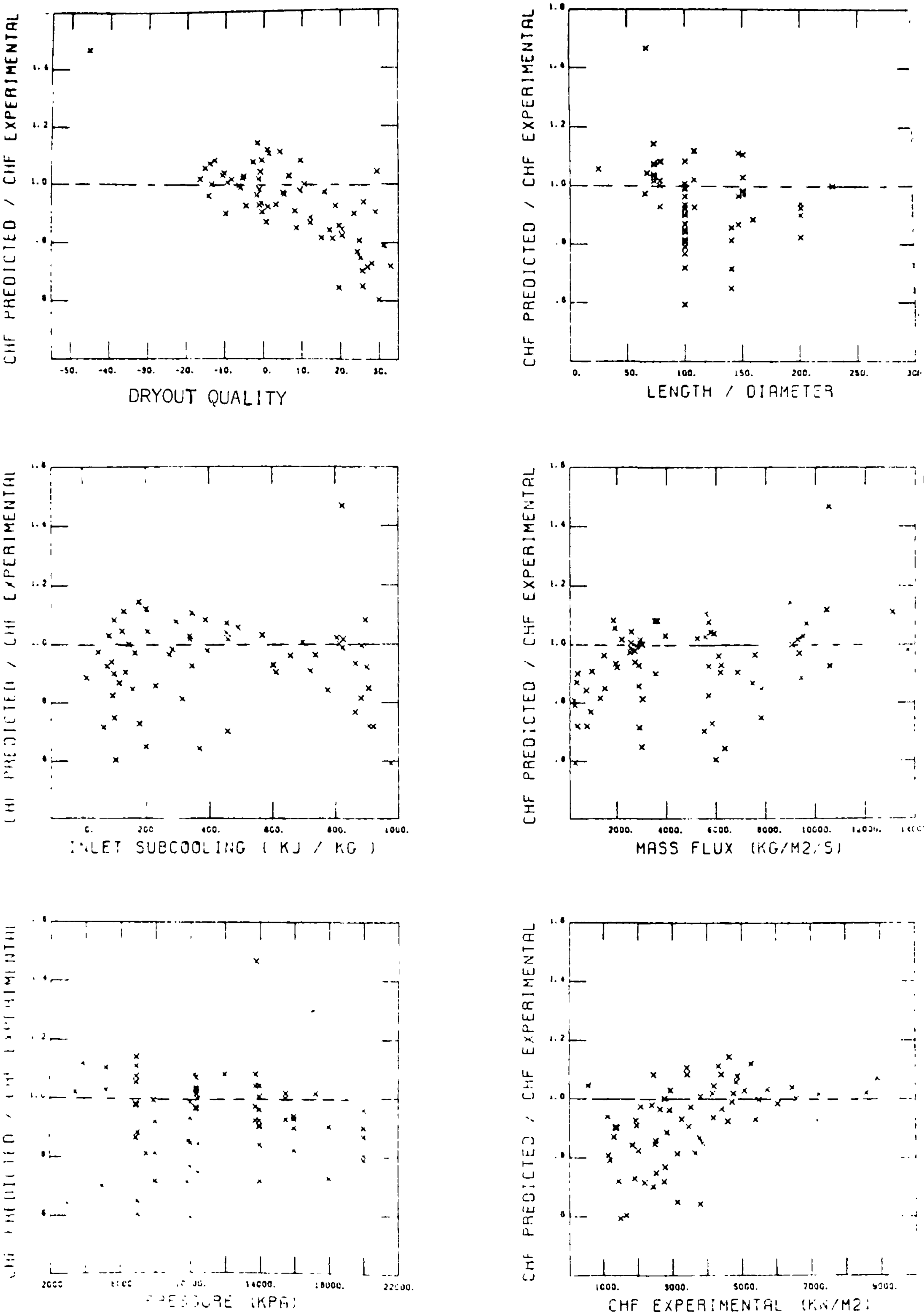

FIGURE 5. WEISMAN & PEI'S MODEL CHF PREDICTIONS FOR WATER

APPENDIX H

Results from testing Katto's correlation with experimental CHF data for Freon-114, Freon-21, Freon-12, Carbon Dioxide and Water

