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**AN INVESTIGATION OF THE EFFECT OF
FLOW OBSTRUCTIONS ON CRITICAL HEAT FLUX,
PRESSURE DROP AND HEAT TRANSFER**

by

D.A. Vaitekunas

A dissertation submitted to the Faculty of Graduate and Postdoctoral Studies
of the Ottawa-Carleton Institute for Mechanical and Aerospace Engineering
at the University of Ottawa in partial fulfilment of the requirements for the
degree of Doctor of Philosophy in Mechanical Engineering

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ABSTRACT

A series of single-phase and two-phase flow experiments were conducted to investigate the effect of flow obstructions on heat transfer, pressure drop, and critical heat flux inside an 8 mm tube. A novel technique of positioning flow obstructions using an external magnetic ring was used to vary the type, spacing, and number of obstacles. Experiments on a single 18%-area and 30%-area ring in liquid Freon-134a show a maximum increase in heat transfer of 10% to 60% at the flow obstacle, and an exponential decay in relative enhancement over 5 to 10 diameters downstream. The associated pressure drop for the 18% ring and 30% ring show a head loss coefficient of 0.12 and 0.26, respectively. A total of 755 CHF data points were obtained for both 30% rings and 3×6% area square blockages in Freon-134a and Freon-22. Relative increases of 60% to 100% were obtained in CHF for the same local quality, and 20% to 50% for the same inlet temperature. The results show an exponential rise in CHF with decreased spacing from the exit. There was no accumulative effect (at the exit) when more than 1 obstacle was used to increase CHF, and no decrease in nominal CHF was observed.

Analytical models of dryout in annular flow were implemented using an object-oriented framework to simulate the effect of various flow enhancement mechanisms on CHF. Numerous reference tube models were assessed for use in enhancement model analysis. Detailed analysis of liquid film stripping, droplet impingement, and mass transfer enhancement using the models of Whalley et al. (1974), and Hewitt and Govan (1990) show that droplet impingement and mass transfer enhancement are the most likely causes of increased CHF. A 10% to 30% run-off of the entrained liquid impinging on the flow obstruction surface is enough to produce a maximum increase of 20% to 50% in predicted CHF for the same inlet temperature. Subsequently, increases in mass transfer up to 150% to 180% over 30 to 50 diameters are necessary to produce the same CHF enhancement. A different set of flow enhancement parameters were required for each inlet condition, given the complex nature of flow around the obstacle, current limitations in the reference models, and the analytical equivalency between both droplet impingement and mass transfer enhancement. Several recommendations are made for further research in the areas of reference tube modelling, flow visualization, obstacle modelling, and object-oriented simulation.

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NOMENCLATURE

Variables:

a_t	centrifugal acceleration (m/s ²)
A	surface or flow area (m ²)
AT	outer wall perimeter and wall-to-ambient temperature difference integrated over the length of a channel (m ² ·°C)
C	droplet concentration (kg/m ³)
C_E	equilibrium concentration (kg/m ³)
C_p	specific heat (J/kg·°C)
d	tube diameter (m)
D	deposition rate (kg/m ² ·s)
e	roughness height (m)
E	entrainment rate (kg/m ² ·s)
f	friction factor
G	mass flux (kg/m ² ·s)
g	gravitational constant (9.81 m/s ²)
h	heat transfer coefficient (W/m ² ·°C)
Δh_{eq}	equivalent wave-height (m)
H	channel height (m)
H'	correlated obstacle height (m)

i	enthalpy (J/kg)
k	repeated roughness height (m) or mass-transfer coefficient (m/s)
K	thermal conductivity (W/m·°C), head-loss coefficient or simple proportionality constant
L	channel or tube length (m)
N	number of data
N_{obs}	number of flow obstructions
p	roughness pitch (m)
P	pressure (Pa) or wetted perimeter
ΔP	pressure drop (Pa)
q	heat flux (W/m ²)
r	radius (m)
R_{Nu}	relative Nusselt number ratio
R_{CHF}	relative CHF ratio
s	streamline (m)
S	analog signal
SP	flow obstruction spacing (m)
T	temperature (°C)
u	local velocity (m/s)
U	free-stream velocity (m/s)
V	superficial velocity (m/s)
w	obstruction width (m)
W	perimeter (m)
x	horizontal axial distance (m), vapour quality, or ratio signal
y	lateral distance (m)
z	vertical axial distance (m)
α	void fraction or thermal diffusivity (m ² /s)
β	delta-winglet angle of attack (°)

Γ	volumetric mass-transfer rate ($\text{kg/m}^3\cdot\text{s}$)
δ	film or boundary layer thickness (m)
ϵ	blockage area ratio
ϵ_M	turbulent eddy viscosity (m^2/s)
ϵ_s	equivalent sand roughness (m)
η	heat transfer performance index or spacer mixing parameter
θ	centrifugal acceleration ratio
λ	Darcy friction factor
λ	mass diffusivity (m^2/s)
μ	fluid dynamic viscosity ($\text{kg/m}\cdot\text{s}$)
ν	kinematic viscosity (m^2/s)
ρ	fluid density (kg/m^3)
σ	surface tension (N/m)
τ	shear stress
v	specific volume (m^3/kg)

Non-dimensional Numbers:

Le	Lewis number (α/λ)
Nu	Nusselt number (hL/K)
Pr	Prandtl number ($\mu C_p/K$)
Re	Reynolds number ($\rho u L/\mu$)
S	surface Weber number ($\tau \delta/\sigma$)
Sc	Schmidt number (ν/λ)
Sh	Sherwood number (kd/λ)
St	Stanton number ($h/\rho C_p u$ or k/u)
X	Lockhart-Martinelli parameter ($\Delta P_{F,l}/\Delta P_{F,g}$)
ϕ	two-phase multiplier ($\Delta P_{F,TP}/\Delta P_{F,lo}$)

Correlating Parameters:

(K, B)	universal velocity profile (White, 1991)
ΔB	downward shift parameter (Clauser, 1956)
C	Lockhart-Martinelli correlating constant (Chisholm, 1967)
(F, g)	regular roughness fitting functions (Webb et al., 1971)
(β, z)	head loss correlation (Idel'chik, 1966)
(a, b)	CHF correlation constants (Doerffer et al., 1995)
$(n_1, n_2, \dots, n_5)$	CHF correlation exponents (Doerffer et al., 1995)
n	exponent for diameter effect on CHF (Groeneveld et al., 1986)
(A, m, b)	equilibrium concentration correlation (Hutchinson and Whalley, 1973)
(A_1, b_1)	entrainment correlation (Hewitt and Govan, 1990)
(A_2, b_2)	critical film flow (Hewitt and Govan, 1990)
(ϕ, ψ)	grid-spacer amplitude and decay constants (Tong, 1975)
K_{strip}	portion of liquid-film stripped away at obstacle
K_{depos}	portion of entrained liquid deposited on the wall at obstacle
(A_o, b)	heat/mass-transfer enhancement (amplitude and decay rate)

Subscripts:

av	average
avg	average
b	fluid properties pertaining to the bulk fluid temperature (single-phase)
c	core, CHF or characteristic
crit	critical angle of attack for flow separation
e	hydrodynamic equivalent
eff	effective
f	bulk fluid temperature
film	single-phase film temperature $T_{\text{film}} = (T_w + T_f)/2$
F	frictional
g	vapour

gc	vapour core
go	all vapour
i	interfacial or input
in	inlet
l	liquid
lam	laminar
lE	entrained liquid
lF	liquid film
lFC	critical liquid-film flow
lg	difference between saturated liquid and vapour
lo	al liquid
max	maximum allowable
min	minimum allowable
mix	mixture
no-tape	without twisted tape
o	outer or nominal
oaf	at OAF
obs	with obstacle
out	outlet
peak	peak film thickness location
R	ribbed-wall
ref	without obstacle
s	smooth
sat	saturated
sg	spacer-to-gas
sp	spacer
tape	with twisted tape
turb	turbulent
TP	two-phase

vap	evaporative
w	wall
∞	free-stream

Superscripts:

*	standard spacer configuration
+	non-dimensional

Modifiers:

$\diamond$	average mixture quantity
$\bar{}$	cross-section average quantity

Abbreviations:

BWR	boiling water reactor
CHF	critical heat flux
ID	inner diameter
OD	outer diameter
OAF	onset of annular flow
RMS	root mean square

Chapter 1 INTRODUCTION

1.1 Background

Many industrial processes rely on two-phase flow and heat transfer as an efficient method of heat removal and energy transport. Some examples are refrigeration, air-conditioning, heat pipes, electric power, hydrocarbon and chemical refining. The design of two-phase flow systems is governed by three parameters:

- rate of heat transfer - single-phase or two-phase, forced or natural circulation,
- critical heat flux (CHF) - a condition whereby a small increase in heat flux gives rise to a significant deterioration in the heat transfer between fluid and heated surface,
- pressure drop - the losses associated with viscous dissipation and form losses (e.g., flow obstructions), particularly in forced circulation systems.

CHF is often associated with large and rapid excursions in the temperature of the heated surface, which can lead to detrimental effects referred to as “burnout” or “boiling crisis”. “Departure from nucleate boiling” (DNB) and “dryout” are terms used to describe the underlying flow and heat-transfer mechanisms of this phenomena. Critical Heat Flux or CHF is a more general term for the phenomena and makes no specific inference to its nature or consequence.

Even though a system is designed to operate under single-phase flow conditions, the evaluation of CHF may be required in the event of an accident. One such system is the CANDU Pressurized Heavy Water (CANDU-PHW) nuclear reactor, illustrated in Figure 1.1. The CANDU reactor employs single-phase heavy-water as both moderator and primary coolant in the reactor core. The pressurized heavy-water circulates through a steam generator and transfers heat to light-water flowing in a secondary loop, which is then converted to steam to feed the turbine generators. The design of this subcooled/low-quality (mostly single-phase) fuel channel minimizes heavy-water losses and the high costs associated with its production (\$300/kg in 1987 according to Knief, 1992).

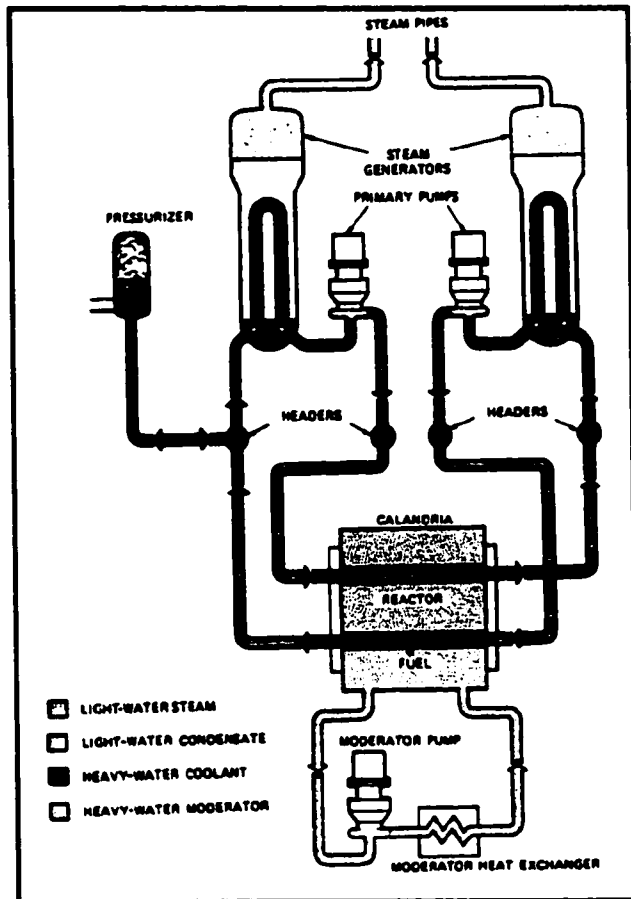


Figure 1.1: Simplified steam-cycle schematic for the CANDU-PHW system, adapted from Knief (1992) with permission of Atomic Energy of Canada Limited.

However, the evaluation of CHF plays a critical role in establishing the safe operating limit of the reactor in terms of a thermal margin (the difference between operating power and critical channel power or CCP). Alternatively, boilers and boiling water reactors (BWR) operate on a once-through cycle, employing two-phase light-water as both primary coolant and source of steam for the turbine generators. In these systems, a more direct relation exists between CHF and the safe operating (non-dryout) limit of the system.

1.2 CHF Mechanisms

Numerous CHF mechanisms have been postulated depending on the flow conditions and geometry of boiling. These can be classified into four categories:

- pool boiling
- low quality or subcooled internal flow boiling
- high quality internal flow boiling
- external boiling in crossflow

Pool boiling refers to boiling in a quiescent pool of fluid where, following the work of Zuber (1959), CHF is assumed to occur as a result of hydrodynamic instability in the vapour-liquid interface. As the heat flux is increased, the nucleate vapour bubbles, leaving the heated surface coalesce to form evenly-spaced vapour columns. Eventually, the vapour production becomes so large that the liquid surface tension, maintaining the stability in the liquid-vapour interface, can no longer sustain the dynamic pressure forces of the vapour velocity and the columns breakdown. At this point, the heated surface becomes blanketed with a vapour film, reducing heat transfer to that of film-boiling. This phenomena is commonly termed departure from nucleate boiling (DNB). The hydrodynamic theory of Taylor waves and Kelvin-Helmholtz instabilities are combined with empirical correlations for nucleate pool boiling heat transfer to model CHF (Whalley, 1990). Haramura and Katto (1983) extended the work of Zuber (1959) and the experimental observations of several other experimenters to model the DNB of such finite bodies as horizontal cylinders and ribbon tape, in both pool boiling and flow boiling, taking into account the inflow conditions of the liquid to the heated surface.

In flow boiling, the situation is somewhat more complex because of the various flow regimes and transitions that can occur along the boiling length. Some of these, illustrated in Figure 1.2, are described as follows:

- bubbly flow – flow is principally liquid with evenly-dispersed and uniformly-sized vapour bubbles,
- plug (slug) flow – vapour flows as large bullet-shaped bubbles,

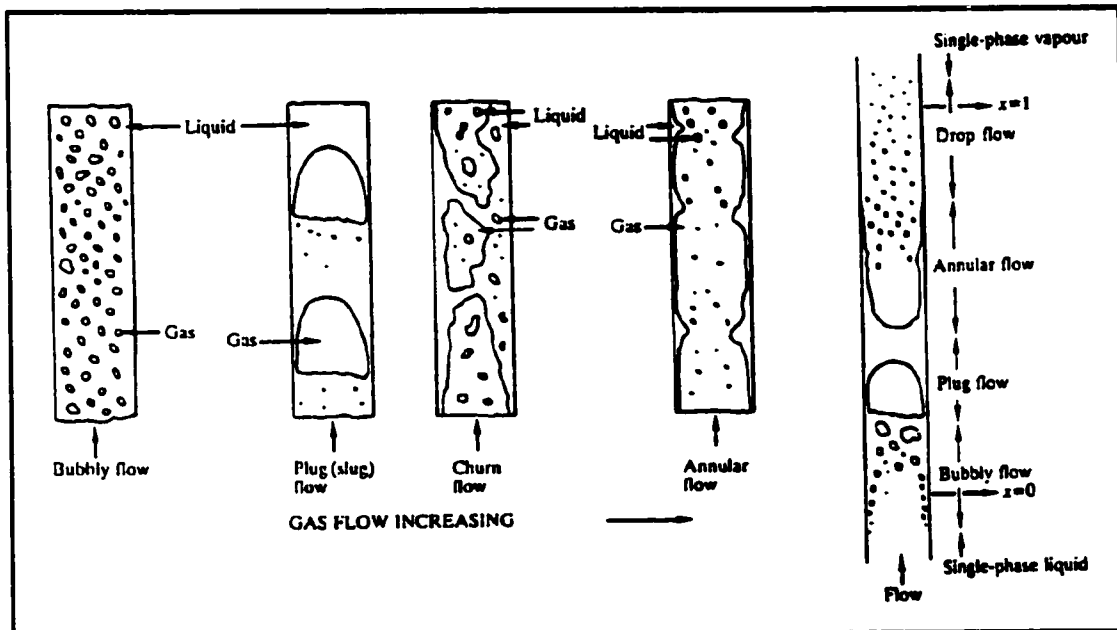


Figure 1.2: Flow patterns in an evaporating flow, adapted from Whalley (1990) with permission of Oxford University Press.