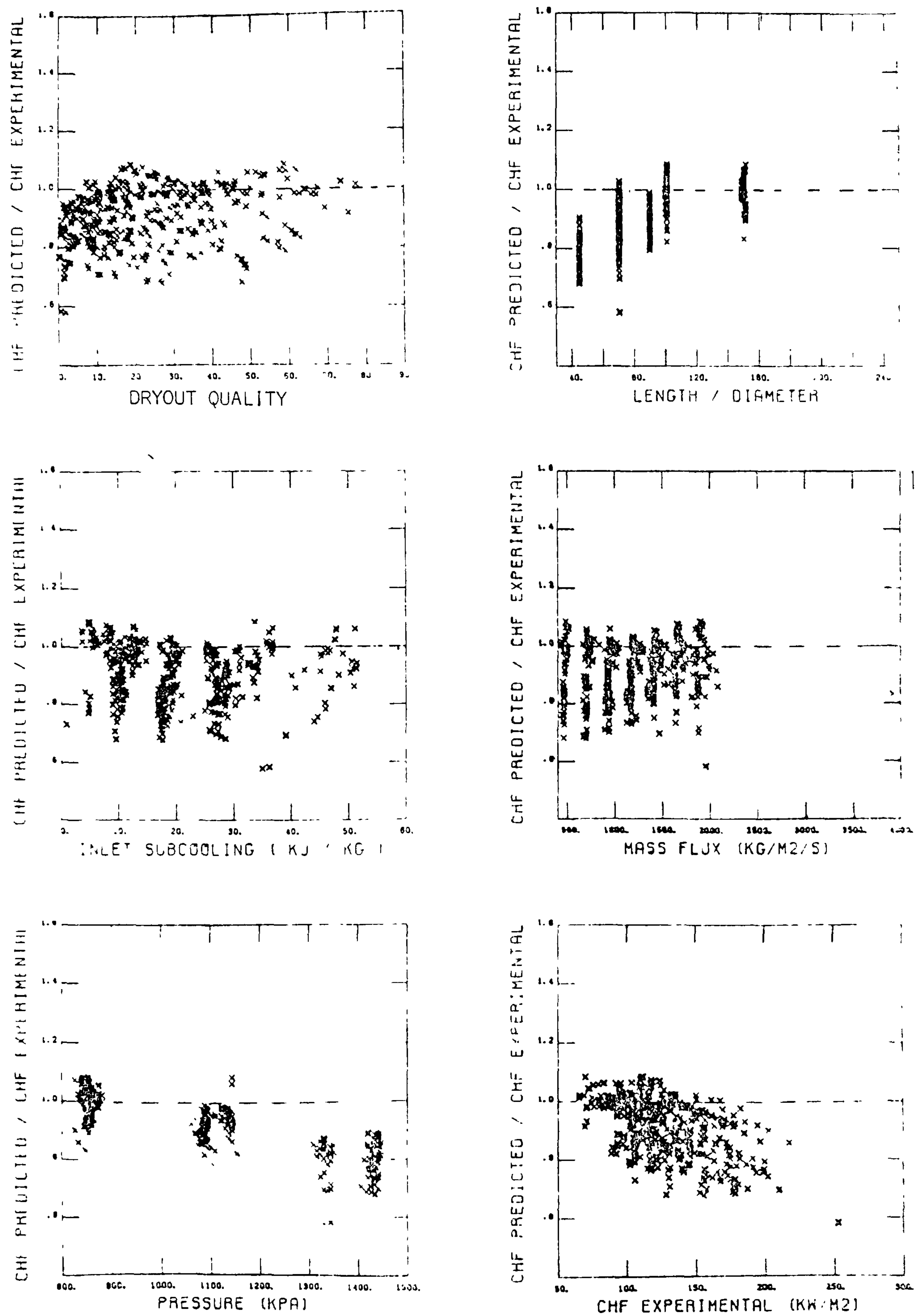

FIGURE 1: ATTO'S CORRELATION CHF PREDICTIONS FOR FREON-114

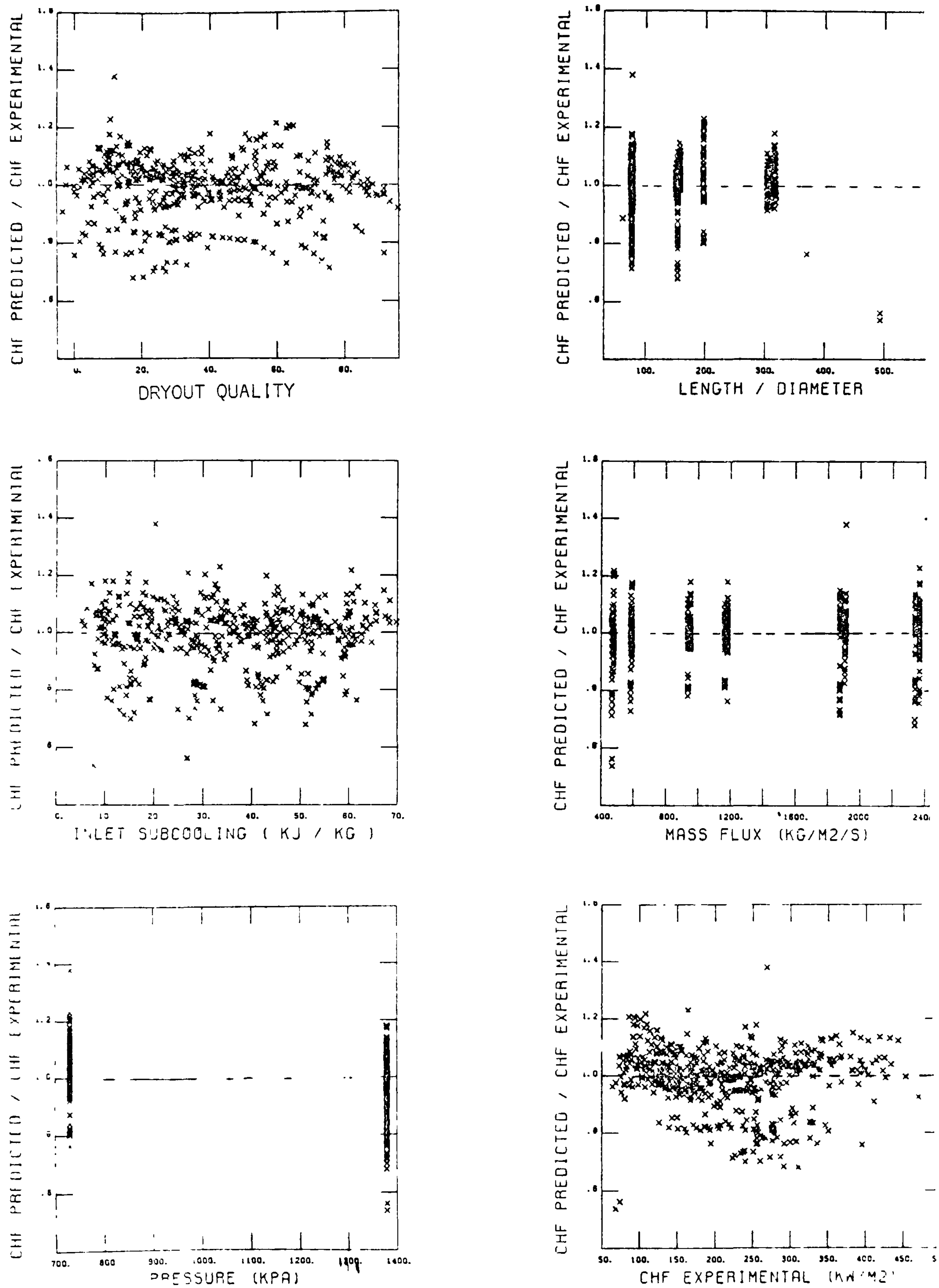

FIGURE 2. KATTO'S CORRELATION CHF PREDICTIONS FOR FREON-21

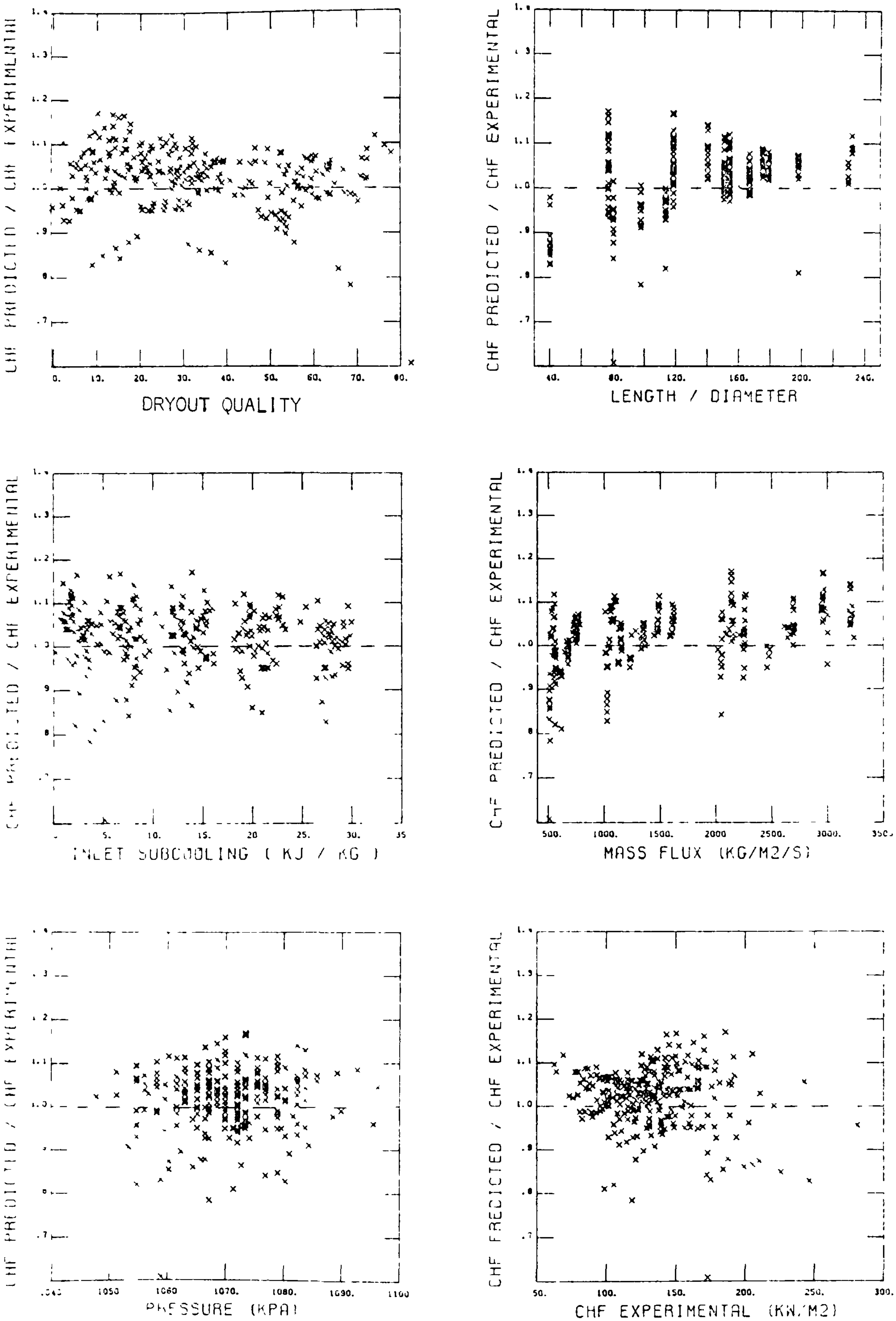

FIGURE 3. KATTO'S CORRELATION CHF PREDICTIONS FOR FREON-12

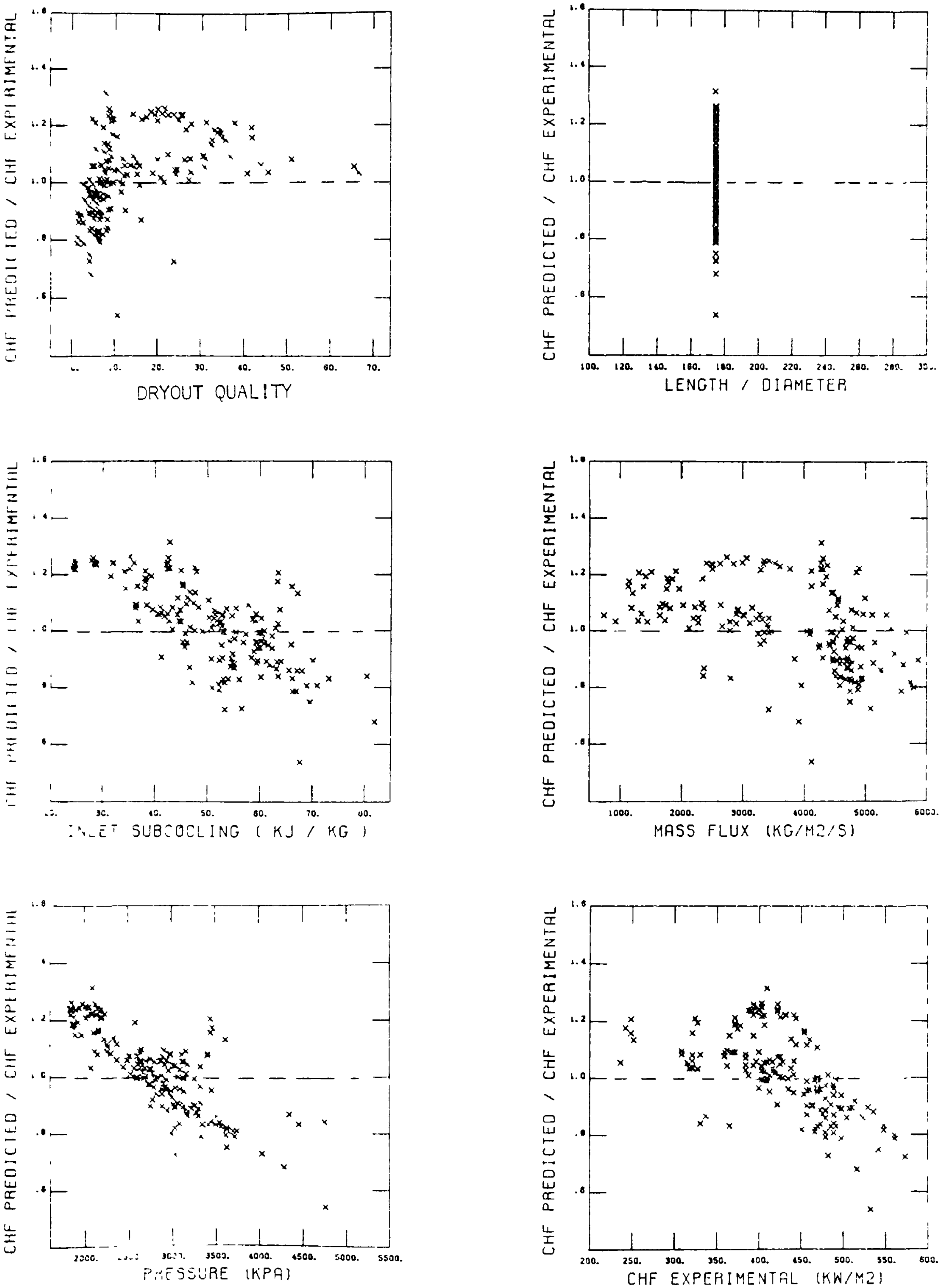

FIGURE 4. KATTO'S CORRELATION CHF PREDICTIONS FOR CARBON DIOXIDE

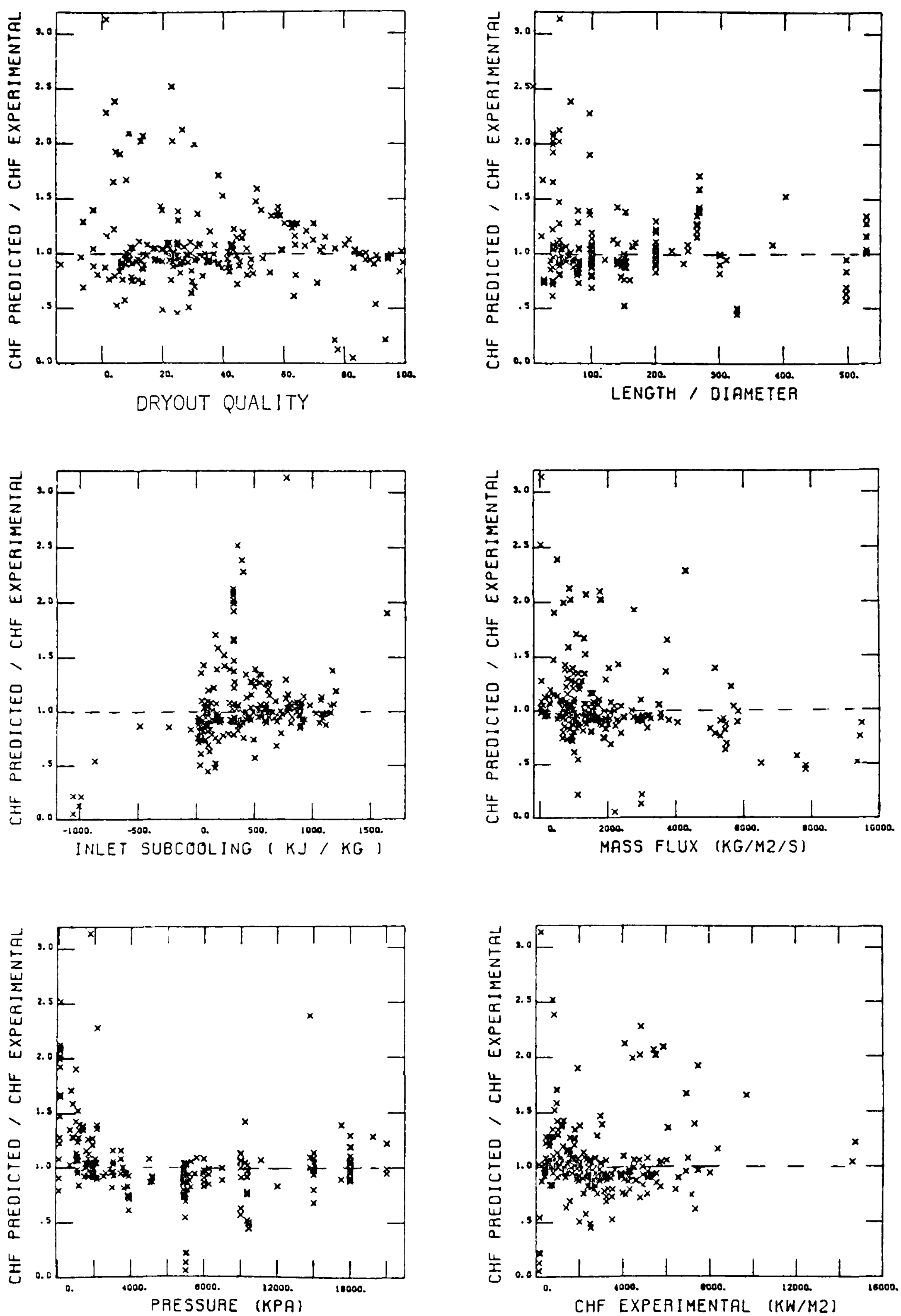

FIGURE 5. KATTO'S CORRELATION CHF PREDICTION FOR WATER

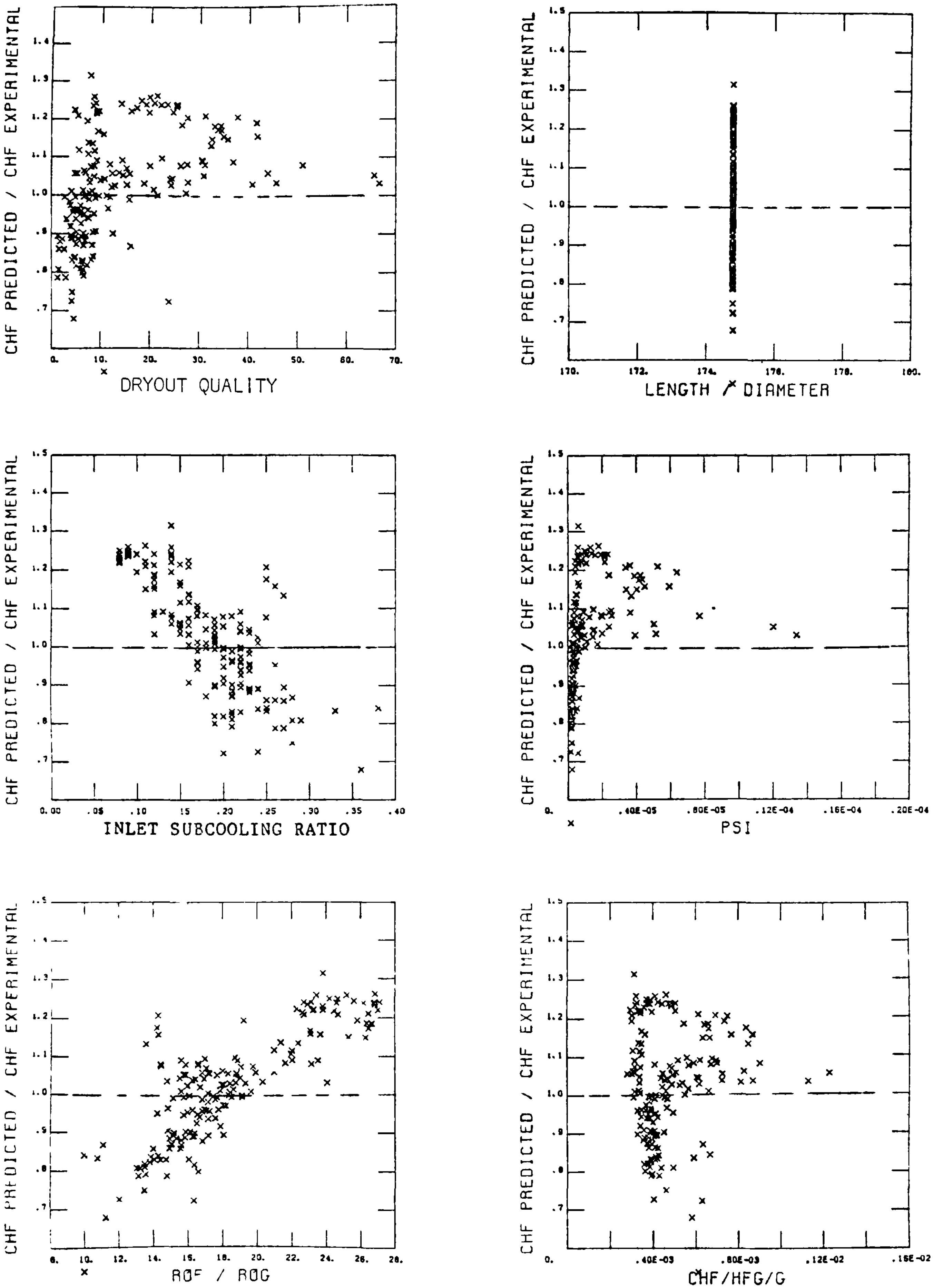

FIGURE 6. KATTO'S CORRELATION CHF PREDICTIONS FOR CARBON DIOXIDE

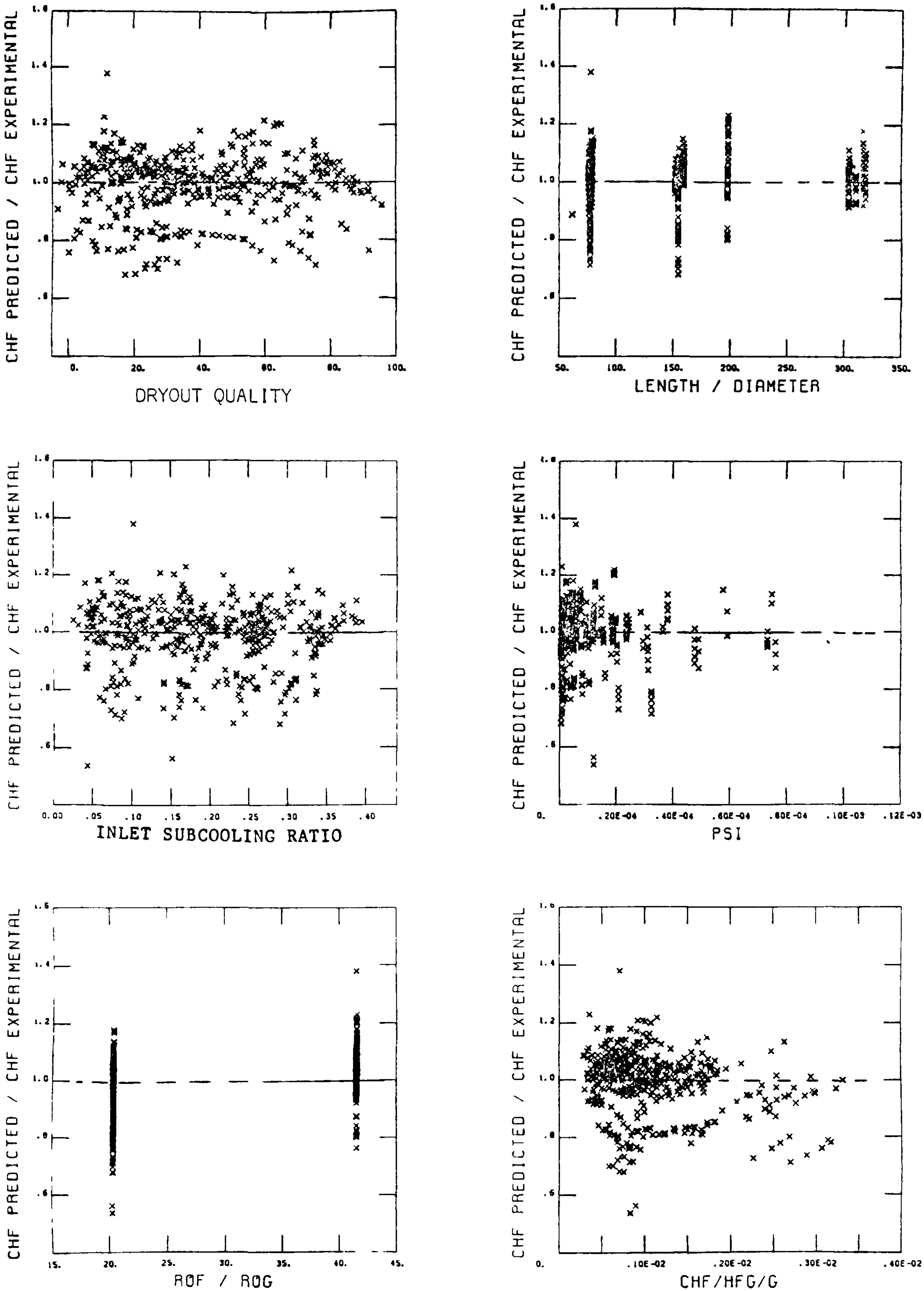

FIGURE 7. KATTO'S CORRELATION CHF PREDICTIONS FOR FREON-21

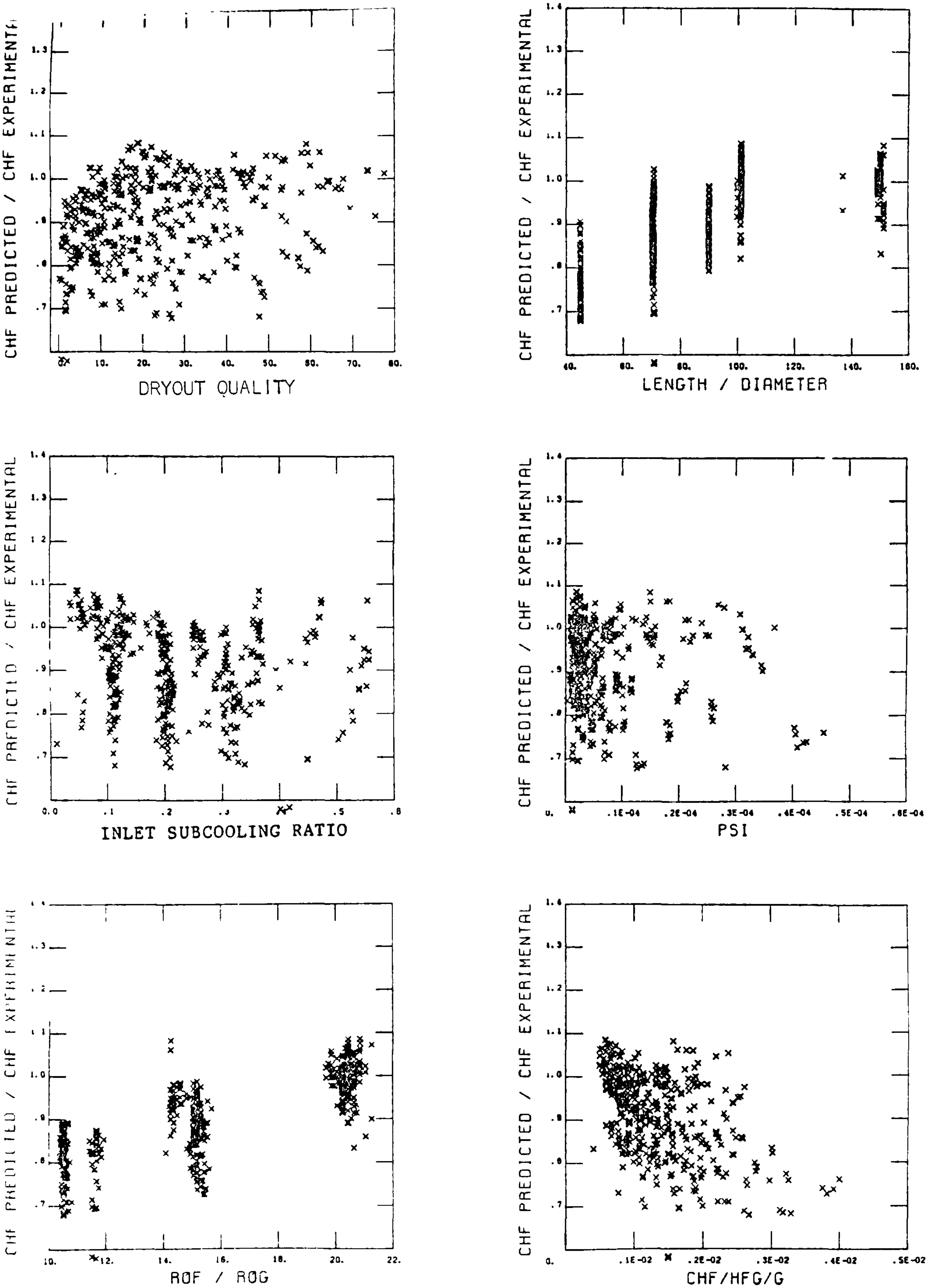

FIGURE 8. KATTO'S CORRELATION CHF PREDICTIONS FOR FREON-114

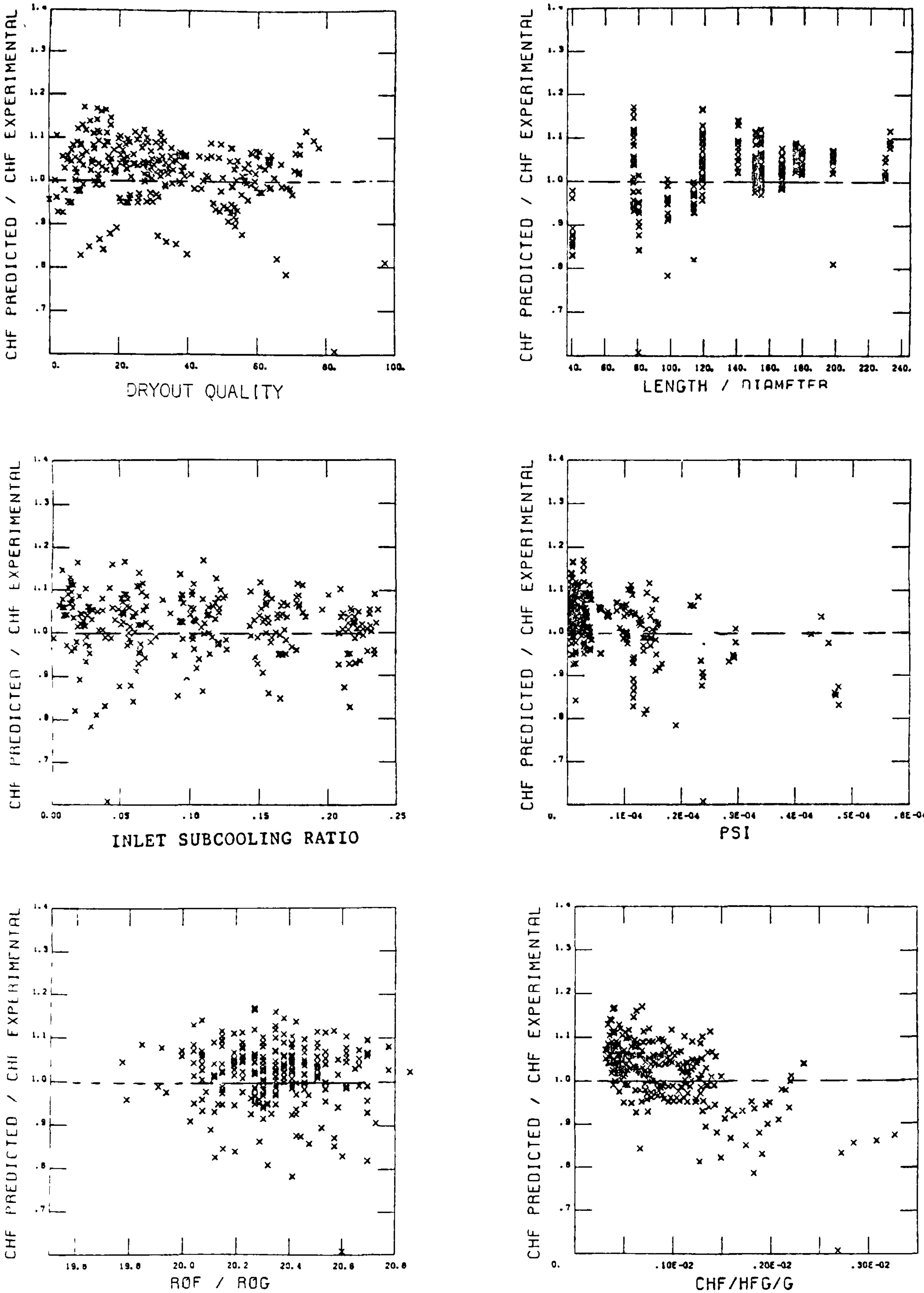

FIGURE 9. KATTO'S CORRELATION CHF PREDICTIONS FOR FREON-12

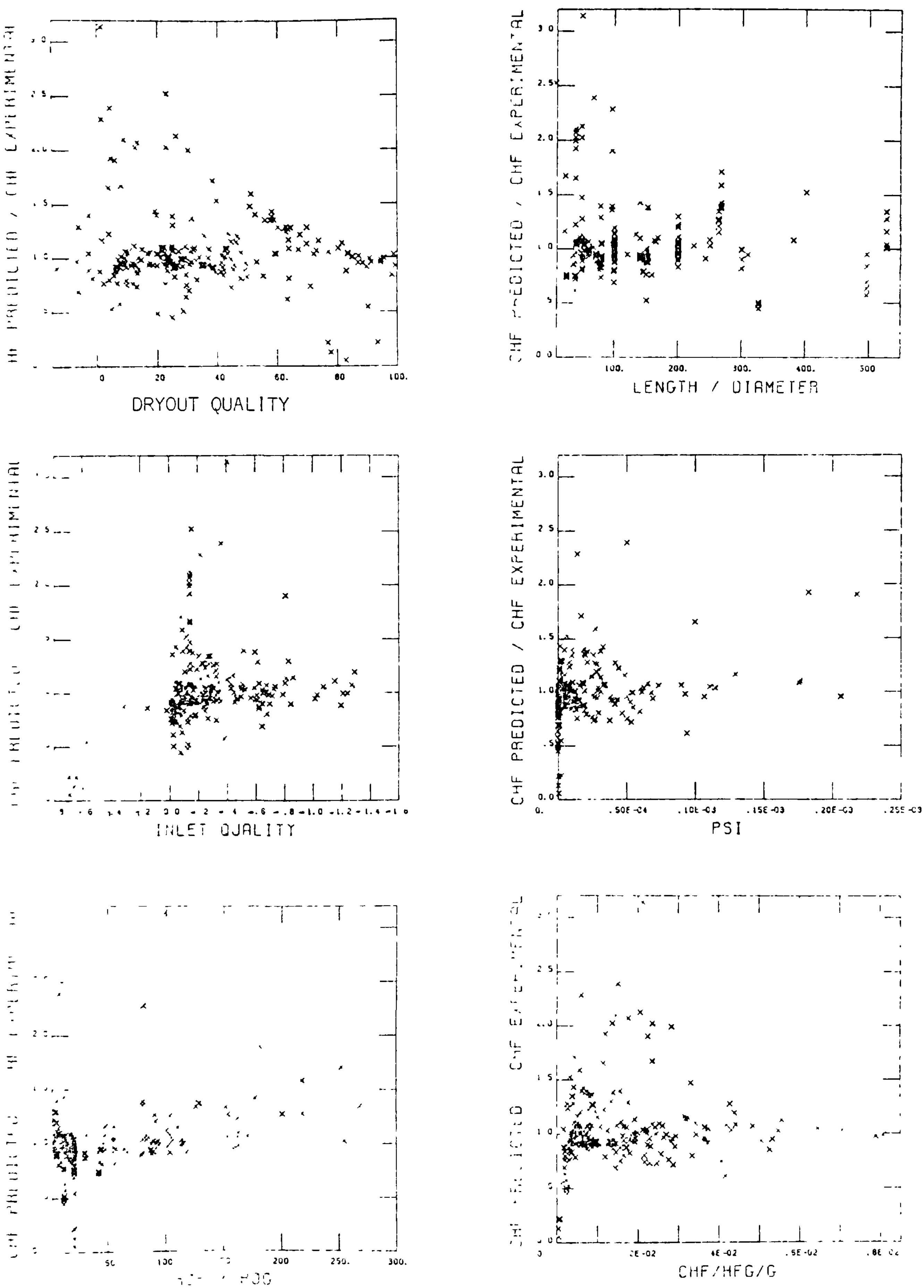

FIGURE 10. KATTO'S CORRELATION CHF PREDICTIONS FOR WATER

APPENDIX I

Results from testing non-dimensional CHF table with experimental CHF data for carbon dioxide, Freon-21, Freon-114, Freon-12, nitrogen, Freon-113 and Water