- churn flow - highly unstable flow of an oscillatory nature with liquid near the wall continually pulsating up and down,
- annular flow – liquid film covering the wall with vapour and dispersed liquid droplets flowing in the central core,
- droplet flow – flow is principally vapour containing evenly-dispersed liquid droplets.

Although other flow patterns may exist, depending on the orientation and flow conditions (e.g., horizontal stratified or slug flow), they are beyond the scope of this discussion. The flow inside the CANDU fuel channel is horizontal, but for the range of mass flux considered in this study, the flow can be assumed to be either homogeneous or annular.

For low quality internal flow boiling, pertaining to the bubbly flow and plug flow regimes, various CHF mechanisms have been postulated. According to Weisman (1992), early attempts at modelling CHF in flow boiling concentrated on the same underlying mechanism as

in pool boiling. However since then, many theoretical and correlating methods have been developed:

- DNB occurs as the thin liquid sub-layer beneath the bubbly layer reaches a critical superheat (Tong et al., 1965),
- inhibition of enthalpy transport to the bubbly layer due to flow separation of the liquid and bubbly layers (Kutateladze and Leontev, 1966; Hancox and Nicoll, 1973),
- blockage of the liquid flow to the wall by the vapour flow from the wall (Bergelson, 1980; Smogalev, 1981),
- dryout of the liquid sub-layer beneath vapour clots flowing along the wall (Lee and Mudawar, 1988; Katto, 1990),
- bubble coalescence in the bubbly layer due to inadequate vapour removal at the edge of the bubbly layer (Hebel et al., 1981; Weisman and Pei, 1983).

In the plug and slug flow region, the above mechanisms are somewhat more pronounced given the large size of the vapour clots. Fiori and Bergles (1970) observed that CHF was associated with the passage of vapour plugs and resulted from the evaporation of the thin liquid layer beneath the vapour plug. They observed fluctuations in surface temperature during the momentary dryout of the vapour passage. These fluctuations grew in amplitude and the temperature level increased rapidly when the wall temperature exceeded a postulated maximum value for re-wetting. At low flow and low pressure, Mishima and Ishii (1982) and El-Genk et al. (1988) associated CHF with the transition from different flow regimes: annular to annular mist (dryout), churn to annular, and slug to churn.

For high quality internal flow boiling, the flow is normally assumed to be annular. A widely accepted CHF mechanism is the depletion of a liquid film or "dryout". Dryout results from the combined evaporation and entrainment of the liquid film and is counteracted by turbulence-induced deposition of entrained droplets. In this regime, the emphasis has been to

accurately model the mass transfer mechanisms governing entrainment and deposition in order to predict the dryout location and CHF.

In external boiling, vapour is generated on the outer surface of rods or tubes, as illustrated in Figure 1.3. Normally, a vapour cavity appears in the wake of the cylinder, reducing the amount of cooling liquid reaching the back of the cylinder, and eventually inducing CHF. Examples of external boiling are the horizontal kettle and thermosiphon reboilers used to provide vapour in the distillation process of chemical refining. A number of heated cylinders are grouped together to form a tube bank, and the fluid is evaporated on the outside of the tubes. Whether the tube bank is in pool boiling (kettle), natural circulation

(thermosiphon), or forced convective boiling, the heat transfer and CHF of the downstream cylinders are augmented by the flow around the upstream cylinders. This results in the use of bundle correction factors ($F_b > 1$), the first cited example of heat transfer and CHF enhancement (Thome, 1990).

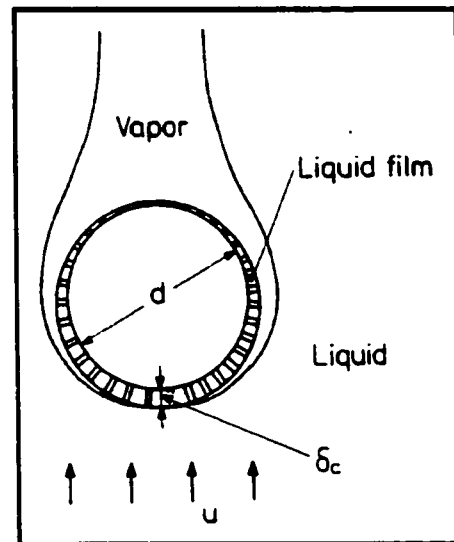


Figure 1.3: Forced convective boiling on a cylinder in cross flow, adapted from Haramura and Katto (1983) with permission of Elsevier Science.

Internal flow boiling within a CANDU nuclear fuel bundle, as illustrated in Figure 1.4, is also enhanced by the presence of various flow obstacles. Although the bundle CHF is lower than that of a hydrodynamic equivalent circular tube ($d=d_e$), according to Groeneveld et al. (1992), heat transfer and CHF are increased locally in the subchannel from higher turbulence levels within the small inter-element gaps, and from cross-flow between adjacent subchannels. Turbulence levels are also increased everywhere in the bundle by upstream flow obstructions such as end-plates, bearing pads, and inter-element spacers. The enhancement associated with these devices has led to the addition of extra flow obstructions to the fuel bundle in the form of

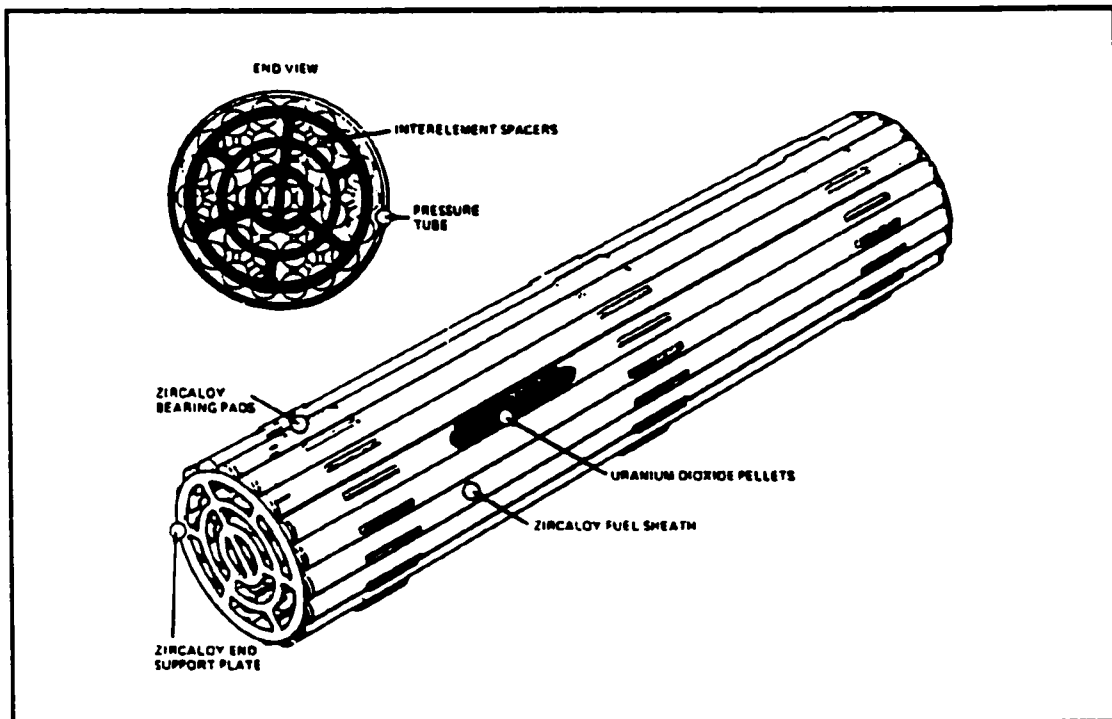


Figure 1.4: Fuel assembly for a representative CANDU-PHW, adapted from Knief (1992) with permission of Atomic Energy of Canada Limited.

appendages. For the design of these enhanced fuel bundles, the challenge is to optimize the shape and location of the appendages in order to maximize CHF, while minimizing the costs associated with manufacturing and increased pumping.

Each type of nuclear reactor has its own specific fuel bundle design. Groeneveld and Yousef (1980) classified the various rod spacing devices into six types, as illustrated in Figure 1.5. Given the tight lattice arrangement of the CANDU-PHW fuel bundle, the spacing devices are limited to the wear-pad and plate-type (end-plate) spacers. These differences in flow channel geometry and the positioning of spacing devices are important when considering the experimental and modelling results for a specific type of nuclear fuel-rod bundle.

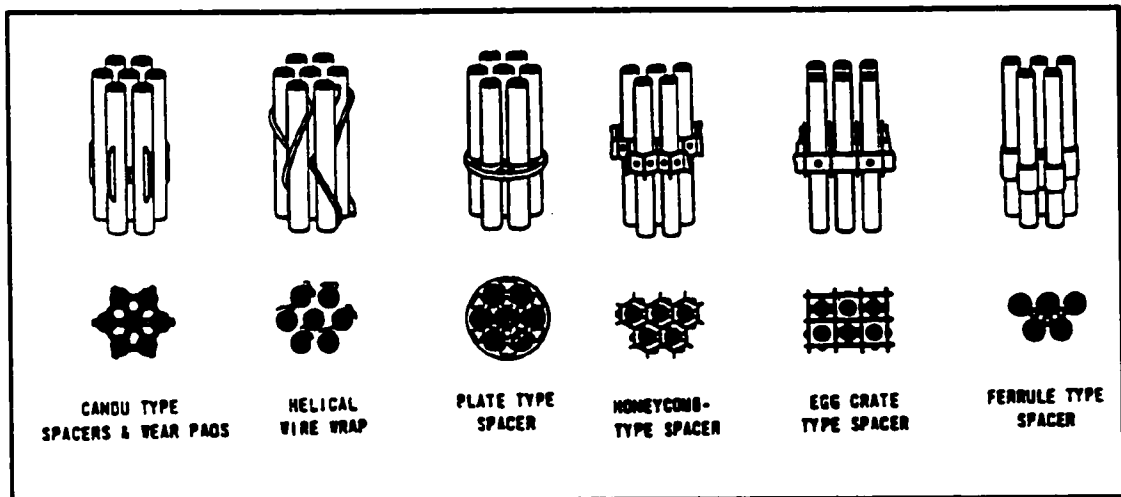


Figure 1.5: Types of rod spacing devices, adapted from Groeneveld and Yousef (1980) with permission of D.C. Groeneveld.

1.3 Enhancement Technology

Before surveying the literature on heat transfer and CHF enhancement and associated pressure losses, it is important to classify the various devices and techniques used to enhance heat transfer surfaces. This will define the physical characteristics and operating mechanisms of each device and emphasize technologies relevant to the current study. Enhancement techniques are classified as either active or passive: passive techniques enhance flow mechanisms already present in the fluid, while active techniques introduce other enhancement mechanisms through an external source.

In pool boiling, the passive techniques employed are:

- surface pitting (corrosive chemicals)
- porous surface coatings
- dendritic surface scaling
- non-wetting spots (Teflon or epoxy)

These either promote nucleation sites or reduce the amount of superheat required for nucleate boiling (Thome, 1990). Techniques used to enhance pool boiling within a tube bundle involve welding or casting fins on the shell-side of the tubes. These primarily serve to increase the boiling heat transfer area per unit area of conduction, as in single-phase flow systems.

In flow boiling, passive techniques consist of altering the flow geometry to promote and increase mean flow turbulence. This augments both the convective boiling heat transfer and the supply of liquid to the vapour generation sites. These passive devices are classified as surface-roughness:

- helical-ribbed bore tubes
- cylindrical inserts
- spacers
- appendages
- wire wrap or wire mesh

or vortex-generators:

- twisted tape inserts
- twisted wire inserts
- winglets

The helical-ribbed bore tube, illustrated in Figure 1.6a, is an example of uniformly-distributed or regular roughness commonly found in conventional boiler tubes (Watson et al., 1974; Kitto and Wiener, 1982). The other roughness devices (Figure 1.6b; Figure 1.6c) are spaced far enough apart to be considered as discrete roughness. The DNB mechanism of CHF is suppressed by higher liquid-core turbulence through increased capacity of the liquid to penetrate the near-wall bubbly layer. The dryout mechanism of CHF in annular flow is enhanced by increased core-turbulence through increased droplet deposition and prolonged existence of the liquid-film. The position and shape of the roughness element can sometimes decrease CHF by stagnating the bubbly layer in the low quality region or stripping the liquid-film in the high quality region. Therefore, it is important to understand the underlying CHF mechanism and the effects of introducing a flow obstruction. For example, some of the negative effects of flow

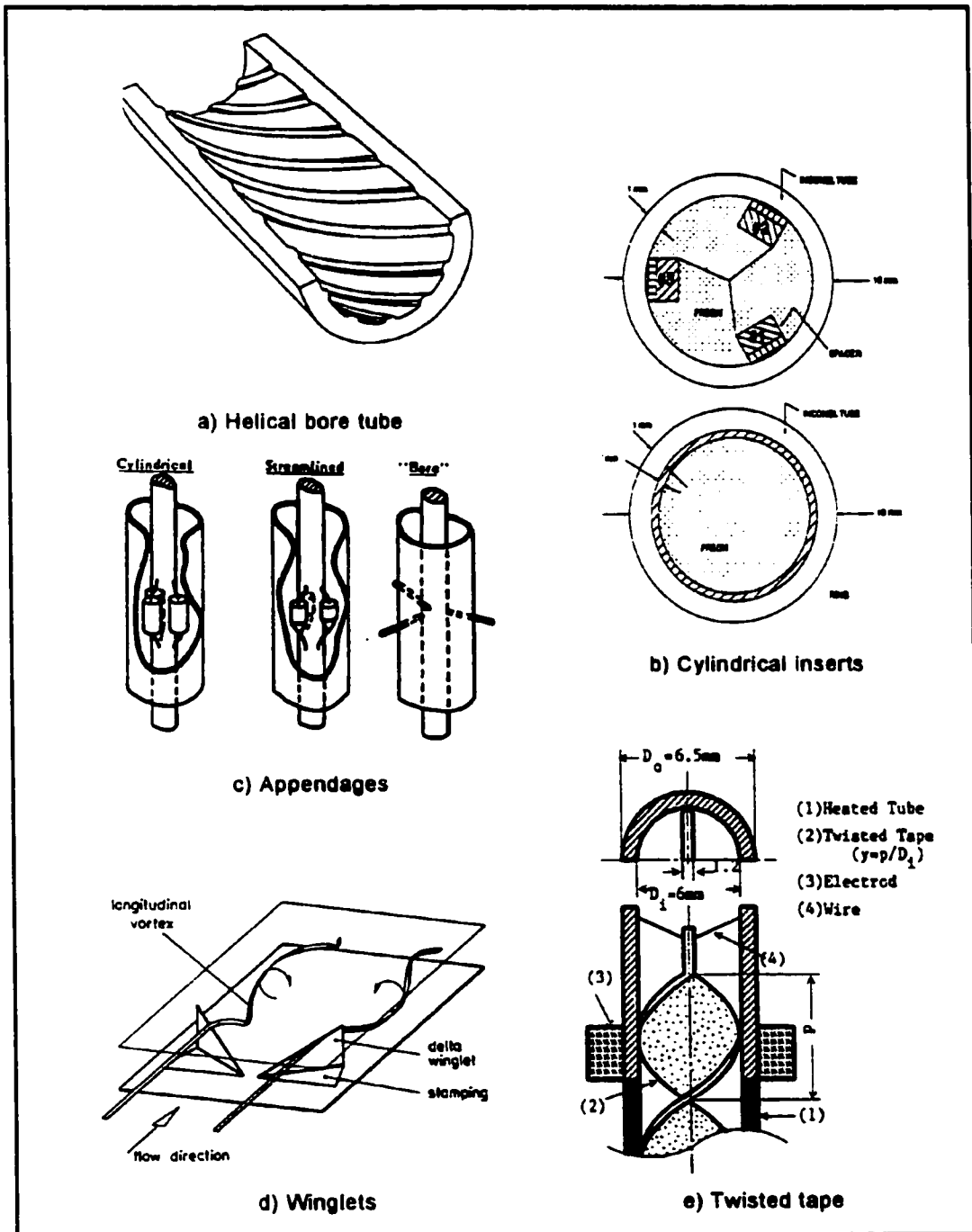


Figure 1.6: Surface-roughness and vortex-generator devices, taken from various sources: a) Thome (1990) with permission of Taylor & Francis, Inc./Routledge, Inc.(www.routledge-ny.com), c) Ilic (1975), d) Tiggelbeck et al. (1991) with permission of Elsevier Science, and e) Inasaka et al. (1991) with permission of ASME.

obstructions on liquid-film can enhance CHF through removal of the parasitic liquid-film occurring on the unheated surface of a flow channel (e.g., the outer pressure-tube in a CANDU fuel bundle), re-directing the liquid to vapour generation sites.