$$\Psi_{\kappa} = \frac{\sigma\ \rho_f}{G^2 L}$$

$$\Psi_{\sigma} = \left(\frac{G^2 D}{\rho_f\ \sigma}\right)^{2/3} \times \left(\frac{GD}{\mu_f}\right)^{-.133} \times \left(\frac{GD}{\mu_g}\right)^{-.2}$$

$$\Psi_{\gamma} = \left(\frac{GD}{\mu_f}\right) \times \left(\frac{\gamma^{1/2}\ \ \mu_f}{D\ \rho_f}\right)^{2/3} \times \left(\frac{\mu_f}{\mu_g}\right)^{1/8}$$

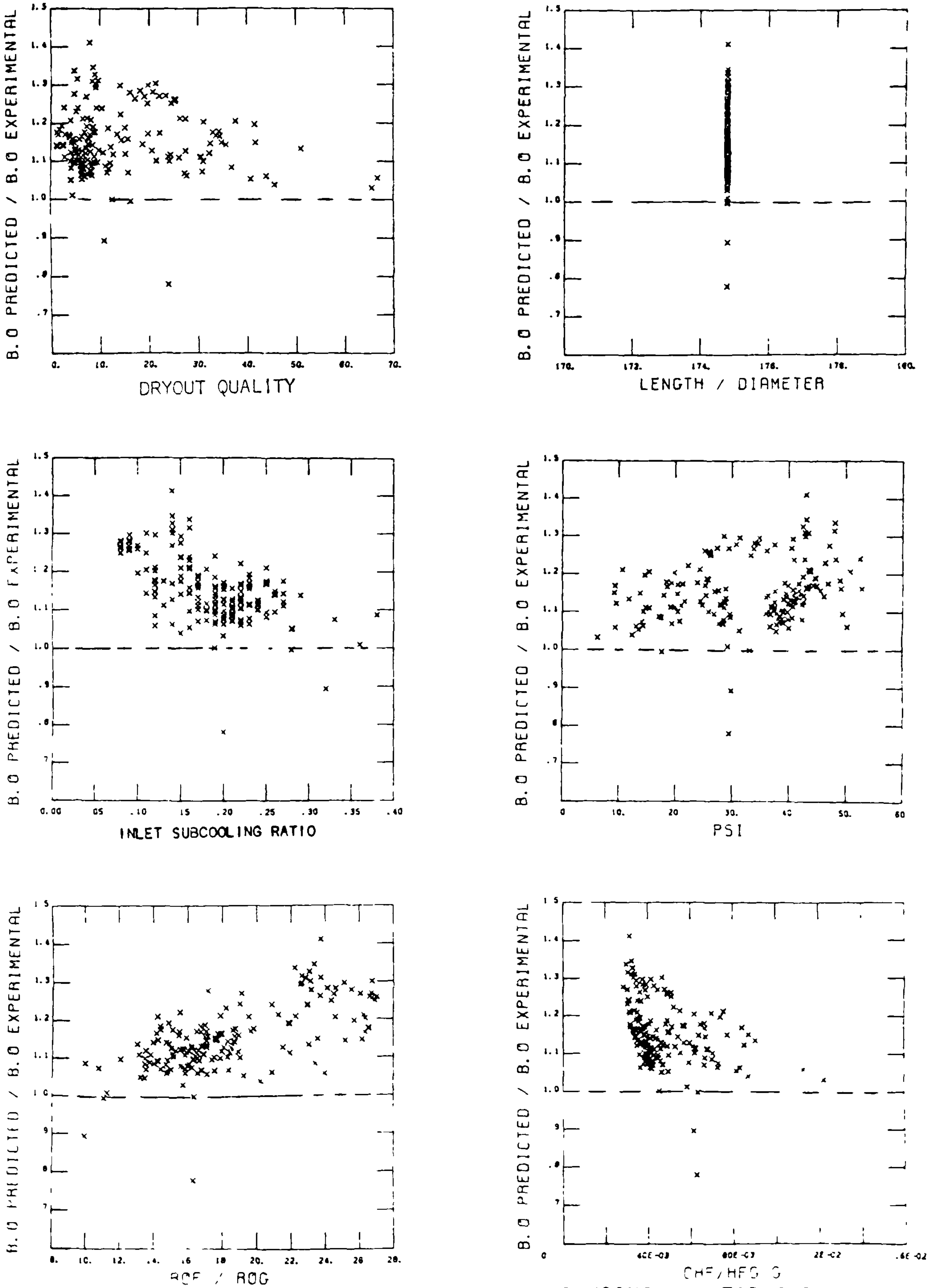

FIGURE 1. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR CARBON DIOXID

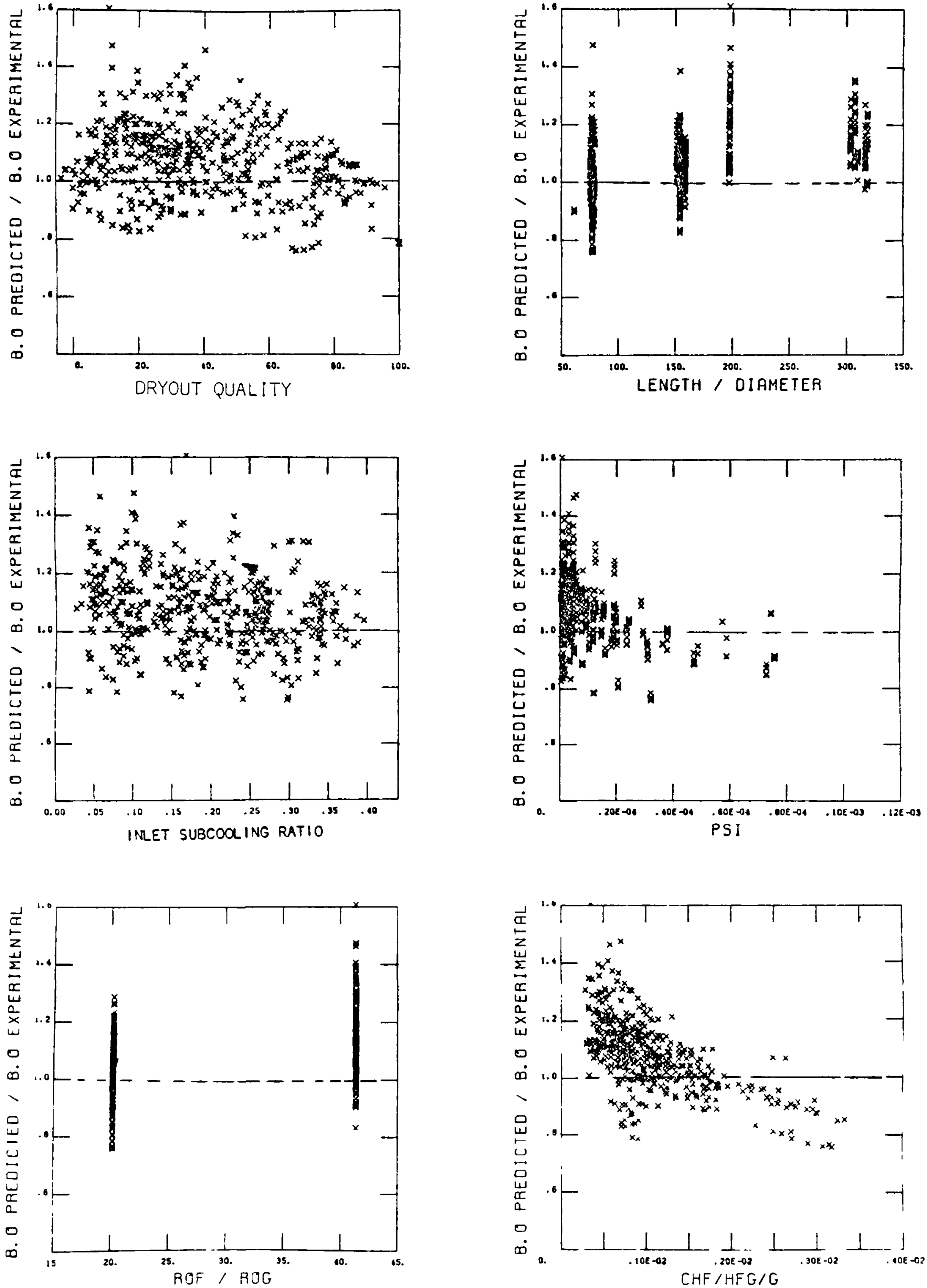

FIGURE 2. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ, FOR FREON-21

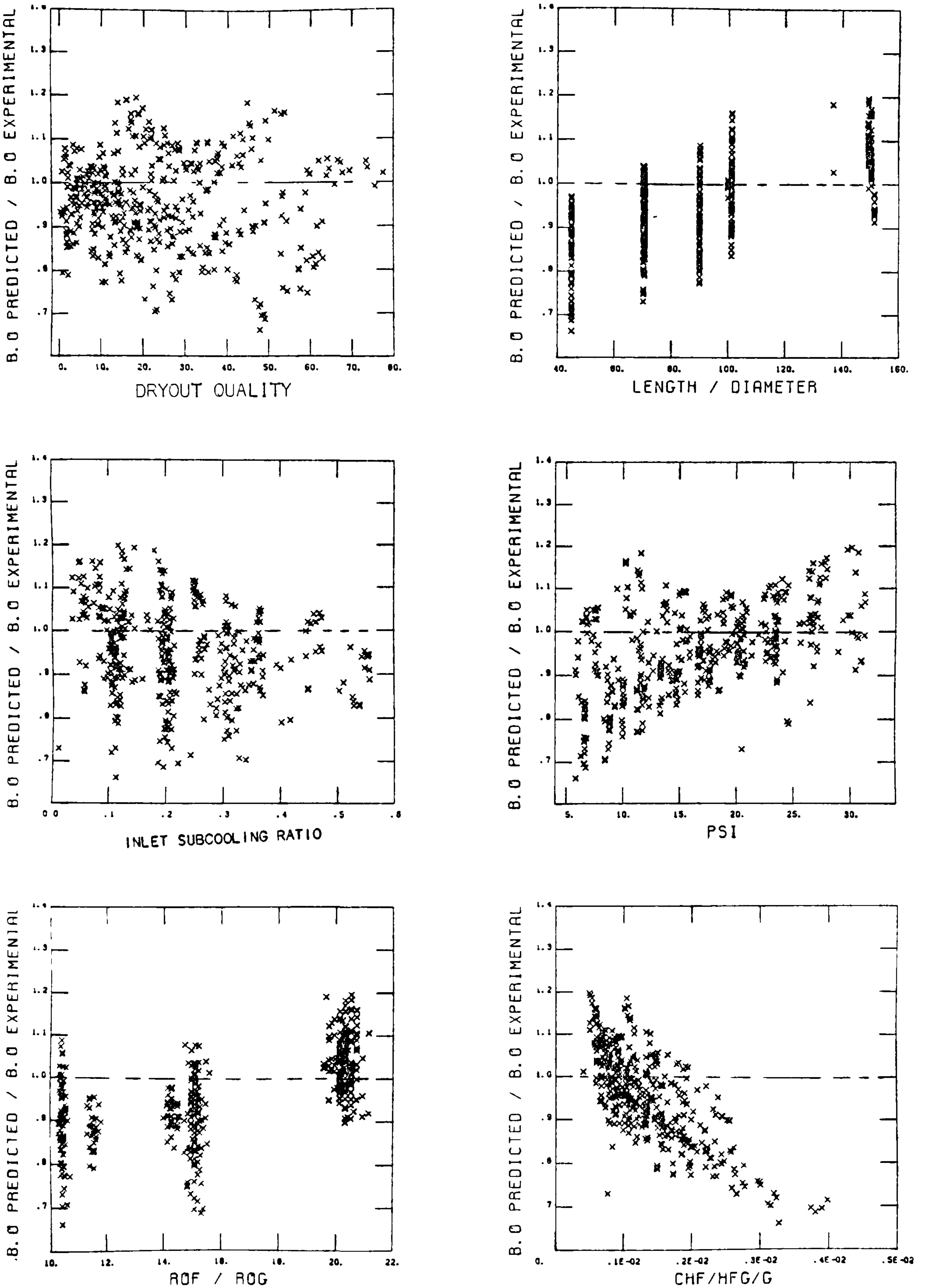

FIGURE 3. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR FREON-114

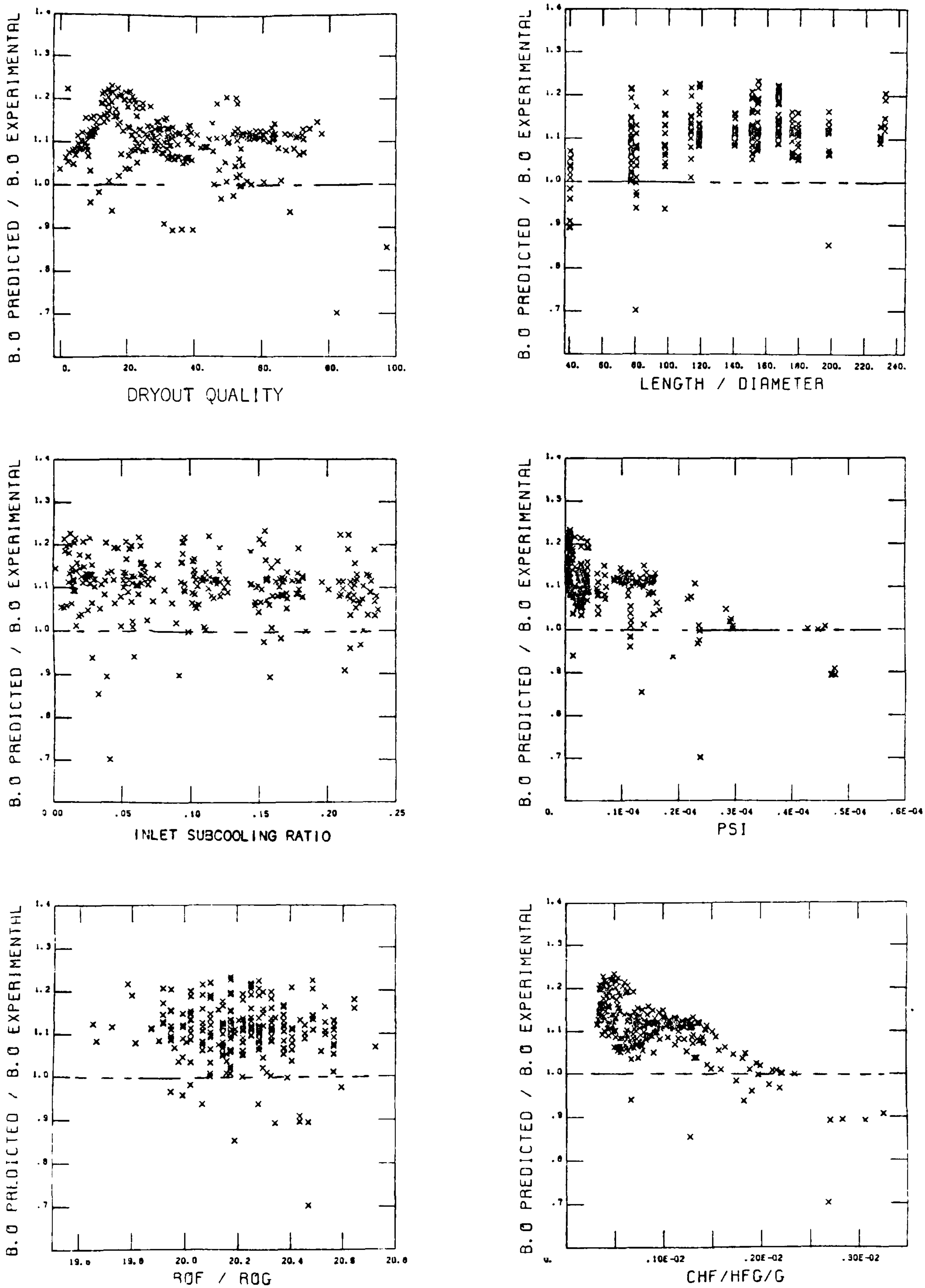

FIGURE 4. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR FREON-12

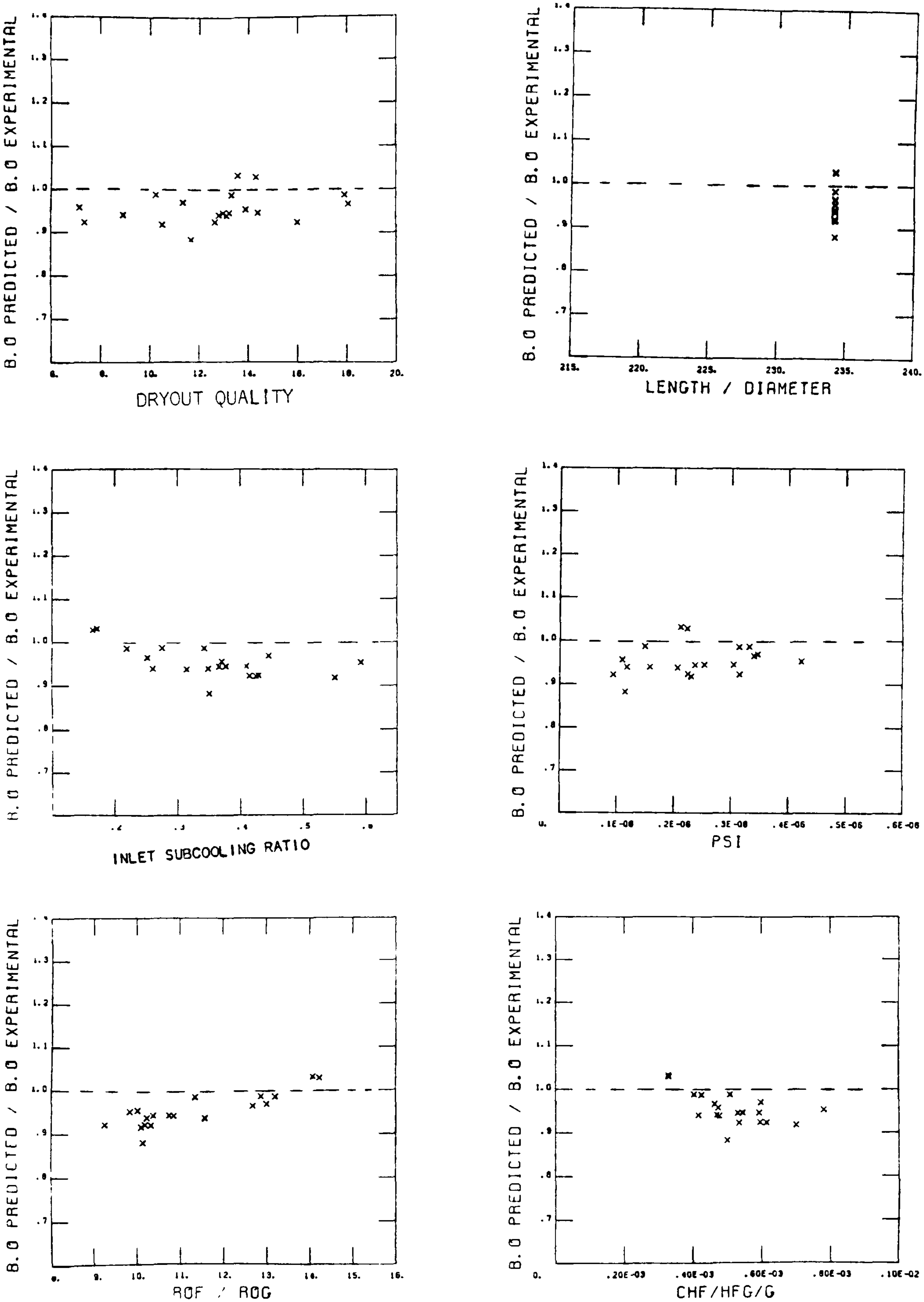

FIGURE 5. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR FREON-11

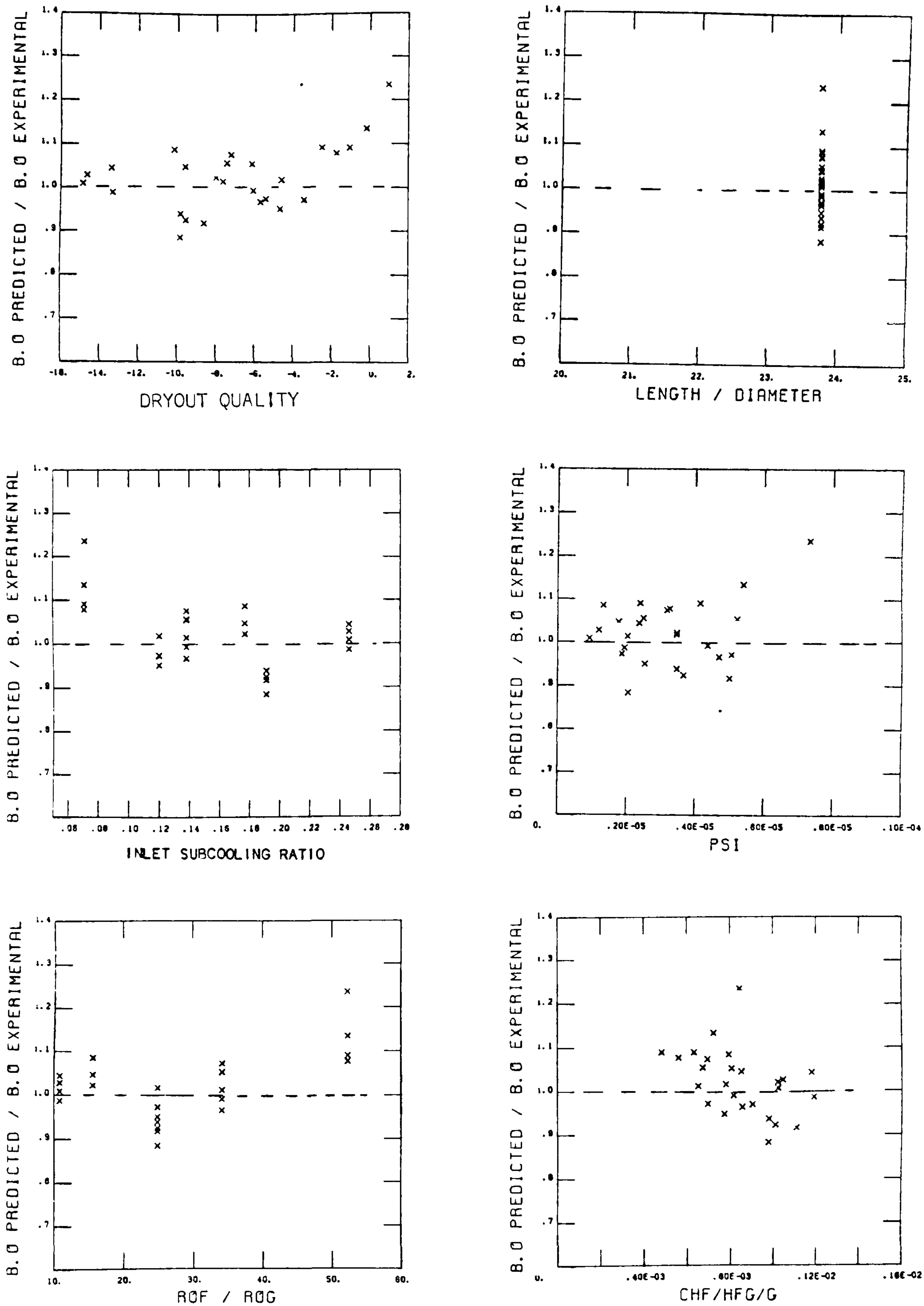

FIGURE 6. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR NITROGEN