The vortex generators (Figure 1.6d; Figure 1.6e) operate in a similar fashion to the roughness elements by increasing downstream turbulence. However, they induce a more structured turbulence pattern which may be advantageous in certain situations. The vortex generators can increase flow turbulence in desired regions of the flow channel, where CHF would normally occur first. For example, positioning a twisted tape within the central core of a two-phase flow channel will direct the resultant turbulence and droplet deposition towards the wall without introducing near-wall vapour stagnation or liquid-film stripping.

The above-mentioned methods of enhancement are all based on passive techniques. A number of active enhancement techniques have been proposed and tested:

- ultrasonic vibration of the fluid and/or heated surface (Thome, 1990)
- inlet flow pulsation (Shuai et al., 1994)
- electrically-induced fluid oscillation (Li et al., 1994)

However, these techniques are often difficult to implement outside the laboratory and to justify economically (Thome, 1990).

1.4 Objectives and Scope

The main objective of the current study is to investigate the enhancement of CHF by flow channel obstructions. The results could be applied to both conventional and nuclear power plants to increase channel power ratings, reduce unit size and cost, and increase service life and reliability, which would lead to significant capital cost savings. In the specific case of nuclear power plants, the enhancement of local CHF may enable higher local over-power trip settings which can facilitate normal plant operations. Any enhancement program must take into account

the additional costs of added components (complicated manufacturing, increased pumping, service-life, and reliability). A small portion of the study will be devoted to the pressure drops associated with flow obstructions. Both experimental and theoretical work will be pursued to improve the mechanistic understanding of such devices and their effect on CHF. As in most two-phase flow studies, the results from single-phase heat transfer and pressure drop will be used as a basis for modelling the two-phase flow. The current investigation will be limited to the positive quality region of evaporative flow where the flow is assumed annular and CHF attributed to the dryout of a liquid-film. The following activities were performed as part of the present thesis:

1. Various experimental and modelling studies were carried out on a single vertical tube equipped with sliding cylindrical flow obstructions, representing different blockage geometries, blockage area, and inter-element spacing. The type of flow obstruction used was similar to that found in typical CANDU fuel bundles, namely spacer-type obstructions with abrupt planar geometries. The use of a single-tube eliminated the complexity of fuel bundle subchannel intermixing and isolated the effects of the flow obstruction.
2. Existing experimental and modelling literature on the effect of flow obstructions in single-phase heat transfer, two-phase critical heat flux, and single-phase and two-phase pressure-drop has been reviewed.
3. Specific literature on annular flow dryout modelling, with an emphasis on the liquid-film entrainment and droplet-deposition which govern CHF, has been reviewed. Any previous mechanistic models of spacers or flow obstructions are highlighted.
4. The existing dryout CHF models were assessed against both the CHF lookup table (Groeneveld et al., 1995) and the experimental CHF data of Doerffler and

Groeneveld (1994) and Doerffer et al. (1995) to select one or more candidate models for use in the present study.

5. Various single-phase flow and heat transfer experiments were performed to measure the pressure-drop across a single flow obstruction and the heat-transfer downstream of a flow obstruction at different Reynold's numbers. The results provide a better understanding of the effects of the specific flow obstruction geometries tested.
6. Various two-phase flow experiments were performed in a vertical tube equipped with a series of moveable flow obstructions to assess the effect of flow obstructions on CHF as a function of their number, obstacle spacing, and the flow conditions (mass-flux, pressure, quality).
7. The existing dryout models were compared with experimental CHF, with and without flow obstructions. Various mechanistic and empirical relations were devised and tested to account for the effect of flow obstructions in terms of discrete liquid entrainment, discrete liquid impingement, and downstream decay of mass transfer enhancement.

1.5 Complex Fuel Bundle Design

When considering the complex geometry of a CANDU-PHW fuel bundle, the coolant mass flux and temperature (quality) of a given location may be quite different from the bundle-average values. Experimental or modelling results for a simple flow geometry (e.g., tube or annuli) cannot be applied directly to predict the bundle CHF. Some of the geometric factors affecting CHF are:

- Hydraulic diameter: increases in CHF are obtained using a smaller hydraulic diameter (Groeneveld et al., 1992).

- **Heated surface:** highest values of CHF are obtained inside a tube, followed by annuli heated on both sides, annuli heated on the outside only, and annuli heated on the inside only. Parasitic liquid films on the unheated surface and the effect of curvature on liquid film entrainment are cited as the key factors responsible for these differences in CHF (Rogers, 1966).
- **Heat flux distribution:** cosine and truncated cosine heat flux distributions produce a lower CHF than uniform heat flux distributions (Rogers, 1966).
- **Inter-element spacing:** CHF is increased with increased bundle spacing over the range of 0.4 mm to 2.0 mm (Rogers, 1966); increases in CHF are obtained by increasing the gap size of a concentric annuli from 1.5 to 5 mm, but then CHF drops off after some critical value (Groeneveld et al., 1992).

As described by Rogers (1966), the complex flow geometry of a nuclear fuel-rod bundle results in the non-uniform distribution of mass flux, wetted perimeter, and radial neutron flux throughout the flow subchannels. The resulting imbalance in enthalpy (quality) across the flow area causes CHF to occur at bundle-average qualities well below the critical values of both the tube and annuli.

It should be possible to add various subchannel flow blockages to adjust the subchannel geometries and produce a more uniform flow and quality distribution within the bundle. However, these modifications can also upset existing enthalpy balances within the bundle. The present work is limited to a single tube to isolate the effects of flow obstructions on CHF, separating them from the effects of flow and enthalpy re-distribution which result from the presence of flow subchannels.

1.6 Thesis Structure

The next chapter reviews the existing literature on flow obstructions and annular flow dryout models, forming the basis on which an analytical treatment of CHF enhancement will be derived. Chapter 3 describes the single-phase and two-phase (CHF) experiments used to parameterize and validate the CHF enhancement model. Chapter 4 describes the development of modelling software used to simulate and test the reference-tube and enhanced-tube CHF models. Chapter 5 presents a detailed assessment of the existing dryout models, comparing their results to both the AECL-UO CHF lookup table and specific experiments. The reference data points from the CHF enhancement experiment are further studied by comparing their tube-length profiles and sensitivity to key parameters in the model. Chapter 6 provides a detailed assessment of the CHF enhancement model, starting with a preliminary assessment in water, followed by a detailed statistical and graphical analysis of the 30% ring data in Freon-134a. The final chapter summarizes the findings of this study and indicate areas for future research.

Chapter 2 LITERATURE REVIEW

2.1 Experimental Studies

This section describes numerous experimental and empirical studies carried out on the effect of flow obstructions on single-phase flow and heat transfer, two-phase flow, and CHF. Not all flow obstructions and channel geometries cited are applicable to the tube and cylindrical insert obstruction used in this study, but some of the trends, observations and conclusions do provide insight into the tube flow-obstruction problem.

2.1.1 Effect of Flow Obstructions on Single-Phase Flow and Heat Transfer

Any study of two-phase flow begins with a review of single-phase flow, as many characteristics of two-phase flow are derived from their single-phase counterparts. In this case, the literature on single-phase flow and heat transfer with various enhanced and rib-roughened channels is surveyed. The emphasis is on observed flow patterns, non-dimensional similarity analysis and quantitative characterization of turbulence downstream of a flow obstruction. The flow obstructions found in the CANDU fuel bundle have a spacer pitch-to-height ratio (p/e) in

the range of 60–250. It will be shown that these large pitch ratios produce a particular turbulence pattern downstream of the flow obstacle.

Law of the Wall

Before discussing the literature on single-phase flow in rough channels, the theory on smooth-wall turbulent boundary layers, namely the "law of the wall", is reviewed. Prandtl reasoned in 1933 that the velocity profile in the region close to a wall should only depend on wall shear stress, fluid properties and the distance (y) from the wall:

$$u^+ = \frac{u(y)}{u_\tau} \quad u_\tau = \sqrt{\frac{\tau_w}{\rho}} \quad y^+ = \frac{yu_\tau}{\nu} \quad (2.1)$$

The boundary layer data, presented using the above parameters, collapse into a single "universal" velocity profile, as illustrated in Figure 2.1. The divergence of the data far from the wall indicates a dominance by other effects (i.e., pressure gradient) in the outer region. Coles (1956) referred to the excess velocity illustrated in Figure 2.1 as the "wake-effect" of the free-stream. For a more detailed illustration of the

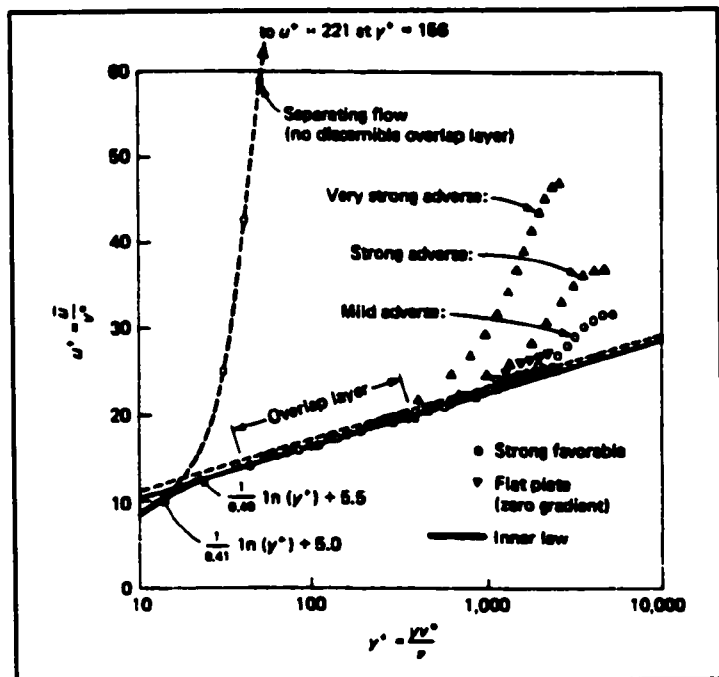


Figure 2.1: Velocity profiles using inner-law variables y^+ and u^+ , adapted from White (1991) with permission of McGraw-Hill.

laminar sub-layer, consult Figure 11-3 in Kays and Crawford (1993).

Various relations have been proposed for the “law of the wall”, such as the three-layer approximation by Whalley (1990) for smooth tubes:

$$\text{laminar sub-layer: } u^+ = y^+ \quad y^+ < 5, \quad (2.2a)$$

$$\text{buffer layer: } u^+ = \frac{1}{0.2} \ln y^+ - 3.05 \quad 5 < y^+ < 30, \quad (2.2b)$$

$$\text{inner-layer: } u^+ = \frac{1}{0.40} \ln y^+ + 5.5 \quad y^+ > 30. \quad (2.2c)$$

The inner-layer relation is based on the following logarithmic overlap law:

$$u^+ = \frac{\bar{u}}{u_{\tau}} = \frac{1}{K} \ln \left(\frac{y u_{\tau}}{\nu} \right) + B \quad (2.3)$$

where ($K=0.40$, $B=5.5$) are universal constants. The overlap law has been derived from the fact the boundary-layer flow is governed by both inner-wall (shear-stress) and outer-wall (i.e., velocity-defect, or retardation in the flow) effects, and that over some finite length both regions merge smoothly ($u_{\text{inner}}=u_{\text{outer}}$). In the case of circular pipes, these relations can be integrated over the flow-area to obtain wall-friction factors:

$$f = \frac{\tau_w}{\frac{1}{2} \rho u_{av}^2} = \frac{\tau_w}{\frac{G^2}{2 \rho}} \quad (2.4)$$

Carrying out the integration with the logarithmic-overlap relation, ignoring both the laminar and buffer layers, results in:

$$\sqrt{\frac{2}{f}} = 2.5 \ln \left(\frac{\text{Re}_d}{2} \sqrt{\frac{f}{2}} \right) + 1.75 \quad (2.5)$$

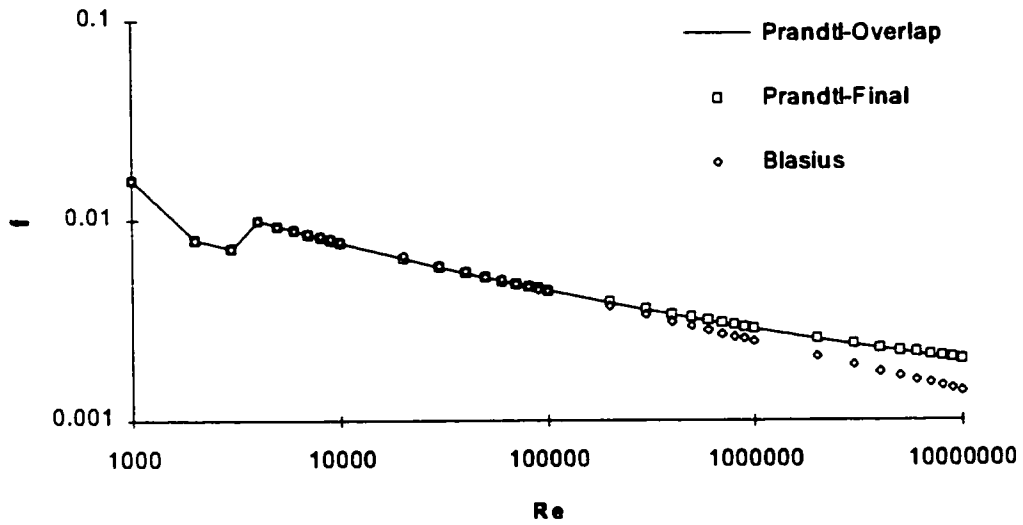


Figure 2.2: Comparison of different friction formulas for a smooth pipe.

Converting to a logarithmic scale:

$$\frac{1}{\sqrt{\Lambda}} = 2.035 \log (Re_d \sqrt{\Lambda}) - 0.913 \quad (2.6)$$

where $\Lambda=4f$ is known as the Darcy friction factor, and f is the Fanning friction factor. According to White (1991), the constants in Equation (2.6) were adjusted by Prandtl to obtain:

$$\frac{1}{\sqrt{\Lambda}} = 2.0 \log (Re_d \sqrt{\Lambda}) - 0.8 \quad (2.7)$$

These friction factors (2.6, 2.7) are compared in Figure 2.2 against the well-known Blasius formula (White, 1991):

$$f = 0.0791 Re_d^{-0.25} \quad (2.8)$$

According to White (1991), the Blasius formula under-predicts friction at high Reynolds numbers ($Re > 10^5$), whereas the Prandtl formulas fit the experimental data for a wide range of Reynolds numbers.