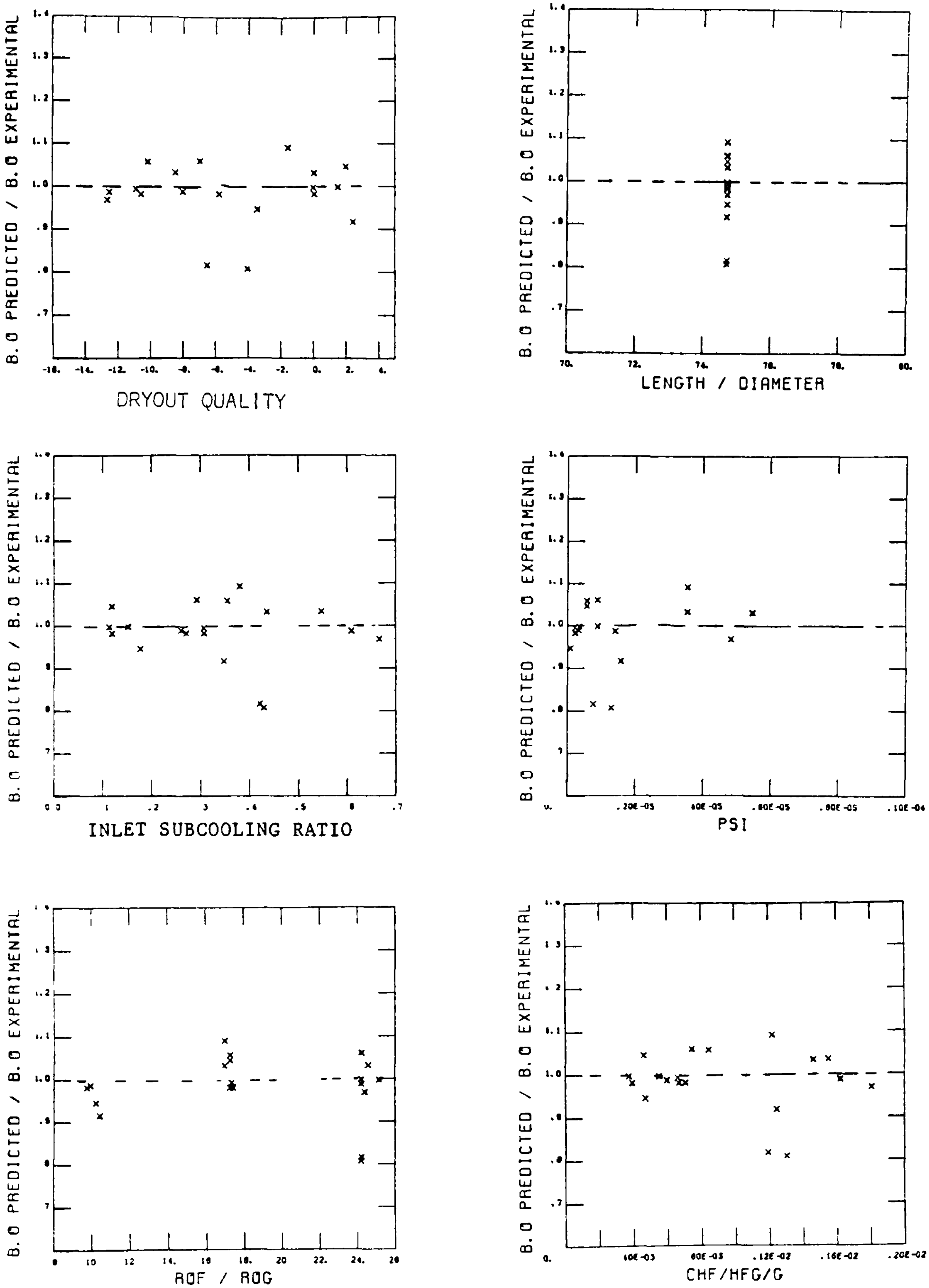

FIGURE 7. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR FREON-113

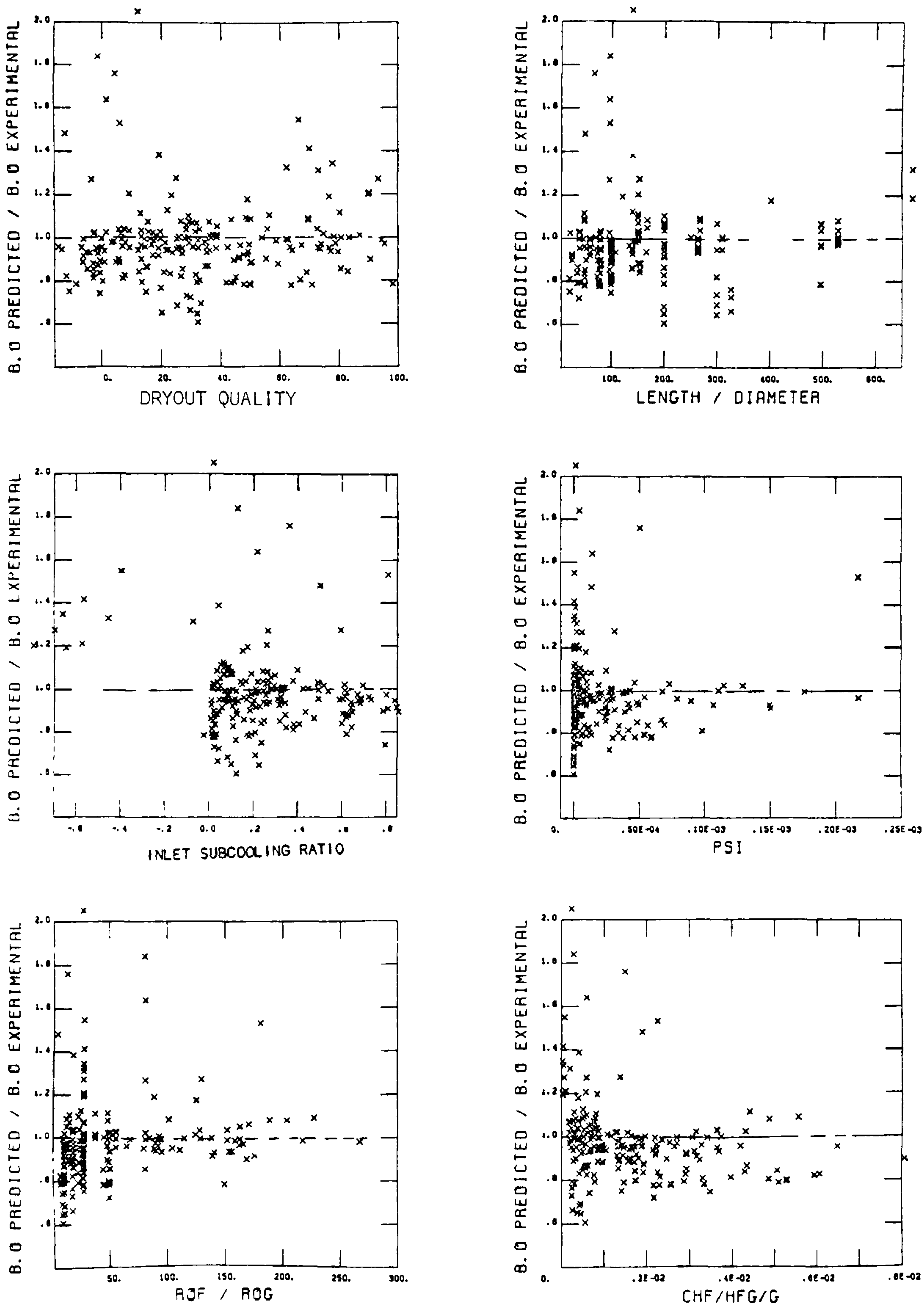

FIGURE 8. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_K FOR WATER

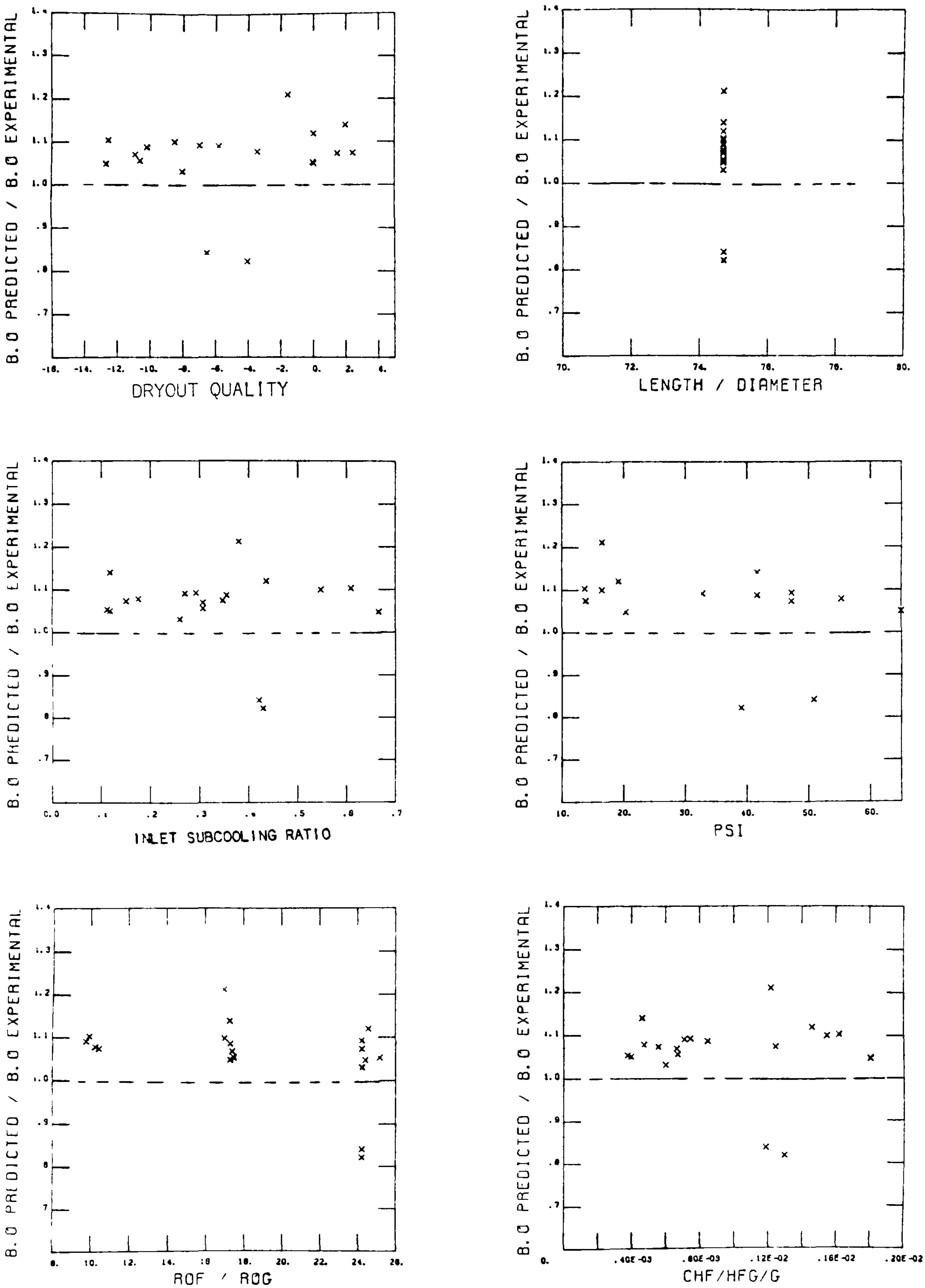

FIGURE 9. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_{γ} FOR FREON-113

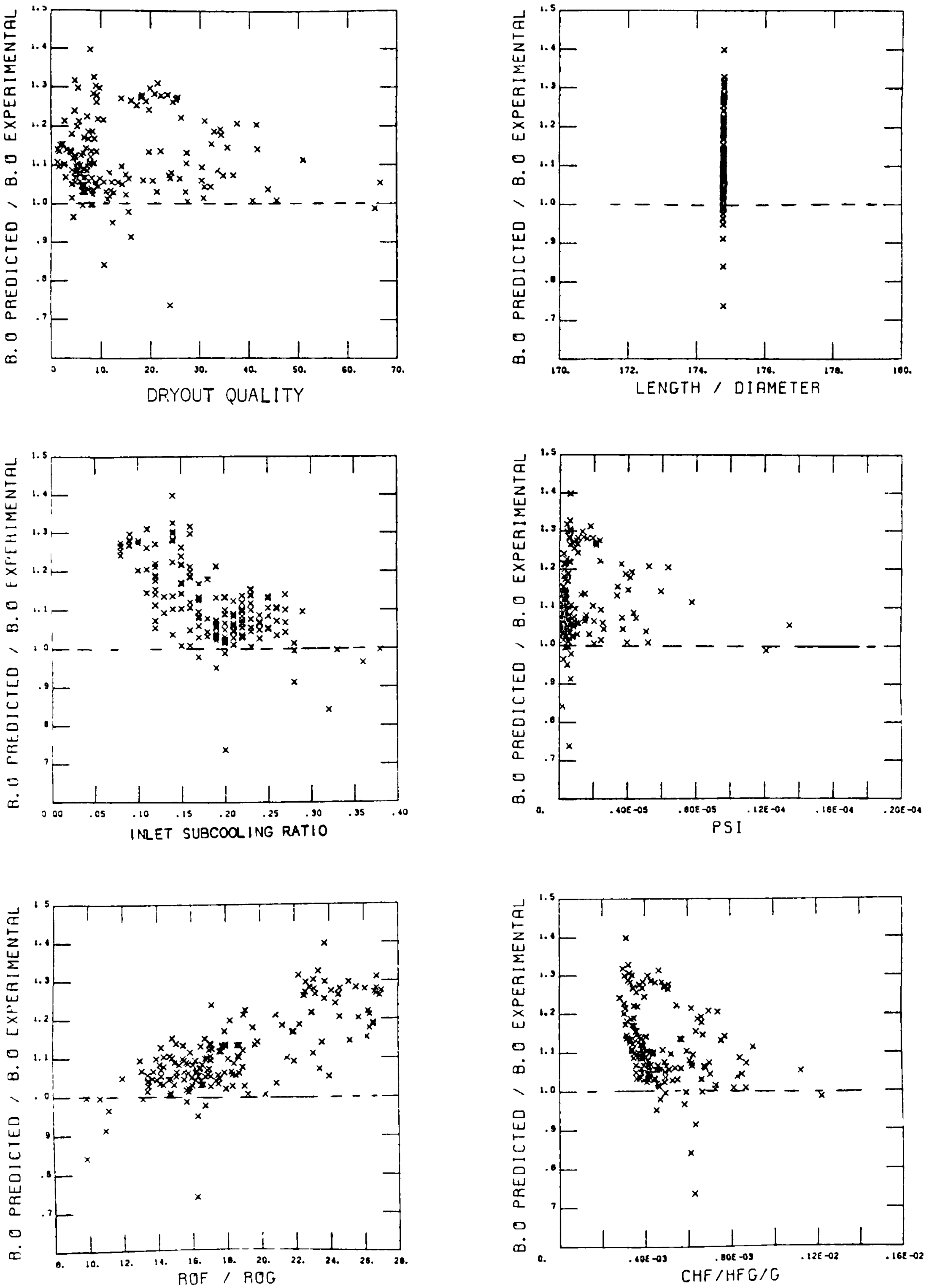

FIGURE 10. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING ψ_K FOR CARBON DIOXI

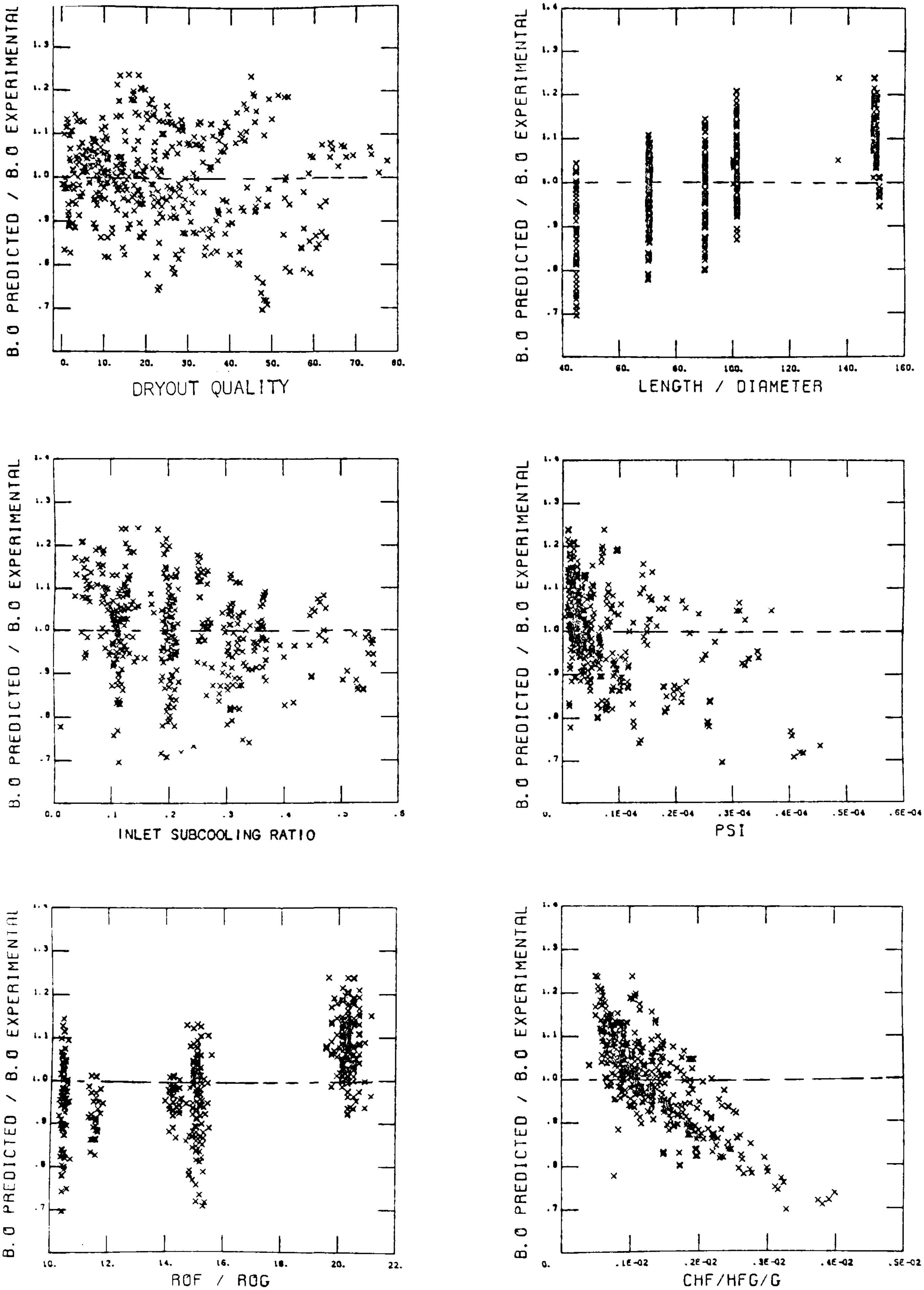

FIGURE 11. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_γ FOR FREON-114

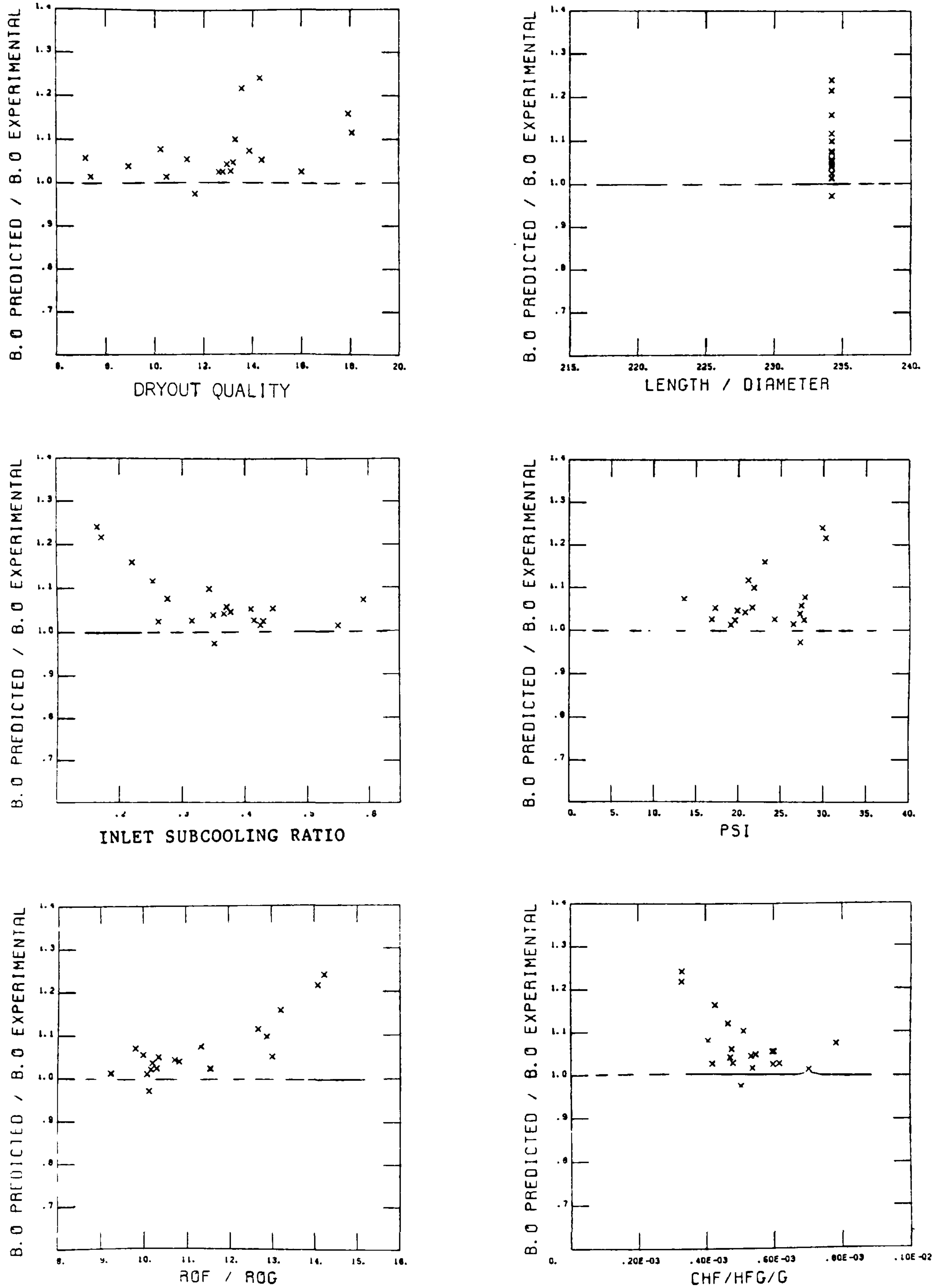

FIGURE 12. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_γ FOR FREON-11

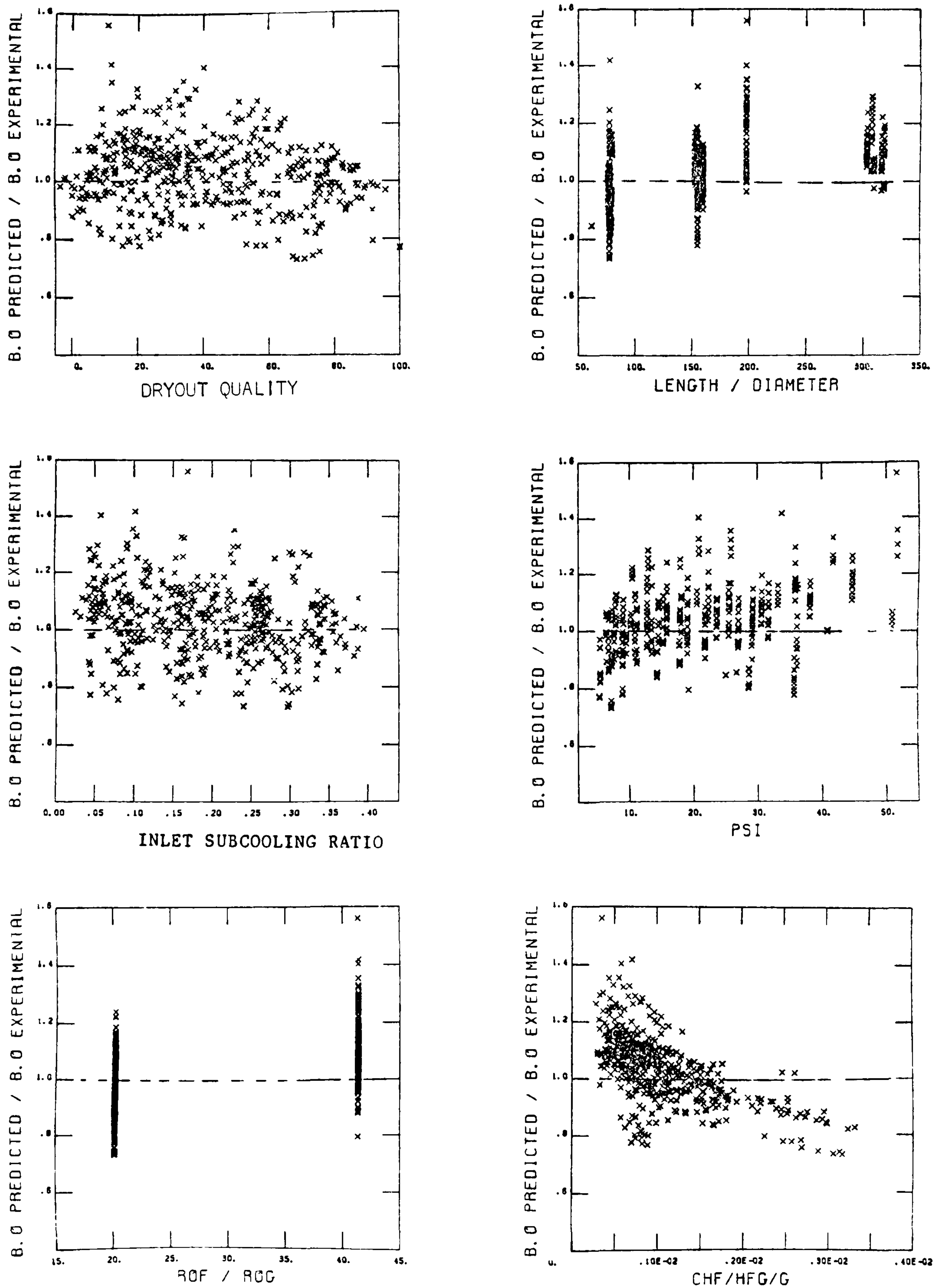

FIGURE 13. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_γ FOR FREON-21

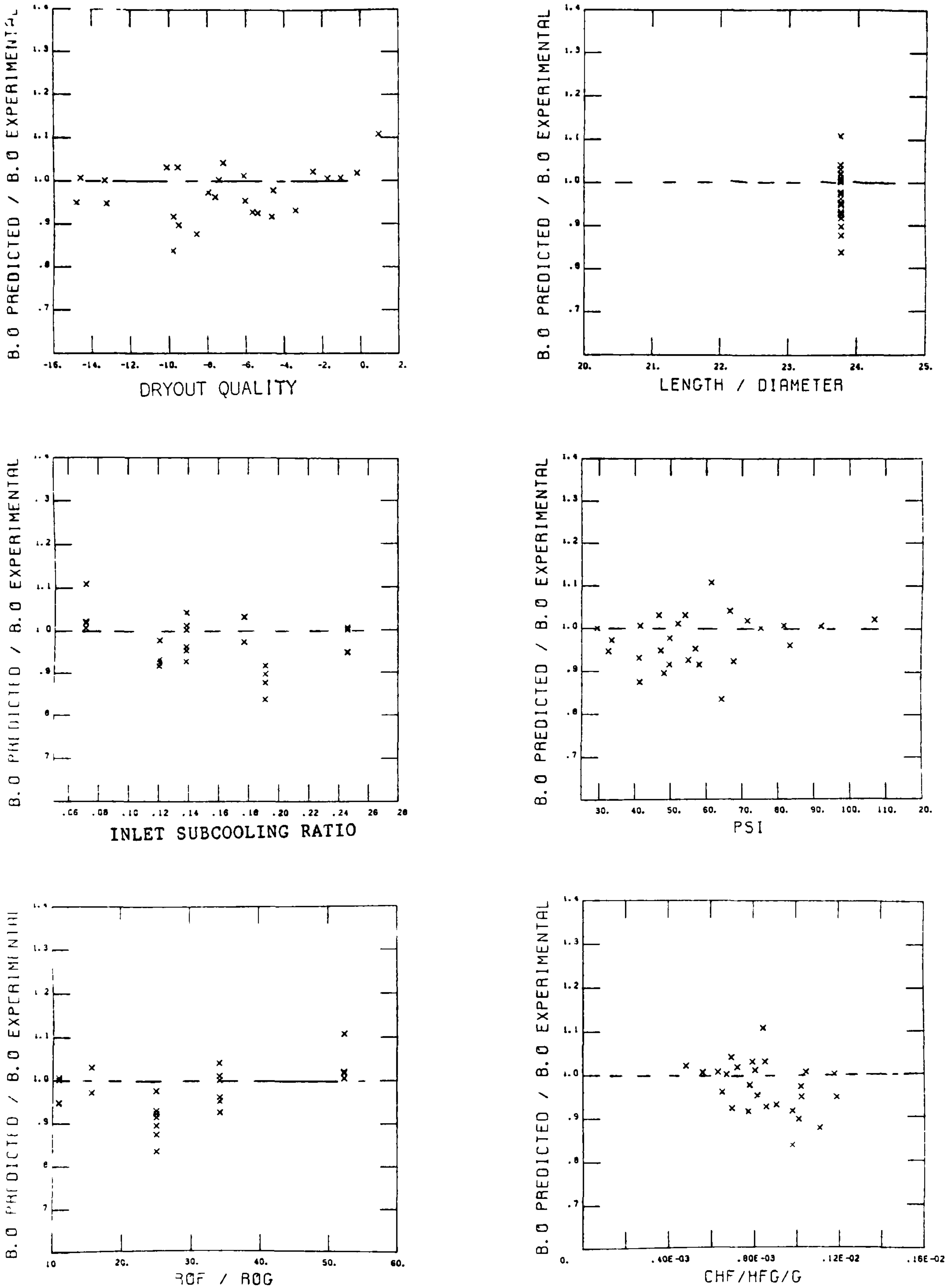

FIGURE 14. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_{γ} FOR NITROGEN

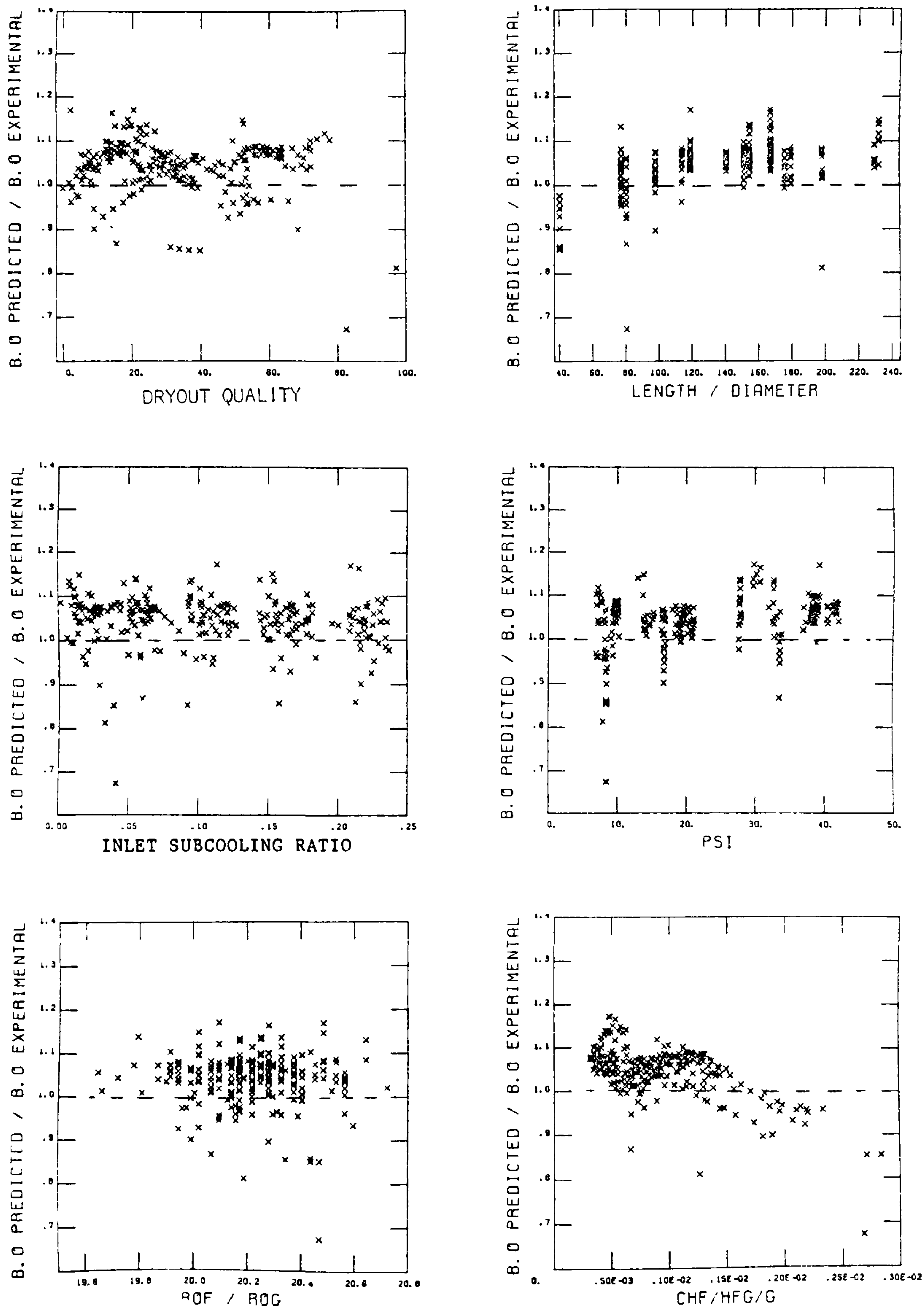

FIGURE 15. NON-DIMENSIONAL CHF TABLE PREDICTIONS USING Ψ_Y FOR FREON-12

APPENDIX J

Application of Non-Dimensional CHF Table, Katto's correlation, Hauptman's correlation, Shah's correlation and Weisman & Pei's model.

$$\mathrm{Psi} = \Psi_K = \frac{\sigma \rho_f}{G^2 L}$$

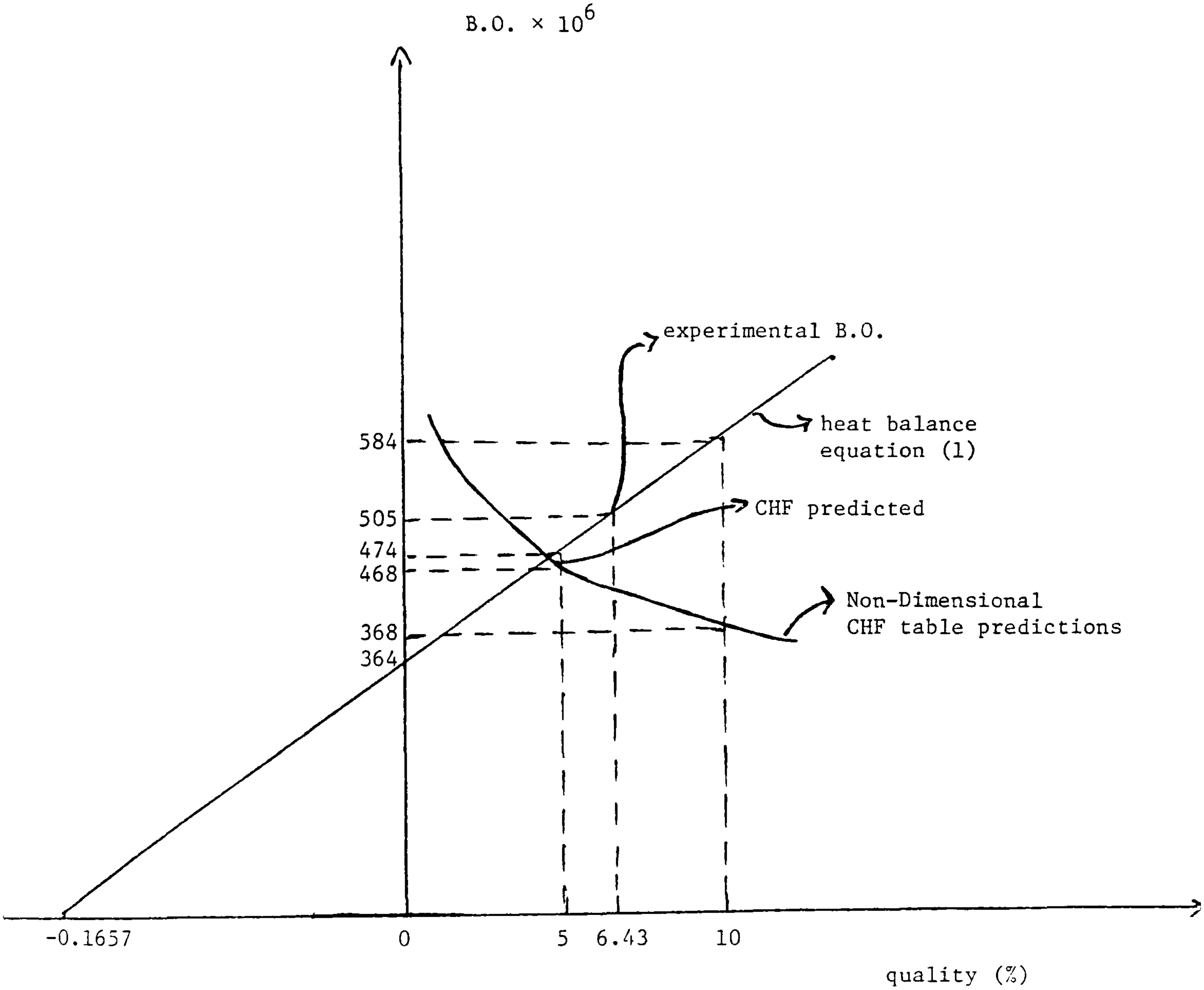

FIGURE J.1 B.O. vs. QUALITY. APPLICATION OF NON-DIMENSIONAL CHF TABLE

Fluid: Freon-12

$P = 1071.5$ kPa; $D = 0.01608$ m, $L = 1.829$ m;

$G = 2462$ Kg/m^2/s, $\Delta H_{in} = 20.8$ kJ/kg;

Experimental CHF = 156.2 kW/m^2; $x_c = 0.0643$

Physical and Thermodynamic properties were obtained from ASHRAE Handbook (1981):

$\rho_f = 1234.5$ kg/m^3; $\lambda = 125.5$ kJ/kg; $\rho_g = 61.6$ kg/m^3;

$\mu_f = 190 \times 10^{-6}$ kg/m/s; $k_f = 0.0625$ W/m°c;

$\mu_g = 1.385 \times 10^{-6}$ kg/m/s; $\sigma = 6.54 \times 10^{-3}$ N/m

Non-Dimensional Table

$$\frac{\Delta H_{in}}{\lambda} = \frac{20.8}{125.5} = 0.1657; \quad \frac{\rho_f}{\rho_g} = \frac{1234.5}{61.6} = 20.04 ,$$

$$\Psi_K = \frac{G\, D^{0.5}}{\sigma^{0.5} \rho_f^{0.5}} \quad \frac{2462 \times 0.01608^{0.5}}{(6.54\times10^{-3})^{0.5} \times (1234.5)^{0.5}} = 110 .$$

$$\frac{q_c}{\lambda G} = \frac{156.2}{125.5\times2462} = 505 \times 10^{-6}; \quad x_c = 0.0643$$

$$K_1 = \mathrm{Exp}\left(\frac{0.008}{D}\right)^{1/3} = \mathrm{Exp}\left(\frac{0.008}{0.016}\right)^{1/3} = 0.79$$

$$\alpha = \frac{x v_g}{x\ v_g + (1-x)\ v_f} =$$