Smooth-Pipe Velocity Profiles

The previous section described the “law of the wall”, applicable to a wide range of turbulent boundary layers (i.e., flat plate), and its use in calculating friction factors in a pipe. Now consider the steady-state, constant-property momentum equation for flow in a horizontal circular pipe (i.e., no gravity force acting in the flow direction):

$$u_z \frac{\partial u_z}{\partial x} + u_r \frac{\partial u_z}{\partial r} - \frac{1}{r} \frac{\partial}{\partial r} \left[(v + \epsilon_M) r \frac{\partial u_z}{\partial r} \right] + \frac{1}{\rho} \frac{d\bar{P}}{dx} = 0 \quad (2.9)$$

Although the fluid viscosity and density are assumed constant, the turbulent eddy viscosity, ϵ_M , can vary across the flow cross-section. Introducing the assumptions for fully-developed pipe flow:

$$u_r = 0 ; \quad \frac{\partial u_z}{\partial x} \ll \frac{\partial u_z}{\partial r} \quad (2.10)$$

the momentum equation is further simplified to:

$$\frac{1}{r} \frac{\partial}{\partial r} \left[(v + \epsilon_M) r \frac{\partial u_z}{\partial r} \right] = \frac{1}{\rho} \frac{d\bar{P}}{dx} \quad (2.11)$$

and with the following definition of shear stress:

$$\tau_{rz} = (\mu + \mu_t) \frac{du_z}{dr} = \rho(v + \epsilon_M) \frac{du_z}{dr} = \tau_r \quad (2.12)$$

Equation (2.11) can be expressed as:

$$\frac{1}{r} \frac{\partial}{\partial r} [\tau_r r] = \frac{d\bar{P}}{dx} = \text{const} \quad (2.13)$$

Integrating Equation (2.13) between $r=0$ and $r=r_o$ results in a linear shear-stress distribution:

$$\frac{\tau(r)}{\tau_o} = \frac{r}{r_o} = 1 - \frac{y}{r_o} \quad (y = r_o - r) \quad (2.14)$$

This shear-stress relation is often used to model the liquid-film in annular (two-phase) flow.

k-Type Roughness

Clauser (1956) proposed a downward shift parameter for modifying the logarithmic overlap velocity profile to account for the effect of a repeated roughness with an average height (k):

$$u^+ = \frac{1}{K} \ln y^+ + B - \Delta B(k^+) \quad (2.15)$$

$$k^+ = \frac{k u_\tau}{\nu}$$

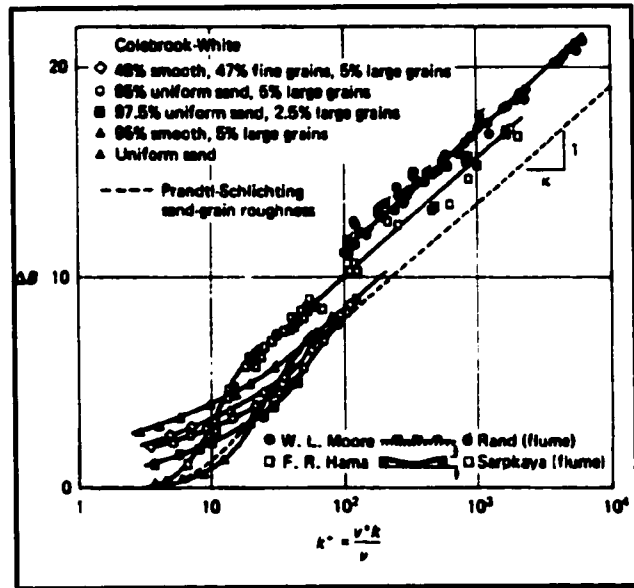


Figure 2.3: Clauser (1956) profile-shift parameter $\Delta B(k^+)$, adapted from White (1991) with permission of Academic Press.

Unfortunately, ΔB is not a unique function of k^+ but varies with the roughness geometry, as illustrated in Figure 2.3. The curves indicate that for $k^+ > 60$, the relation is logarithmic (i.e., no viscosity effect) and this flow has been termed fully rough.

White (1991) curve-fitted the following relation to the sand-grain roughness data:

$$\Delta B_{\text{sand}} = \frac{1}{K} \ln(1 + 0.3 k^+) \quad (2.16)$$

When substituted into Equation (2.15), the following velocity profile for fully-rough *k-type* flow is obtained:

$$\begin{aligned} u^+ &= \frac{1}{K} \ln y^+ + B - \frac{1}{K} \ln(1 + 0.3 k^+) \\ &\approx \frac{1}{K} \ln\left(\frac{y}{k}\right) + 8.5, \quad k^+ > 60 \end{aligned} \quad (2.17)$$

Similar to the Prandtl formula, the above relation can be integrated over the pipe-area to obtain a *k-type* friction formula:

$$\frac{1}{\sqrt{\Lambda}} = 2.0 \log \left[\frac{\text{Re}_d \sqrt{\Lambda}}{1 + 0.1 (k/d) \text{Re}_d \sqrt{\Lambda}} \right] - 0.8 \quad (2.18)$$

which indicates:

$$\left(\frac{k}{d} \right) \text{Re}_d < 10: \quad \text{roughness unimportant}$$

$$\left(\frac{k}{d} \right) \text{Re}_d > 1000: \quad \text{fully-rough flow (independent of}$$

Re)

Similarly, the Colebrook formula (White, 1991) was devised to represent roughness typical of commercial pipes:

$$\frac{1}{\sqrt{\Lambda}} \approx -2.0 \log \left[\frac{k/d}{3.7} + \frac{2.51}{\text{Re}_d \sqrt{\Lambda}} \right] \quad (2.19)$$

which, when plotted for various (k/d) as a function of Re , has come to be known as the *Moody Diagram*. The Colebrook formula displays a similar smooth-pipe and fully-rough flow behaviour. In summary, k-type roughness is a uniform roughness geometry where for certain low-flows, the wall can be treated as smooth while for high-flows, friction becomes independent of Reynolds number and depends only on the relative roughness height (k/d) .

Repeated-Rib Roughness

Webb et al. (1971) studied single-phase friction and heat transfer in tubes with repeated-ribs. Different roughness geometries were tested, characterized by their pitch ratio $(p/d=10, 20, 40)$ and roughness ratio $(e/d=0.01, 0.02, 0.04)$ where p , d and e are the spacing pitch, tube inner diameter and rib height, respectively. They adopted the velocity profile and friction factor relations derived by Nikuradse (1933) for sand-roughness:

$$u^+ = \frac{1}{K} \ln \left(\frac{y}{e} \right) + u_e^+(e^+) \quad (2.20)$$

$$\sqrt{\frac{2}{f}} = \frac{1}{K} \ln \left(\frac{d}{2e} \right) + u_e^+(e^+) - \frac{2}{3K} \quad (2.21)$$

where $K=0.40$ is that obtained for smooth tubes. Note the similarity between Equation (2.20) and the k -type roughness Equation (2.17). Webb et al. correlated the following u_e^+ expression from their experimental data over the entire fully-rough region:

$$u_e^+ = 0.95(p/e)^{0.53} \quad , \quad e^+ = \frac{e u_\tau}{\nu} \quad (2.22)$$

Similarly, they extended the heat transfer correlation for smooth tubes developed by Sparrow et al. (1957):

$$St_s = \frac{h}{\rho C_p u_{av}} = \frac{h}{GC_p} = \frac{f_s/2}{1 + 9.3\sqrt{f_s/2}(\text{Pr} - 1)\text{Pr}^{-1/4}} \quad (2.23)$$

which is based on the heat transfer-momentum analogy. To account for the roughness in both the viscous wall-region and the turbulence-dominated core-region, the following correlating function was derived:

$$St = \frac{f/2}{1 + \sqrt{f/2} [g(e^+, p/e) F(\text{Pr}) - u_e^+]} \quad (2.24)$$

where St and f are the rough-flow values.

Applying the above correlation to the fully-rough flow, they obtained the following fitting-functions:

$$g(e^+) = 4.50(e^+)^{0.28} \quad (2.25)$$

$$F(\text{Pr}) = \text{Pr}^{0.57} \quad (2.26)$$

It should be noted that f and u_e^+ are obtained from Equations (2.21) and (2.22), respectively. They also described an efficiency index (η):

$$\eta = \frac{St/St_s}{f/f_s} = \frac{1 + 9.3\sqrt{f_s/2}(\text{Pr} - 1)\text{Pr}^{-1/4}}{1 + \sqrt{f/2}(g\text{Pr}^{0.57} - u_e^+)} \quad (2.27)$$

which relates the relative friction expenditure necessary to obtain a given increase in heat transfer. The resultant curves show a relative increase in pumping cost ($\eta < 1$) when low Prandtl numbers and large e^+ are considered. Equivalent measures of efficiency could be derived for CHF enhancement.

Discrete Roughness

This section describes some of the detailed experiments carried out in both flat-plate and duct-flow geometries, equipped with discrete flow obstructions. The term *discrete* implies that the obstacles are far enough apart, in relation to their height, and that the flow is neither *continuous* nor *fully-developed*. These obstacles are similar to those found in the CANDU fuel bundle and will provide useful insight into CHF enhancement.

Okamoto et al. (1993) carried out a detailed study of the flow structure and heat transfer over a flat-plate with two-dimensional repeated ribs. Each square rib ($e=10$ mm) was positioned at regular pitch intervals (p) to obtain the following spacer-pitch ratios: $p/e=2, 3, 4, 5, 7, 9, 13$, and 17. The time-average velocity, static pressure, velocity vectors and turbulence intensity were measured in air with a free-stream velocity of $U_\infty=16.0$ m/s, corresponding to $Re=\rho U_\infty e/\mu=1.0 \times 10^4$. The wall and fluid temperatures were measured during heat transfer experiments in air with a free-stream velocity of $U_\infty=12.0$ m/s, corresponding to $Re=7500$. Both rib and groove were heated through a thin stainless steel foil.

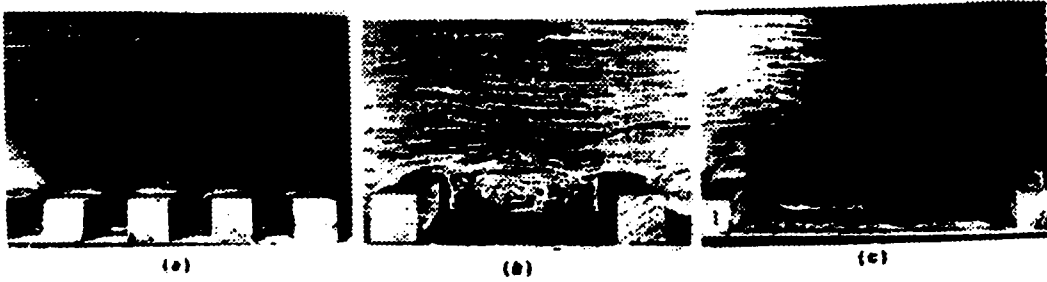


Figure 2.4: Photographs of vortices in water channel with $Re=500$: (a) $p/e=2$; (b) $p/e=5$; (c) $p/e=9$, adapted from Okamoto et al. (1993) with permission of ASME.

Flow visualization in water at $Re=500$, as shown in Figure 2.4, highlights the following characteristic flow structures:

- a small stable vortex positioned in the groove at $p/e=2$,
- a larger stable vortex occupying the entire groove at $p/e=5$, and
- streamlines reattach around the centre of the groove ($x/e=4$) at $p/e=9$.

From these experiments, Okamoto et al. concluded:

- 1) The turbulent shear layer thickness, $U(\delta)=0.99U_\infty$, for a given value of x/e increases with p/e in the range $2 \leq p/e \leq 9$, but remains constant for $p/e > 9$.
- 2) The profiles of turbulent intensity in the shear layer become self-preserving above the ribs and grooves when $p/e \leq 5$. For $p/e=9$, the turbulent intensity in the shear layer above the groove decreases with increasing downstream distance and does not achieve a self-preserving profile.
- 3) The overall magnitude of turbulence intensity and local heat transfer coefficient were found to be a maximum when $p/e=9$.
- 4) The free streamline leaving a rib corner reattaches to the ground plate for $p/e \leq 9$, and in the case of $p/e=9$, reattaches in the middle of the groove ($x/e=4$). The turbulence

intensity and heat transfer increase immediately downstream of the rib up to the point where the streamline reattaches, and then decrease gradually to the next rib.

- 5) The pressure losses are a maximum when the turbulence promotion is a maximum ($p/e=9$).

Tiggelbeck et al. (1991, 1993) studied the flow structure and heat transfer behind double-rows of delta-winglets in transition airflow for application to compact heat exchangers. They investigated the effects of channel Reynolds number ($Re = \rho UH/\mu = 2000-8000$), the winglet angle of attack ($\beta=45^\circ, 65^\circ$), and staggered versus in-line arrangements between rows. Previous studies had shown:

- winglets and other vortex generators produce stable longitudinal vortices in their wake, and
- counter-rotating longitudinal vortices are effective while co-rotating longitudinal vortices are not.

They observed:

- streamwise distances of 7-10 channel heights (L/H) between rows of vortex generators produce the highest local and average heat transfer rates,
- a second row of winglets further enhances the heat transfer from that of a single row,
- the peak local heat transfer behind the second row is higher than that behind the first row, indicating an increase in heat transfer from the second row,
- a critical angle of attack exists: $\beta_{crit} \approx 70^\circ$ for the first row and $\beta_{crit} \approx 55^\circ$ for the second row; the lower value of the second row has been attributed to inhomogeneities and unsteadiness from the increased turbulence behind the first row,



Figure 2.5: Normalized span-average Nusselt numbers for in-line ($\Delta y_{12}=0$) and staggered ($\Delta y_{12}=B/2$) winglets, adapted from Tiggelbeck et al. (1993) with permission of ASME.

- the highest heat transfer rates are obtained when the angle of attack is near the critical value, and
- there are no significant differences between the in-line and staggered row arrangements.

Interestingly, the same optimum spacer-pitch ratios ($p/e=L/H=9$) are obtained with both the square-rib and delta-winglet roughness elements. The channel height and winglet height are the same in this study.

The normalized spanwise-average Nusselt numbers of Tiggelbeck et al. (1993), downstream of a winglet-pair, are shown in Figure 2.5. The term Δy_{12} refers to the lateral spacing between in-line and staggered roughness elements, and B is the lateral spacing between elements of the same row. According to the graph, the Nusselt numbers have been normalized using the measured values farthest downstream (NU_{30}). The heat transfer behind the second row of winglets decays exponentially. One might expect the decay rate to vary with both Reynolds and Prandtl numbers; however, no such empirical data are provided.

Yao et al. (1982) reviewed the enhancement of heat transfer in and around honeycomb and egg-crate rod-bundle spacers under single-phase and post-CHF dispersed-flow conditions. They proposed the following correlation for single-phase heat transfer:

$$\left(\frac{Nu}{Nu_o} \right)_{sp} = 1 + 5.55 \epsilon^2 e^{-0.13(x/d_e)} \quad (Re > 10^4) \quad (2.28)$$

where ϵ is the blockage ratio (A_{sp}/A_o), x the downstream distance, and d_e the hydraulic diameter of the channel. Again, the values are normalized using the values measured farthest downstream.

A comparison by Yao et al. (1982) with available single-phase heat transfer data shows accurate prediction of the downstream effect ($0 < x/d_e < 20$) with the above relation. However, large discrepancies occur in the prediction of maximum heat transfer at the spacer. The simple analogy between friction and heat transfer, which formulates the basis of this correlation, is cited as the probable source of this error and would imply that a specific correlation is required for each bundle and spacer geometry.

Shina et al. (1989, 1991) investigated the heat transfer and pressure drop in a rectangular channel fitted with a suspended plate-type flow obstruction. They defined the following spacer configuration parameters:

- blockage: ratio of spacer thickness to channel height
- clearance: ratio of spacer distance from heated surface to channel height
- length: ratio of spacer length to hydraulic diameter
- existence: ratio of spacer length to spacer pitch
- shape: flat, round, or bevel
- edge: leading, trailing, or both edge shaped

A series of experiments were performed to determine the bulk-fluid modelling parameters associated with each spacer. A performance index was defined:

$$\frac{\eta}{\eta^*} = \frac{(Nu/Nu^*)}{(f_e/f_e^*)} \quad (2.29)$$

where (Nu^*, f_e^*) refer to a standard spacer (square leading and trailing edge). Their results indicate:

- the Reynolds number has little or no effect on either the relative heat transfer enhancement $(Nu(x)/Nu(\infty))$ or the decay rate (b) ,
- the blockage ratio has the strongest influence on both heat transfer and pressure drop, with overall increases in performance obtained at larger blockage ratios, and
- the largest performance index is obtained with an airfoil-type spacer where both leading and trailing edges are shaped.

From all of these studies, one can conclude the following about discrete-roughness turbulence-promotion:

- 1) When the pitch ratio is small $(p/e < 9)$ and a groove between adjacent spacers is evident, a vortex generated in the recirculation zone behind the obstruction can occupy the entire groove. This results in increased turbulence from recirculation which does not penetrate the boundary layer above the roughness plane.
- 2) When the spacer pitch is large $(p/e > 9)$, the turbulence generation is limited by a decay rate following reattachment of the free streamline leaving the roughness element.

- 3) Maximum turbulence promotion is obtained when the spacer pitch (p/e) is such that reattachment has just occurred, somewhere around half-way between adjacent roughness elements.
- 4) Under most conditions, the relative increase in average heat transfer (St/St_0) is smaller than the relative increase in pressure drop (f/f_0).

2.1.2 Effect of Flow Obstructions on Two-Phase Flow and CHF

This section describes various two-phase flow experiments with an emphasis on the pressure drop and flow structure around flow obstacles. At present, only heat-flux controlled wall boundaries in annular flow are considered, where the two-phase heat transfer coefficient is not as important as the hydrodynamic processes of annular flow. Most two-phase flow heat transfer involving flow obstructions pertains to the post-dryout (post-CHF) region and is not considered in the present study.

Pressure Drop

According to a survey by Groeneveld and Yousef (1980), the two-phase pressure drop across flow obstacles is best predicted using either a homogeneous flow model or the Chisholm (1967) correlation method. The homogeneous flow model uses a single-phase head-loss coefficient:

$$\Delta P = \frac{1}{2} K \rho \bar{u}^2 = \frac{1}{2} K \frac{G^2}{\rho} \quad (2.30)$$

and a two-phase multiplier:

$$\phi_{lo}^2 = \frac{(dP/ds)_{F,TP}}{(dP/ds)_{F,lo}} = \frac{\frac{1}{2} K_{TP} \frac{G^2}{\langle \rho \rangle}}{\frac{1}{2} K_{lo} \frac{G^2}{\rho_l}} = \frac{\rho_l}{\langle \rho \rangle} \quad (2.31)$$

to define the two-phase pressure gradient. Similarly, the same can be defined for other possible phase distributions:

$$\phi_{go}^2 = \frac{(dP/ds)_{F,TP}}{(dP/ds)_{F,go}} = \frac{\frac{1}{2} K_{TP} \frac{G^2}{\langle \rho \rangle}}{\frac{1}{2} K_{go} \frac{G^2}{\rho_g}} = \frac{\rho_g}{\langle \rho \rangle} \quad (2.32)$$

$$\phi_l^2 = \frac{(dP/ds)_{F,TP}}{(dP/ds)_{F,l}} = \frac{\frac{1}{2} K_{TP} \frac{G^2}{\langle \rho \rangle}}{\frac{1}{2} K_l \frac{G_l^2}{\rho_l}} = \frac{1}{(1-x)^2} \frac{\rho_l}{\langle \rho \rangle} \quad (2.33)$$

$$\phi_g^2 = \frac{(dP/ds)_{F,TP}}{(dP/ds)_{F,g}} = \frac{\frac{1}{2} K_{TP} \frac{G^2}{\langle \rho \rangle}}{\frac{1}{2} K_g \frac{G_g^2}{\rho_g}} = \frac{1}{x^2} \frac{\rho_g}{\langle \rho \rangle} \quad (2.34)$$

ϕ_{lo}^2 and ϕ_{go}^2 relate the two-phase pressure gradient to the single-phase pressure gradient of the liquid and vapour flowing through the same tube diameter with the same total mass flux, respectively. Similarly, ϕ_l^2 and ϕ_g^2 relate the two-phase pressure gradient to the single-phase

pressure gradient of each phase component flowing through the same tube diameter. The two latter two-phase multipliers become undefined when their phase components are zero. Assuming the same head-loss coefficient (K) in both single-phase and two-phase flow, and making use of the following homogeneous mixture density relation:

$$\langle \rho \rangle = \frac{\rho_l \rho_g}{\rho_l x + \rho_g (1 - x)} \quad (2.35)$$

$$v_{lg} = v_g - v_l = \frac{1}{\rho_g} - \frac{1}{\rho_l} = \frac{\rho_l - \rho_g}{\rho_l \rho_g} \quad (2.36)$$

the homogeneous pressure-drop at a spacer can be defined using the following two-phase multiplier:

$$\Phi_{lo}^2 = \frac{\Delta P_{sp,TP}}{\Delta P_{sp,lo}} = 1 + x \frac{v_{lg}}{v_l} \quad (2.37)$$

Similarly, Chisholm (1967) used the Lockhart-Martinelli parameter:

$$X^2 = \frac{(dP/ds)_{F,l}}{(dP/ds)_{F,g}} \quad (2.38)$$

where

$$\begin{aligned} \left(\frac{dP}{ds} \right)_{F,l} &= \frac{1}{2} K \frac{G_l^2}{\rho_l} = (1-x)^2 \frac{K G^2}{2 \rho_l} = (1-x)^2 \left(\frac{dP}{ds} \right)_{F,lo} \\ \left(\frac{dP}{ds} \right)_{F,g} &= \frac{1}{2} K \frac{G_g^2}{\rho_g} = x^2 \frac{K G^2}{2 \rho_g} = x^2 \left(\frac{dP}{ds} \right)_{F,go} \end{aligned} \quad (2.39)$$

to define a correlating function:

$$\begin{aligned} \left(\frac{dP}{ds} \right)_{F,TP} &= \left(\frac{dP}{ds} \right)_{F,l} + C \left[\left(\frac{dP}{ds} \right)_{F,l} \left(\frac{dP}{ds} \right)_{F,g} \right]^{\frac{1}{2}} + \left(\frac{dP}{ds} \right)_{F,g} \\ &= \left(\frac{dP}{ds} \right)_{F,lo} (1-x)^2 \left[1 + \frac{C}{X} + \frac{1}{X^2} \right] \end{aligned} \quad (2.40)$$

from which the following two-phase friction multiplier is defined:

$$\Phi_{lo}^2 = \frac{\Delta P_{sp,TP}}{\Delta P_{sp,lo}} = (1-x)^2 \left[1 + \frac{C}{X} + \frac{1}{X^2} \right] \quad (2.41)$$

Chisholm and Sutherland (1969) used this method to model pipe fittings, where they used the following expression for C :

$$C = \left[1 + (C_2 - 1) \left(\frac{v_{lg}}{v_l} \right)^{0.5} \right] \left[\left(\frac{v_g}{v_l} \right)^{0.5} + \left(\frac{v_l}{v_g} \right)^{0.5} \right] \quad (2.42)$$

where empirical values of C_2 were obtained for different types of pipe fittings.

Groeneveld and Yousef (1980) recommend the homogeneous model as the most thoroughly verified method of calculating spacer pressure-drops, and suggest the spacer-loss coefficients given in Table 2.1. The symbols ϵ , e , and d_e denote the obstructed fraction (A_{sp}/A_o), spacer height, and hydraulic diameter, respectively. Normally, the hydraulic diameter (d_e) of the flow passage without the flow obstruction is used.

Table 2.1: Recommended spacer-loss coefficients (taken from Groeneveld and Yousef, 1980).

Reference	Spacer Loss Coefficient
De Strodeur (1961)	$K = C_s \frac{\epsilon}{(1 - \epsilon)^2}, \quad C_s = 1.65, \quad Re > 4 \times 10^4$
Rehme (1971)	$K = C_v \epsilon^2, \quad C_v = 6.5, \quad Re > 5 \times 10^4$
Idel'chik (1966)	$K = \frac{\beta \left(\frac{\epsilon}{2} + \tau \epsilon^{3/2} + \epsilon^2 \right) + f_e \frac{e}{d_e}}{(1 - \epsilon)^2}$ β from Fig. 3; τ from Table versus (e/d_e) in Idel'chik (1966)
De Paz (1975)	$K = \frac{0.75 \epsilon + \epsilon^2 + f_e \frac{e}{d_e}}{(1 - \epsilon)^2}$
thin plate orifice (conventional)	$K = \left[\frac{1}{C_c (1 - \epsilon)} - 1 \right], \quad C_c = \frac{A_{\text{vena contracta}}}{A_{\text{orifice}}}$
Voj (1973)	$K = \frac{\epsilon}{1 - \epsilon} \left[2.12 + \frac{10^4 (1 - \epsilon)^2}{Re} \right]$

Critical Heat Flux

Groeneveld and Yousef (1980) provide a comprehensive review of the effect of spacers on CHF and their results are summarized in Table 2.2. The majority of these experiments were carried out in complex bundle geometries, making it difficult to isolate single mechanisms of CHF enhancement. The following paragraphs describe a subset of CHF experiments reviewed by the author involving single tube geometries.

Moeck et al. (1964) carried out experiments in a heated tube fitted with a twisted tape ($p/d=11-69$), and an internally-heated annulus ($ID=15.2$ mm, $OD=21.8$ mm) fitted with rings ($w=1.27$ mm) on the inside of the outer surface of various heights ($e=0.0, 0.38, 0.76, 1.27$ mm) and pitch spacings ($p=38, 76, 114$ mm). Both these devices re-direct the liquid flow towards the heated wall, thereby increasing CHF. The centrifugal forces of the swirl flow introduced by the twisted tape re-direct the liquid droplets towards the outer (heated) wall. The roughness rings of the annulus strip the parasitic film from the outer (unheated) wall, promoting film development on the inner (heated) surface. For the twisted tape, a minimum flow of liquid at the outlet ($G_{l,out}>82$ kg/m²·s) was found to maintain a continuous liquid-film on both the tape and the wall surfaces. Overall, CHF was increased with increased twist-ratios (lower p/d) and higher exit quality. For the roughened annulus, increases in dryout heat flux up to 500% were obtained by increasing the roughness height from 0 to 1.27 mm at the same spacing ($p=38$ mm). Increases in dryout heat flux up to 35% were obtained by decreasing the roughness spacing from 114 mm to 38 mm. Generally, the largest dryout heat fluxes were obtained with the smallest ring spacings and the largest roughness height, where the experimental data were sometimes limited by the maximum power output of the test section heater.

Tong et al. (1967) measured CHF on a single uniformly heated rod centred in an unheated square channel, using a smooth and rib-roughened rod ($e=0.0025$ in., $p=0.05$ in., $p/e=20$). Their data were compared with those of other similar experiments. Previous subcooled-CHF experiments at $e=0.013$ in. showed increases of up to 100% in CHF for the same local condition (P, G, x), while Tong's experiment in high-quality boiling at $e=0.0025$ in. showed decreases of up to 40% for the same (P, G, x). The subcooled results at $e=0.0025$ in. showed negligible change in CHF. These results were attributed to: large roughness in the subcooled region which disrupts the bubbly layer in the near-wall region (increasing CHF), low roughness in the subcooled region which does not disrupt the bubbly layer (having no effect), and small repeated roughness in the high-quality region which hinders liquid-film development (decreasing CHF).

Table 2.2: Spacer effect on CHF (taken from Groeneveld and Yousef, 1980).

Reference	Geometry	Spacer Type	Flow Conditions	Observed Effect
Peterlongo (1964)	tube	obstacle inside tube ($\epsilon=0.5$)	$P=5$ MPa, $x=0-0.14$, $G=1-4$ Mg/m ² ·s	0-10% reduction in critical power. Contact area obstacle/tube covered 30% of heated perimeter.
Adorni (1964)	annulus	pin spacers	$P=5$ MPa, $x=0-0.6$, $G=1.1-3.8$ Mg/m ² ·s	Presence of 3 sets of spacers increased dryout power 5-50%. Maximum increase at high x .
Shiralkar (1970)	rectangular channel	several shapes: cylinders, rectangular objects	air-water, $V_{av}=13-40$ m/s	Adiabatic study: depending on shape of flow obstruction, adiabatic film dryout occurred upstream or downstream of flow obstruction.
Ilic (1973, 1975)	annulus	3 cylindrical spacers (cylinder axis parallel to flow) $\epsilon=0.2$ $p=305$ and 152 mm	$P=7$ MPa, $G=0.5-3$ Mg/m ² ·s, subcooled inlet	Increases in critical power up to 80%. Maximum increase at high flows, low inlet subcooling, and short spacer pitch (p). Streamlining spacer resulted in smaller increases in critical power.
Perepelitsa (1978)	4-rod	Honeycomb-type spacer with mixing vanes, $p=175$ and 350 mm	$P=6.9$ MPa, $T_m=240-280$ °C, $G=1.0-2.5$ Mg/m ² ·s	Mixing vanes increase critical power by 35%
Katsaounis (1977)	annulus	annular orifice $\epsilon=0.69$	$P=7-21$ MPa, $G=0.4-4.0$ Mg/m ² ·s, subcooled inlet	Increase of 17% in CHF.
Rudzinski (1976)	18-rod	ferrule-type grid spacer $\epsilon=0.20$	$P=7-8.4$ MPa, $x=0.05-0.5$, $G=1.35-5$ Mg/m ² ·s	No effect at low flows. At high flows, grid spacer produces 20% higher CHF. Grid spacer acts as film tripper.
Gaspari (1970)	19-rod	plate-type spacers $\epsilon=0.50$, ferrule-type spacers $\epsilon=0.10$	$P=3-5$ MPa, $x_m=0.3-0.4$, $G=0.2-7.2$ Mg/m ² ·s	Both types of grids act as film tripper. Plate-type grid resulted in 8% lower critical power than ferrule-type grid, but higher pressure drop penalty.
Gaspari (1968)	7-rod	grid spacers $\epsilon=0.03$, plate spacers $\epsilon=0.50$, ferrule spacers $\epsilon=0.18$	$P=3-5$ MPa, $x_m=0.3-0.4$, $G=0.4-2.2$ Mg/m ² ·s	Highest increase with plate and ferrule spacers at high x (25% increase over grid spacers)

Table 2.2 (Continued): Spacer effect on CHF (taken from Groeneveld and Yousef, 1980)

Reference	Geometry	Spacer Type	Flow Conditions	Observed Effect
Becker (1964)	7-rod	grid spacers	$P=3$ MPa, $x=0.1-0.5$, $G=0.1-0.9$ Mg/m ² ·s	Low flow tests, CHF increased by 4%.
Kobori (1976), Takayasu (1974)	28-rod	grid spacers	$P=7$ MPa, $x=0.1-0.5$, $G=1.2-2.6$ Mg/m ² ·s	Grid spacers had maximum beneficial effect at low G and low x ; 10-40% increase in CHF due to reducing pitch (p) from 42 to 26 cm.
Yates (1975)	25-rod	mixing vane grids	$P=10-15$ MPa, $x<0.14$, $G=1.35-3.7$ Mg/m ² ·s	Reducing pitch (p) from 65 to 40 cm increases CHF 20-31%; maximum increase at high x .
Macbeth (1974)	31-rod	grid spacers, $p=160$ mm, $x=0.40$	$P=7$ MPa, $x=0.25-0.75$, $G=0.5-2.9$ Mg/m ² ·s	Large increases over 37-rod bundle: up to 50% in critical power or 150% in CHF (constant x); by increasing x from 0.13 to 0.40.
Stevens (1966)	19-rod	castellated grids; tubular grids; helical wire wraps	$P=7.0$ MPa, subcooled inlet, $G=0.7-2.0$ Mg/m ² ·s	Compared to wire wraps, castellated grids increase critical power by 14% while tubular grids increase it by 26%.
Zielke (1974)	3x3 square array	egg-crate type spacer, $p=254, 381, 533$ mm	$P=10-16.5$ MPa, $G=0.55-2.74$ Mg/m ² ·s, subcooled inlet	No effect of pitch (p) on CHF at high flows.
Aden (unpublished)	3-rod	grid spacers equipped with short twisted tapes $p=350$ mm	$P=7.35-9.8$ MPa, $G=0.6-2.0$ Mg/m ² ·s, subcooled inlet	Twisted tapes increase critical power by 20%; maximum increase at high flows.
Aden (unpublished)	19-rod	grid spacers equipped with short twisted tapes or flow deflectors $p=80, 175, 206, 350$ mm	$P=7.35-9.6$ MPa, $G=0.6-2.0$ Mg/m ² ·s, two-phase inlet	Increase in critical power of 25-35% for spacers with twisted tapes and 40-60% for spacers with flow deflectors. Reduction in pitch (p) from 206 to 80 mm increases critical power by 10%.
Smolin (1978)	7-rod	honeycomb spacers $p=700, 350, 175$ mm	$P=7.35$ MPa, $G=3$ Mg/m ² ·s	CHF increased by 15% and 30% by decreasing pitch (p) from 700 to 350 mm and 175 mm, respectively.
Aden (1978)	19-rod, 7 m heated length	ferrule-type spacers $p=89, 100, 120, 200$ mm	$P=7-8$ MPa, $G=1-3$ Mg/m ² ·s, $T_m=255-265$ °C	Increases in critical power up to 60%.