$$\alpha = \frac{0.0643 \times 0.01624}{0.0643 \times 0.01624 + (0.9357) \times 0.00081} \simeq 1$$

$$K_2 = \mathrm{Exp}\left(\frac{D}{L} \times \mathrm{Exp}(2\times\alpha)\right) =$$

$$K_2 = \mathrm{Exp}\left(\frac{0.01608}{1.829} \times \mathrm{Exp}(2)\right) = 1.067$$

By applying heat balance equation:

$$x = 4 \frac{q_c}{\lambda G} \cdot \frac{L}{D} - \frac{\Delta H_{in}}{\lambda} = 4 \times BO \times \frac{1.829}{0.01608} - 0.1657$$

$$x = 455 \times BO - 0.1657 \qquad (1)$$

<u>Assume $x_c = 10\%$</u>

By interpolation

$$BO = 488 + \frac{(379 - 488)}{(123.44-98.15)} \times (110 - 98.15) = 437. \times 10^{-6}$$

apply correction factor; $BO = 437 \times 10^{-6} \times 0.79 \times 1.067$

$$\underline{BO = 368 \times 10^{-6}}$$

from equation (1). $x_c = 10\%$ then

$$\underline{BO = 583.96 \times 10^{-6}}$$

Figure J.1 illustrates the application of the non-dimensional CHF table.

Assume $x = 5\%$ By interpolation

$$B.O. = 620. + \frac{(479 - 620)}{(123.4-98.75)} \times (110 - 98.75) = 555.6 \times 10^{-6}$$

apply correction factors: $B.O. = 555.6 \times 10^{-6} \times 0.79 \times 1.067$

$$\underline{B.O. = 468.4 \times 10^{-6}}$$

from (1) at $x = 5\% = \underline{B.O. = 47.4 \times 10^{-6}}$

by interpolation $\underline{B.O. = 47.0 \times 10^{-6}}$

$$CHF_{pred} = 470 \times 10^{-6} \times 125.5 \times 2462 = 145.22 \text{ kW/m}^2$$

$$\underline{CHF_{pred} = 145.22 \text{ kW/m}^2}$$

$$\frac{CHF_{pred}}{CHF_{exp}} = \frac{145.22}{156.2} = 0.9297$$

$$\text{Error} = \frac{145.22 - 156.2}{156.2} \times 100 = -7\%$$

Summary of CHF Prediction using Non-Dimensional Table (Ψ_K), Katto's correlation, Weisman & Pei's model, Shah's correlation and Hauptmann's correlation.

Correlation/Model	$\frac{CHF_{pred}}{CHF_{exp}}$	% Error
Non-Dimensional CHF table using Ψ_K	0.9297	- 7.0
Weisman & Pei's model	1.1246	12.46
Shah's correlation	0.88348	-11.65
Hauptmann's correlation	0.768	-23.17
Katto's correlation	1.126	12.67

$$\% \text{ Error} = \frac{CHF_{pred} - CHF_{exp}}{CHF_{exp}} \times 100$$