Table 2.2 (Concluded): Spacer effect on CHF (taken from Groeneveld and Yousef, 1980)

Reference	Geometry	Spacer Type	Flow Conditions	Observed Effect
Ryabov (1977)	18-rod	grid spacers equipped with short twisted tapes or flow deflectors $p=175$ mm	$P=7.4$ MPa, $G=1.0-1.5$ Mg/m ² ·s, $T_{in}=200$ °C (subcooled)	Short twisted tapes increased CHF by 25-35% over the standard grids, while flow deflectors resulted in a CHF increase of 40-60%.
Germak (1973)	3x3 and 4x4 square array	egg-crate type grid and mixing vane grids $p=254-508$ mm	$P=10.2-16.75$ MPa, $G=1.4-5.0$ Mg/m ² ·s, $T_{in}=221-330$ °C	CHF was increased by 4.4% due to reduction in pitch (p) from 508 to 254 mm. Mixing vanes increased the CHF from 3-5.5%.
Adorni (1964)	7-rod	ferrule-type spacers in the middle, pin spacers on the outside, $\epsilon=0.19$, $p=400$ mm	$P=5$ MPa, $x_{in}=-0.2$ to $+0.6$, $G=1.1-2.2$ Mg/m ² ·s	CHF increased by 18%.
Adorni (1966)	7-rod	ferrule-type spacers in the middle, pin spacers on the outside ($\epsilon=0.19$, $p=407$ mm); wire wraps in the middle, pin spacers on the outside ($p=407$ mm)	$P=5-7$ MPa, $x_{in}=-0.2$ to $+0.4$, $G=1.1-3.8$ Mg/m ² ·s	Wire wraps increase CHF by 6-65% over the ferrule spacers. Maximum increase in CHF at high x_{in} .
Groeneveld (1978)	31-rod	plate-type spacers ($\epsilon=0.35$; $p=152, 229, 457$ mm)	$P=7.15-10.4$ MPa, $\Delta H_{in}=15-500$ kJ/kg, $G=1.1-6.7$ Mg/m ² ·s	CHF increased by over 200% by reducing pitch (p) from 457 mm to 152 mm.
Janssen (1969)	16-rod	transverse circular wire $p=495$ mm	$P=4-2-8.75$ MPa, $G=0.34-1.70$ Mg/m ² ·s, subcooled inlet	With the last spacer 100 mm before the end of the heated length, CHF is improved. With the last spacer 470 mm before the end of the heated length, CHF at high flows is reduced.
Ginoux (1978)	16-rod	egg-crate type spacers with and without twisted tapes	$P=10.0$ MPa, $G=0.50-2.50$ Mg/m ² ·s, inlet subcooling 8°C	Spacers without twisted tapes decrease the CHF up to 20%, while spacers with twisted tapes improve CHF up to 17% at high flow.

Watson et al. (1974) investigated the CHF of both subcooled and positive-quality steam flow through vertical and inclined, smooth and helical-ribbed tubes. CHF normally occurred at the exit, with increases in CHF up to 120% obtained in the ribbed vertical tube at high mass flux. At low mass flux ($G < 543 \text{ kg/m}^2\cdot\text{s}$), CHF sometimes occurred upstream at values still higher than those of the smooth tube for the same local conditions (P, G, x). The increase in CHF was attributed to an increase in droplet deposition and suppression of droplet entrainment from the swirling action of the spiral-rib.

Ilic (1975) evaluated CHF in an internally-heated annulus fitted with various rod-spacing devices to maintain the gap between the internal rod and the external tube. Three types of spacers were used and are illustrated in Figure 1.6c: 3-pin (bare), 3 surface-mounted cylinders (cylindrical), and 3 streamlined cylinders (streamlined). Using various numbers and spacings (3 bare at $p=920 \text{ mm}$, 9 cylindrical at $p=305 \text{ mm}$, 15 cylindrical at $p=152 \text{ mm}$, etc.), comparisons were made for the same inlet conditions. At high mass flux, increases in CHF up to 60% were measured for the flat-faced cylindrical spacer at the lowest pitch-spacing ($p=152 \text{ mm}$). Less enhancement was detected at the larger spacing ($p=305 \text{ mm}$), the flat-faced spacer produced the largest increase in CHF, and the number of spacers had the greatest overall impact on CHF. Although the spacers were mounted on the centre rod, they also contacted the outer shell, aiding in the removal of parasitic liquid from the unheated wall. The lesser enhancement with streamlining could be attributed to a lesser capacity of the spacer to strip the liquid from the outer shell. The increased effect of multiple spacers in the annulus can be explained by earlier and continuous removal of the parasitic liquid film.

Tong (1975) proposed the following empirical correction factor for the effect of spacer-grids on CHF in rod-bundles:

$$F_s = 1 + \phi K e^{-\psi(z/d_c)} \text{Re}^{0.6} (d_c/0.5)^{-0.32} \quad (2.43)$$

where ϕ and ψ are empirical constants ($\phi=0.00005$, $\psi=0.0128$), K is the head-loss coefficient for the spacer grid, and z is the downstream distance from the spacer. This enhancement effect of

a grid spacer decays exponentially with distance, diminishes with larger diameters, and increases with higher flow ($Re = Gd/\mu[1-a]$) and larger head-loss.

Kitto and Wiener (1982) extended the work of Watson et al. (1974) to include non-uniform circumferential heating effects on the smooth versus spiral-ribbed internal tubes. The relationship between non-uniform and uniform circumferential heating (q_{peak}/q_{avg}) for CHF in vertical tubes is independent of quality for the ribbed-tube, while a strong function of quality for the smooth tube. Again, CHF is always higher in the ribbed-tube with greater increases with higher quality. These findings were attributed to the re-distribution of liquid film by the spiral-rib from regions of low heat-flux to regions of high heat-flux.

Inasaka et al. (1991) investigated the CHF of subcooled boiling in tubes ($d=6$ mm; $L=0.10$ m) with internal twisted tapes of varying twist ratios ($p/d=2.7, 4.4, 8.7, \infty$). Increases in CHF up to 200% were measured for the same local condition (P, G, x) and the following correlation was fitted to the data:

$$\frac{q_{c, tape}}{q_{c, no-tape}} = (1 + 0.01 \theta)^{1/6} \quad (2.44)$$

$$\theta = \frac{a_t}{g_c} \quad a_t = \frac{\pi^2 V^2}{2 d y^2} \quad 10 < \theta < 10^5$$

where a_t is the centrifugal acceleration of the liquid at the tube wall, and V the superficial axial liquid velocity. The correlation is based on the premise that centrifugal forces acting on the water disrupt the bubbly layer along the wall, preventing the occurrence of DNB-type vapour blanketing. This method of correlation proved more accurate than previous attempts at using an increased water velocity near the wall (due to the longer swirl-flow streamlines), which implies the centrifugal acceleration is more prominent than streamwise flow patterns in augmenting CHF.

Special Effects

This section describes some adiabatic two-phase flow experiments involving air-water mixtures at atmospheric pressure or special electrolytic solutions to better understand the flow patterns and mechanisms of CHF enhancement. Shiralkar and Lahey (1973) studied the effect of blunt flow obstacles on liquid-film flow in an attempt to explain why CHF in fuel bundles tends to occur just upstream of a flow obstacle. A force balance on a dry-patch revealed the most important terms to be the dynamic pressure of the liquid and the surface tension forces. With obstacles, an additional force is present due to the pressure rise in front of the obstacle associated with stagnation of the vapour stream. From flow visualizations in air-water, the following observations were made:

- Without obstacles: "At low air and liquid flow rates, ripples appeared on the surface which rapidly formed two-dimensional waves. On increasing the air or liquid flow rates, the water surface became pebbled. At still higher air flows, roll waves formed on the liquid surface."
- With obstacles: "... as the liquid film flow was reduced, dry patches were observed near the obstacles. Typically, these patches occurred in front ... Sometimes the dry patch occurred behind the object, particularly for the short cylinder."

Using a semi-quantitative analysis, it was determined that the kinetic energy of the waves in the liquid film and the pressure rise in the stagnation region of the air stream were the dominant factors in the dryout upstream of an obstacle. The dryout downstream of an obstacle was found to be dependent on the strength of the air vortex and the liquid film momentum in the wake of the obstacle.

Namie and Shiozaki (1991, 1993) investigated the entrainment fraction, the ratio of entrained liquid droplet flow to total liquid flow, in air-water flow inside tubes fitted with helically-ribbed and wired inner surfaces. Various rib heights, wire diameters, and pitch ratios were used. The total liquid flow was varied from 17 to 83 g/s in the 19.5 mm ID tube ($G_T=560$

to 2700 kg/m²·s), and the air velocity from 20 to 60 m/s. The entrainment fraction at the outlet was measured as a function of the air velocity, tube-type and liquid flow rate. It was found that the entrainment fraction decreased with increased roughness height ($\pi e/p$), increased air velocity, and decreased helical pitch. Flow visualization showed that the disturbance waves in the liquid film were disrupted by the helical roughness, reducing their number and height, and changing their shape from two-dimensional (annulus) to three-dimensional waves. Namie and Shiozaki attributed these effects to two possible flow mechanisms: re-direction of the film flow by the helical structures (reducing the kinetic energy of the film), and centrifugal forces (induced by the swirl-flow) acting on the liquid film. To determine which of the two entrainment suppression mechanisms was dominant, a similar set of experiments were performed in an annulus with helical ribs mounted on the inner-rod surface, reversing the direction of centrifugal body forces acting on the liquid-film. A similar reduction in droplet entrainment was observed, indicating flow-redirection as the most probable cause of entrainment suppression.

Berger and Hau (1979) studied the effect of square-rib roughness on the mass transfer inside tubes. They used an electrochemical analogue technique in which the tube wall was constructed from discrete (isolated) cathodes, and the electrical current measured across a common anode downstream. A special aqueous electrolytic solution was used which ensured the reaction at the cathodes dominated the current, permitting a direct measure of the average mass-transfer rate across each wall-section downstream of the rib. The pitch ratios were varied from $p/e=3$ to 10 for a fixed height-to-diameter ratio ($d=110$ mm, $e=4$ mm, $e/d=0.0364$), corresponding to a 14% blockage area. The Reynolds number was varied from 10^4 to 2.5×10^5 . The mass-transfer coefficients on the ribbed-wall ($k_R(x)$) were compared to that of a smooth pipe (k_s) taken from the earlier work of Berger and Hau (1977):

$$St_s = \frac{k_s}{\bar{u}} = 0.0165 Re^{-0.4} Sc^{-0.67} \quad (Sc > 1000) \quad (2.45)$$

The results for $k_R(x)/k_s$, shown in Figure 2.6, indicate a two-cycle rise and decay between each rib element. A first rapid rise-and-fall occurs before and after the obstacle associated with flow

redirection in front of the rib and in the wake behind the rib. A second progressive rise occurs in the recirculation zone following the rib up to the reattachment point, 4 or 5 rib-heights downstream. This phenomena has already been illustrated in the single-phase heat-transfer experiment by Okamoto et al. (1993), reinforcing the analogy between heat and mass transfer. Following reattachment of the boundary layer, mass transfer decreases as the boundary layer re-develops and approaches that of a smooth tube. In all cases, the values of $k_R(x)$ were higher than those measured in the smooth tube. As the mean flow (Re) is increased, the ratio $k_R(x)/k_s$ decreases — which is attributed to the fact that the mean flow

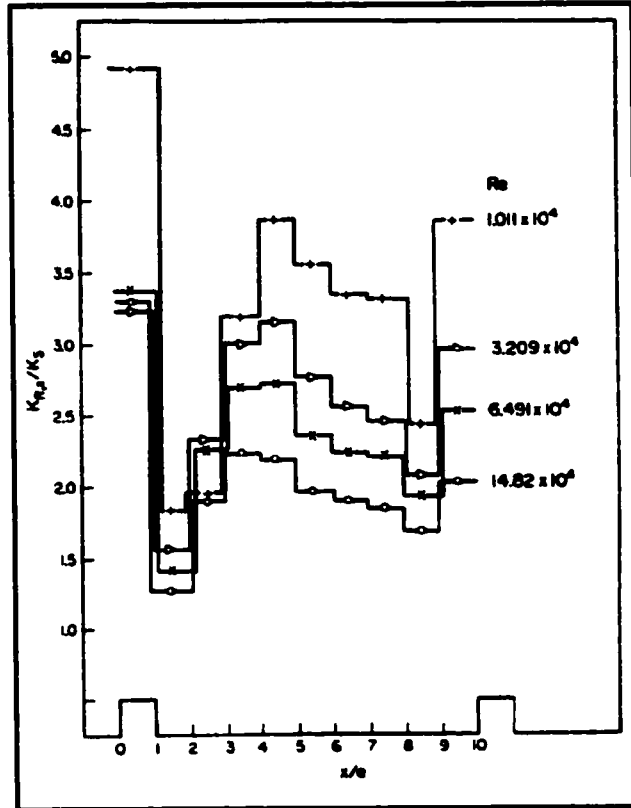


Figure 2.6: Mass transfer coefficient distribution downstream of a roughness rib for $p/e=10$ and $Sc=1535$, adapted from Berger and Hau (1979) with permission of Elsevier Science.

turbulence increases with Re, diminishing the relative contribution of the roughness element. Berger and Hau fitted the following correlation to the average mass-transfer rates ($p/e=10$):

$$St_R = \frac{\bar{k}_R}{\bar{u}} = 0.281 Re^{-0.305} Sc^{-0.67} \quad (Sc > 1000) \quad (2.46)$$

which, when combined with the previous relation, defines the average mass-transfer enhancement ratio:

$$\frac{St_R}{St_s} = \frac{\bar{k}_R}{k_s} = \frac{0.281}{0.0165} \frac{Re^{-0.305}}{Re^{-0.14}} \frac{Sc^{0.67}}{Sc^{-0.67}} = 17.03 Re^{-0.165} \quad (2.47)$$

and represents an increase in mass transfer of 200-400% over the range $10^4 < Re < 3 \times 10^5$. Berger and Hau also observed:

1. For high Schmidt numbers ($1000 < Sc < 7000$), the normalized mean Stanton number, St_R/St_s , is independent of Sc , but decreases with increased Re . However, from their previous experiments, this mean-flow effect is very small at low Schmidt or Prandtl numbers.
2. The normalized distribution of mass transfer, $k_R(x)/\bar{k}_R$, is independent of Sc over a wide range of Schmidt or Prandtl numbers.

No relations for the normalized local mass-transfer enhancement ratio, $k_R(x)/k_s$, or the effects of low Schmidt or Prandtl numbers (typical of steam flows) are given.

Nishida et al. (1994) measured the liquid-film thickness and flow patterns near a typical boiling water reactor (BWR) grid spacer in a 4×4 and 9×9 mock-up nuclear fuel bundle, using air-water. They compared two different corner lattice spacer types. The percent change in the corner-rod liquid-film was dependent on the spacer shape, and superficial gas-velocity (G_g/ρ_g), and independent of the superficial liquid-velocity (G_l/ρ_l). A correlation was observed between the percent change in liquid-film thickness in the vicinity of a spacer and the order of rod-dryout in the bundle critical power data (CHF). Further testing on corner, side, and inner rods, using multiple ferrous-type spacers, revealed that although the film thickness decreases across a spacer, the thickness recovers downstream of the spacer. This has been attributed to a net increase in droplet deposition due to the increased turbulence of the air flow. Nishida et al. concluded that BWR-type spacers have two impacts on the liquid-flow: gas-flow turbulence

increases both the droplet deposition and entrainment; the direct interaction of the spacer with the liquid-film can redirect liquid flow through stripping and impingement.

2.2 Modelling Studies

This section reviews the literature on dryout CHF modelling. The first part is a comprehensive review of the different formulations and applications of existing dryout models. The second part describes one particular model and the various constitutive relations which can be incorporated into it, and the third part reviews the literature on spacer modelling.

2.2.1 Existing Dryout Models

The first comprehensive analytical model for dryout CHF in annular flow was developed by Whalley et al. (1974) and is a compilation of various annular flow mechanisms previously studied. The first mechanism is the triangular relation which defines the inter-relation between liquid-film flow, film thickness, and frictional pressure-gradient. The second mechanism is the mass-transfer process describing both the droplet deposition onto the liquid film and the entrainment of liquid-droplets from the wavy surface of the film into the core region. The model provides a closed-form solution to the governing annular flow equations under steady-state, constant-property, and uniform heat-flux conditions within a tube. The droplets and vapour inside the core region are assumed homogeneous. The model was applied to CHF data in water and Freon-12 with errors typically within $\pm 10\%$.

The model by Whalley et al. (1974) was later expanded by Whalley (1977) for dryout in fuel-rod bundles. The equations for a rod-centred subchannel were derived with the

liquid-film, and droplet and vapour core assumed uniform around each rod. The crossflow between adjacent subchannels was modelled using a combination of flow mechanisms:

- the droplet transfer from turbulent mixing between subchannels is a function of the droplet concentration-gradient between adjacent subchannels,
- the droplet transfer from the gas crossflow between subchannels is a function of the entrained droplet fraction in the subchannel from which the crossflow originated, and
- the gas crossflow itself arising from pressure-gradients between adjacent subchannels tends to re-distribute the vapour so that the total axial pressure-gradient is the same in all subchannels.

The model was shown to predict CHF with reasonable agreement to both 7-rod and 16-rod bundle CHF data.

Saito et al. (1978) presented a model similar to Whalley (1977), except the subchannel was flow-centred instead of rod-centred (i.e., more than one film per rod) and included the transient terms in the formulation. The crossflow between subchannels was neglected, with each subchannel in parallel having the same bundle-average mass flux. A generalized formulation of the axial mass, momentum, and energy equations for a multi-fluid system are presented and applied to various flow geometries: tube, annuli, and rod bundle. The model not only includes the interfacial drag between film and vapour (Whalley et al., 1974), but also considers the drag force between entrained droplets and vapour. An extensive validation process was undertaken to verify the model against the following experiments:

- entrained liquid fraction, pressure-gradient, and film thickness of equilibrium air-water flows in a pipe,
- entrained liquid-flow rate, film thickness, and pressure-gradient of non-equilibrium air-water flows in a pipe,
- entrained liquid and liquid-film fractions at the channel exit of boiling water flow in a tube,

- pressure-drop and CHF in boiling water flow ($P=7.0$ MPa, uniform and non-uniform axial heat-flux distribution),
- rod-film fraction and rod film thickness for boiling water flow in an annulus ($P=7.0$ MPa),
- CHF for boiling water in a uniformly heated annulus ($P=7.0$ MPa, unheated outer tube),
- CHF for boiling water in a bilaterally heated annulus ($P=7.0$ MPa),
- CHF for boiling water in a 16-rod bundle ($P=7.0$ MPa, uniform axial and radial power distributions).

The RMS accuracy of the model was $\pm 15\%$, except in 16-rod bundles where under-predictions in CHF as much as 50% were observed at low flow conditions ($G=100$ kg/m²·s). It should be noted that flow-boiling tests were conducted using steam at 7 MPa under steady-state conditions. Sugawara (1990), and Sugawara and Miyamoto (1990) presented a model very similar to Saito et al. (1978), except they derived their own entrainment and deposition relations and attempted a more mechanistic transition to annular flow.

More recently, Hewitt and Govan (1990) have provided a new set of entrainment/deposition relations which cover a wide range of fluids, pressure, and mass flux. They successfully applied the relations to model steady adiabatic flows, evaporative flows in both dryout and post-dryout, as well as condensation flows, and transient dryout and rewetting.

From the existing dryout models, numerous forms of the constitutive relations governing interfacial shear stress, entrainment, deposition, and transition to annular flow are obtained, with their range of applicability provided in only a few cases. Since the present study only considers steady-state CHF inside a tube, the model formulation by Whalley et al. (1974) was chosen for its relative simplicity and applicability to a wide range of flows. To select the appropriate constitutive relations, those obtained from all the existing models are described and form the basis of the assessment of current CHF dryout models in Chapter 5.

2.2.2 The Whalley Model

The annular flow dryout model of Whalley et al. (1974) is a three-fluid model, separating the flow into liquid-film, entrained droplets and vapour, as illustrated in Figure 2.7. The following assumptions are made:

- constant fluid properties (i.e., no flashing)
- constant area flow channel
- steady-state conditions
- liquid droplets and vapour are homogeneous in the central core
- phases are in saturated thermodynamic equilibrium

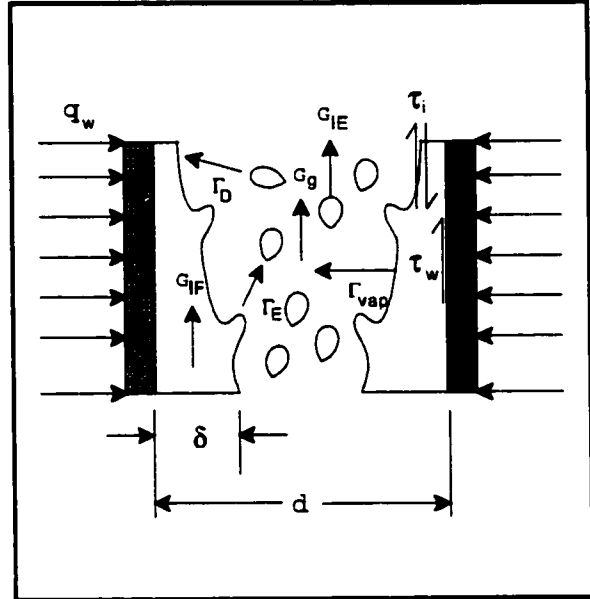


Figure 2.7: Three-fluid modelling in annular two-phase flow.

Conservation Laws

From the conservation of mass on each fluid component:

$$\frac{d}{ds}(\rho_l u_{lF} \alpha_{lF}) = \frac{dG_{lF}}{ds} = \Gamma_D - \Gamma_E - \Gamma_{vap} \quad (2.48)$$

$$\frac{d}{ds}(\rho_l u_{lE} \alpha_{lE}) = \frac{dG_{lE}}{ds} = \Gamma_E - \Gamma_D \quad (2.49)$$

$$\frac{d}{ds}(\rho_g u_g \alpha_g) = \frac{dG_g}{ds} = \Gamma_{vap} \quad (2.50)$$

where the following liquid-phase fractions (α_{lF} , α_{lE}), void fractions (α_g , α_c , α_{gc}):

$$\begin{aligned} \alpha_{lF} &= \frac{A_{lF}}{A} = 1 - \alpha_c & \alpha_{lE} &= \frac{A_{lE}}{A} = (1 - \alpha_{gc}) \alpha_c & \alpha_g &= \frac{A_g}{A} = \alpha_{gc} \alpha_c \\ \alpha_c &= \frac{A_c}{A} = \left[1 - 2 \left(\frac{\delta}{d} \right) \right]^2 & \alpha_{gc} &= \frac{1}{1 + \left(\frac{\rho_g}{\rho_l} \right) \left(\frac{1 - x_c}{x_c} \right)} \end{aligned} \quad (2.51)$$

and core quality are defined:

$$x_c = \frac{G_g}{G_c} = \frac{G_g}{G_g + G_{lE}} \quad (2.52)$$

From the conservation of momentum:

$$\begin{aligned} \frac{d}{ds}(G_{lF} u_{lF}) &= (\Gamma_D - \Gamma_E - \Gamma_{vap}) u_i - \alpha_{lF} \frac{dP}{ds} \\ &+ \rho_l \alpha_{lF} g_s - \tau_w \frac{W_w}{A} + \tau_i \frac{W_i}{A} \end{aligned} \quad (2.53)$$

$$\frac{dG_{lE} u_{lE}}{ds} = (\Gamma_E - \Gamma_D) u_i - \alpha_{lE} \frac{dP}{ds} + \rho_l \alpha_{lE} g_s \quad (2.54)$$

$$\frac{dG_g u_g}{ds} = \Gamma_{vap} u_i - \alpha_g \frac{dP}{ds} + \rho_g \alpha_g g_s - \tau_i \frac{W_i}{A} \quad (2.55)$$

The mean fluid velocity (u_i) at the interface is used to describe the lateral transfer of momentum between film, droplets, and vapour. The g_s term is used to define the gravity force acting in the flow direction (i.e., $g_s = g \vec{n}_s \cdot \vec{n}_z = g \cos \theta_s$). Summing up only the core terms:

$$\frac{dG_c u_c}{ds} = (\Gamma_E + \Gamma_{vap} - \Gamma_D) u_i + \rho_c \alpha_c g_s - \alpha_c \frac{dP}{ds} - \tau_i \frac{W_i}{A} \quad (2.56)$$

and assuming a uniform turbulent core:

$$u_i = u_{IF}(\delta) = u_c(\delta) = u_c \quad (2.57)$$

Substituting the core continuity equation:

$$\frac{dG_c}{ds} = \Gamma_E + \Gamma_{vap} - \Gamma_D \quad (2.58)$$

into the core momentum equation results in the following pressure gradient equation:

$$\frac{dP}{ds} = \rho_c g_s - \frac{1}{\alpha_c} \left[\tau_i \frac{W_i}{A} + G_c \frac{du_c}{ds} \right] \quad (2.59)$$

where the core density is defined as:

$$\rho_c = (1 - \alpha_{gc}) \rho_l + \alpha_{gc} \rho_g = \frac{\alpha_{lg} \rho_l + \alpha_g \rho_g}{\alpha_c} \quad (2.60)$$

If the liquid-film is sufficiently thin ($\alpha_c \approx 1$), the pressure-drop can be further simplified to:

$$\frac{dP}{ds} = \rho_c g_s - \tau_i \frac{W_i}{A} - G_c \frac{du_c}{ds} \quad (2.61)$$

where

$$\frac{W_w}{A} = \frac{4}{d} \quad \frac{W_i}{A} = \frac{4 d_i}{d^2} \quad d_i = d - 2\delta \quad (2.62)$$

From the conservation of energy:

$$\frac{d}{ds} (G_{lf} i_l) = (\Gamma_D - \Gamma_E) i_l - \Gamma_{vap} i_g + q_w \frac{W_w}{A} \quad (2.63)$$

$$\frac{d}{ds} (G_{le} i_l) = (\Gamma_E - \Gamma_D) i_l \quad (2.64)$$

$$\frac{d}{ds} (G_g i_g) = \Gamma_{vap} i_g \quad (2.65)$$

Introducing the enthalpy of vaporization:

$$i_g = i_l + i_{lg} \quad (2.66)$$

and substituting the liquid-film continuity equation into the film energy equation:

$$\begin{aligned}
\frac{d}{ds}(G_{IF} i_l) &= (\Gamma_D - \Gamma_E) i_l - \Gamma_{vap} (i_l + i_{lg}) + q_w \frac{W_w}{A} \\
&= (\Gamma_D - \Gamma_E - \Gamma_{vap}) i_l - \Gamma_{vap} i_{lg} + q_w \frac{W_w}{A}
\end{aligned} \tag{2.67}$$

results in the following expression for the volumetric evaporation rate (Γ_{vap}):

$$\Gamma_{vap} = \frac{q_w}{i_{lg}} \frac{W_w}{A} = \frac{q_w}{i_{lg}} \frac{4}{d} \tag{2.68}$$

It should be noted that since the fluid properties are assumed constant:

$$\frac{di_l}{ds} = \frac{di_l}{dp} \cdot \frac{dp}{ds} = 0 \quad \frac{di_g}{ds} = \frac{di_g}{dp} \cdot \frac{dp}{ds} = 0 \tag{2.69}$$

The volumetric entrainment and deposition rates are normally expressed based on an equivalent mass-flux over the interfacial area:

$$\Gamma_D A \Delta s = D W_w \Delta s \quad \Gamma_E A \Delta s = E W_w \Delta s \tag{2.70}$$

Hence,

$$\Gamma_D = D \frac{4}{d} \quad \Gamma_E = E \frac{4}{d} \tag{2.71}$$

Deposition Relations

A general expression for deposition (D) can be defined using Fick's law:

$$D = - \lambda \left. \frac{\partial C}{\partial y} \right|_i = k (C_c - C_i) = k C \tag{2.72}$$

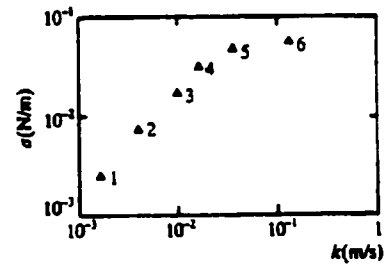
where λ and k are the mass-diffusion and mass-transfer coefficients, respectively. Since the liquid-film interface is all liquid, the concentration is normally neglected ($C_i=0$) and the volumetric droplet concentration within the core is defined as:

$$C = \frac{\int_{A_c} \rho_l u_{lE} dA}{\int_{A_c} u dA} = \frac{\rho_l u_{lE} (1 - \alpha_{gc}) A_c}{u_{lE} (1 - \alpha_{gc}) A_c + u_g \alpha_{gc} A_c} \quad (2.73)$$

$$= \frac{\rho_l u_{lE} (1 - \alpha_{gc}) \alpha_c}{u_{lE} (1 - \alpha_{gc}) \alpha_c + u_g \alpha_{gc} \alpha_c} = \frac{G_{lE}}{\frac{G_{lE}}{\rho_l} + \frac{G_g}{\rho_g}}$$

The various dryout models cited use different correlations to describe the mass-transfer coefficient (k) in Equation (2.72).

Whalley et al. (1974) used the annular flow model itself to predict values of k which best fit the experimental CHF data. This purely empirical approach indicated a functional relationship with liquid surface tension, as illustrated in Figure 2.8, even when different fluids were considered. The following relation has been curve-fit by the author to the data in Figure 2.8:



Pressures and fluids used in Fig.

Data point	Fluid	P (bar)
1	Steam-water	180
2	R12	10.5
3	Steam-water	69
4	Steam-water	24
5	Steam-water	10
6	Steam-water	1.5

Figure 2.8: Mass-transfer coefficients in two-phase flow, adapted from Whalley (1990) with permission of Oxford University Press.

$$\log_{10}(k) = 2.8163 + 4.0685 \log_{10}\sigma + 0.7430 (\log_{10}\sigma)^2 \quad (2.74)$$

where k has units of m/s and σ units of N/m. Whalley and Hewitt (1978) later derived the following relation:

$$\frac{k}{u_c^*} = 87 \sqrt{\frac{\mu_l^2}{d \sigma \rho_l}} \quad u_c^* = \sqrt{\frac{\tau_i}{\rho_c}} \quad (2.75)$$

and Saito et al. (1978) derived their own relation for flow-boiling in round tubes using a limited set of steam-flow deposition data:

$$k = -1.698 \times 10^{-2} - 2.117 \times 10^{-4} C + 2.896 \times 10^{-4} C^2 - 2.192 \times 10^{-8} C^3 + 7.778 \times 10^{-11} C^4 - 1.027 \times 10^{-13} C^5 \quad (2.76)$$

where k has units of m/s and C units of kg/m³. More recently, Hewitt and Govan (1990) derived an empirical relation for k from the data shown in Figure 2.9:

$$k = \begin{cases} 0.1815 \sqrt{\frac{\sigma}{\rho_g d}} & , \frac{C}{\rho_g} \leq 0.3 \\ 0.083 \sqrt{\frac{\sigma}{\rho_g d}} \left(\frac{C}{\rho_g} \right)^{-0.65} & , \frac{C}{\rho_g} > 0.3 \end{cases} \quad (2.77)$$

where k has units of m/s. Sugawara (1990) used the analogy between heat and mass transfer to derive an expression for k . Using the Reynolds-Colburn analogy for heat transfer (Holman, 1981):

$$\text{St Pr}^{2/3} = \frac{h}{\rho C_p u_{av}} \text{Pr}^{2/3} = \frac{f}{2} = A \text{Re}^b \quad \left(\text{Pr} = \frac{\mu C_p}{K} \right) \quad (2.78)$$

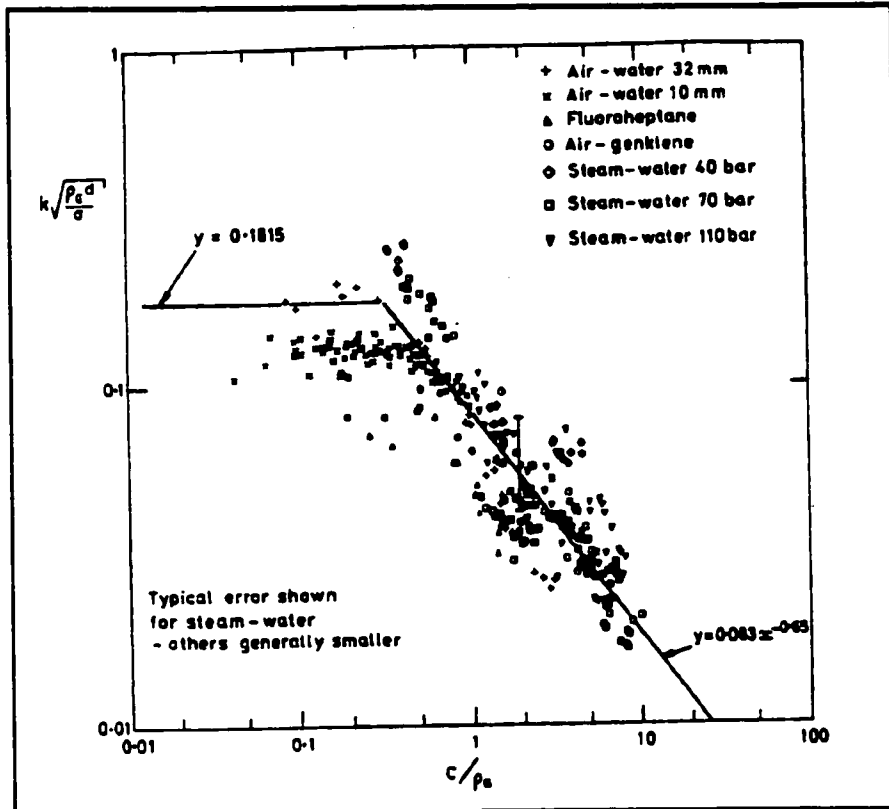


Figure 2.9: Deposition correlation, adapted from Hewitt and Govan (1990) with permission of Elsevier Science.

we can derive a similar expression for mass transfer:

$$\frac{k}{u_{av}} Sc^{2/3} = \frac{f}{2} = A Re^b \quad \left(Sc = \frac{\mu}{\rho \lambda} \right) \quad (2.79)$$

where k/u_{av} is sometimes referred to as the Stanton number for mass transfer. The Prandtl number (Pr) denotes the ratio of kinematic viscosity (eddy diffusivity) to thermal diffusivity, whereas the Schmidt number (Sc) denotes the ratio of kinematic viscosity to mass diffusivity. By introducing the Lewis number (Le), the ratio of thermal to mass diffusivity, we arrive at the following empirical form for mass transfer:

$$\frac{k}{u_{av}} = A \text{Re}^b \text{Sc}^{-2/3} = A \text{Re}^b \text{Pr}^{-2/3} \left(\frac{\text{Sc}}{\text{Pr}} \right)^{-2/3} = A \text{Re}^b \text{Pr}^{-2/3} \text{Le}^{-2/3} \quad (2.80)$$

which, when compared with Sugawara (1990):

$$\frac{k}{u_g} = 9.0 \times 10^{-3} \left(\frac{C}{\rho_g} \right)^{-0.5} \text{Re}^{-0.2} \text{Pr}^{-2/3} \quad \left\{ \begin{array}{l} 0.1 < p < 7 \text{ MPa} \\ 10^4 < \text{Re}_g < 10^6 \end{array} \right. \quad (2.81)$$

indicates a Lewis number of unity was assumed ($\text{Sc}=\text{Pr}$). In this case where liquid droplets are diffusing through vapour, it is not evident that the mass and thermal diffusivities should be the same. However, this may have been partially compensated for by the use of a non-dimensional concentration (C/ρ_g) in the above correlation, which varies with both quality and pressure. Sugawara also defined a deposition suppression term to account for the fact that the vapour leaving the liquid-film through evaporation opposes the deposition of droplets onto the liquid-film:

$$D' = D - u_b e^{(-\delta/\delta_n)} C = D - \left(\frac{q_w}{\rho_g i_{lg}} \right) e^{(-\delta/\delta_n)} C \geq 0 \quad (2.82)$$

$$\delta_n = 7.90 \left(\frac{P}{P_{cr}} \right) \left(\frac{30 v}{\sqrt{\tau_{LF} / \rho_l}} \right) \quad (2.83)$$

The term δ/δ_n denotes a relatively thin liquid-film, where the radial gas stream is assumed to have a significant effect on droplet deposition, and is shown to have a significant impact on both film flow and CHF for large boiling-lengths (i.e., in excess of 300 diameters).

Entrainment Relations

The entrainment of liquid (E) from the wall to the core region of annular flow is different from deposition since the source of droplets is a saturated liquid ($C_w=0$). Whalley et al. (1974) modelled entrainment as a process tending towards hydrodynamic equilibrium:

$$E = k C_E \quad (2.84)$$

Hutchinson and Whalley (1973) found

a strong correlation between the equilibrium concentration (C_E) obtained in adiabatic air-water experiments and the interfacial Weber number:

$$S = \frac{\tau_i \delta}{\sigma} = \frac{\text{shear forces}}{\text{surface tension forces}} \quad (2.85)$$

as illustrated in Figure 2.10, to which the following relation was fitted (Tahir et al., 1987):

$$C_E = \begin{cases} 0.036 - 4.22 \left(\frac{\tau_i \delta}{\sigma} \right) + 253 \left(\frac{\tau_i \delta}{\sigma} \right)^2 - 427 \left(\frac{\tau_i \delta}{\sigma} \right)^3, & \left(\frac{\tau_i \delta}{\sigma} \right) < 0.3 \\ 10 \left[0.33 - 2.22 \left(\frac{\tau_i \delta}{\sigma} \right) \right], & \left(\frac{\tau_i \delta}{\sigma} \right) \geq 0.3 \end{cases} \quad (2.86)$$

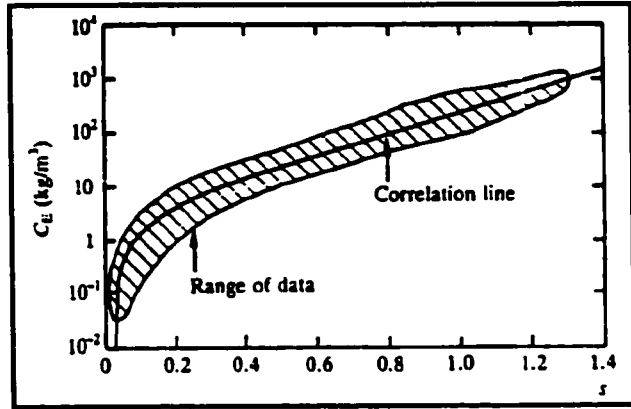


Figure 2.10: Entrainment correlation, adapted from Hutchinson and Whalley (1973) with permission of Elsevier Science.

Saito et al. (1978) derived a similar series of expressions to correlate the equilibrium entrainment rate directly:

$$\begin{aligned}
 E = & -2.695 \times 10^{-3} - 1.104 \left(\frac{\tau_i \delta}{\sigma} \right) + 4.444 \times 10 \left(\frac{\tau_i \delta}{\sigma} \right)^2 \\
 & + 1.241 \times 10^3 \left(\frac{\tau_i \delta}{\sigma} \right)^3 - 3.775 \times 10^3 \left(\frac{\tau_i \delta}{\sigma} \right)^4 \\
 & + 4.077 \times 10^3 \left(\frac{\tau_i \delta}{\sigma} \right)^5 - 1.510 \times 10^3 \left(\frac{\tau_i \delta}{\sigma} \right)^6, \quad \left(\frac{\tau_i \delta}{\sigma} \right) \leq 1 \quad (2.87)
 \end{aligned}$$

$$\begin{aligned}
 E = & -4.504 \times 10 + 1.824 \times 10^2 \left(\frac{\tau_i \delta}{\sigma} \right) \\
 & - 6.828 \times 10 \left(\frac{\tau_i \delta}{\sigma} \right)^2 + 1.343 \times 10 \left(\frac{\tau_i \delta}{\sigma} \right)^3, \quad 1 < \left(\frac{\tau_i \delta}{\sigma} \right) \leq 5 \quad (2.88) \\
 & - 1.268 \left(\frac{\tau_i \delta}{\sigma} \right)^4 + 4.519 \times 10^{-2} \left(\frac{\tau_i \delta}{\sigma} \right)^5
 \end{aligned}$$

$$\begin{aligned}
 E = & +4.670 \times 10 + 4.725 \times 10 \left(\frac{\tau_i \delta}{\sigma} \right) \\
 & - 4.534 \left(\frac{\tau_i \delta}{\sigma} \right)^2 + 1.518 \times 10^{-1} \left(\frac{\tau_i \delta}{\sigma} \right)^3, \quad 5 < \left(\frac{\tau_i \delta}{\sigma} \right) \leq 10 \quad (2.89)
 \end{aligned}$$

and

$$E = 0.01 \rho_l \left\{ 1 - e^{-4.605 \left[\left(\frac{\tau_i \delta}{\sigma} \right) - 10 \right]} \right\}, \quad \left(\frac{\tau_i \delta}{\sigma} \right) > 10 \quad (2.90)$$

Equation (2.90) is said to represent the large jump in entrainment typical of churn-annular flow transitions.

Hewitt and Govan (1990) correlated the ratio of entrainment-to-vapour flow rates based on liquid film flow rate directly, as illustrated in Figure 2.11:

$$\frac{E}{G_g} = \begin{cases} 5.75 \times 10^{-5} \left[(G_{lF} - G_{lFC})^2 \frac{d\rho_l}{\sigma\rho_g^2} \right]^{0.316} & , G_{lF} > G_{lFC} \\ 0 & , G_{lF} \leq G_{lFC} \end{cases} \quad (2.91)$$

where the critical film flow rate for the onset of entrainment is given by:

$$\frac{G_{lFC}d}{\mu_l} = Re_{lFC} = \exp \left[5.8504 + 0.4249 \left(\frac{\mu_g}{\mu_l} \right) \sqrt{\frac{\rho_l}{\rho_g}} \right] \quad (2.92)$$

Sugawara (1990) used the following correlation to model entrainment:

$$E = 1.07 S_R , \quad \begin{cases} 0.27 < p < 9 \text{ MPa} \\ 3 \times 10^4 < Re_g < 7 \times 10^5 \end{cases} \quad (2.93)$$

$$S_R = \left(\frac{\tau_i \Delta h_{eq}}{\sigma} \right) \left(\frac{u_g \mu_l}{\sigma} \right) \left(\frac{\rho_l}{\rho_g} \right)^{0.4} \quad (2.94)$$

where the equivalent wave-height (Δh_{eq}) is correlated:

$$\Delta h_{eq} = \begin{cases} \epsilon_s & , Re_g \geq 1 \times 10^5 \\ \epsilon_s [2.13 \log_{10}(Re_g) - 9.68] & , Re_g < 1 \times 10^5 \end{cases} \quad (\Delta h_{eq} \geq 0) \quad (2.95)$$

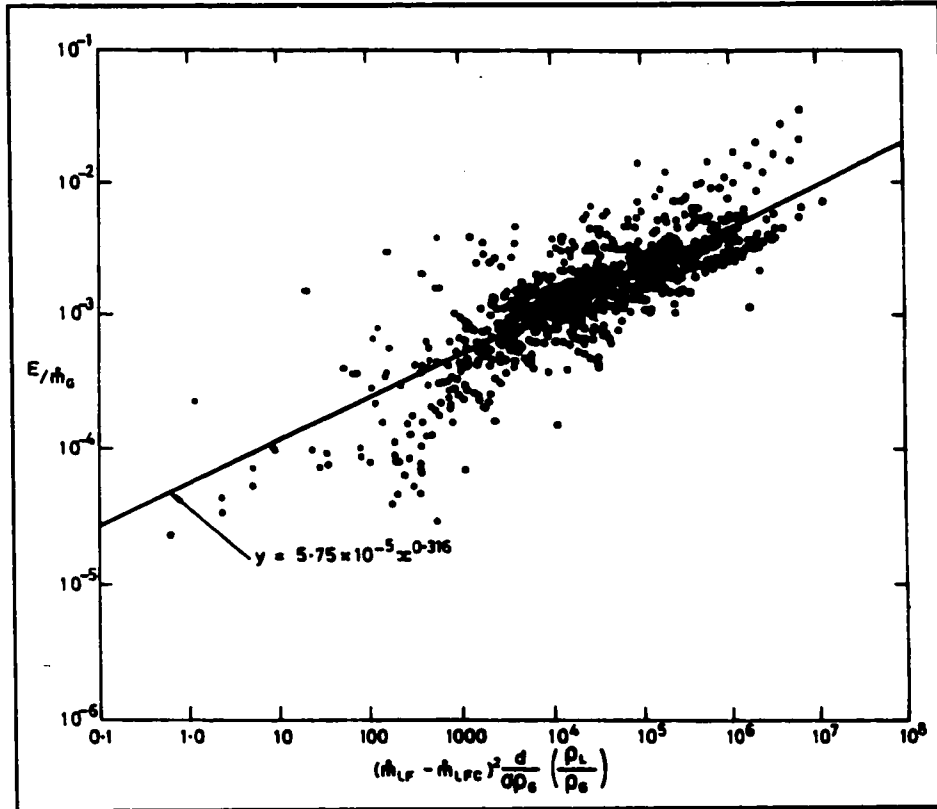


Figure 2.11: Entrainment correlation, adapted from Hewitt and Govan (1990) with permission of Elsevier Science.

against an equivalent sand-roughness defined by:

$$\epsilon_s = 0.57 \delta + 21.73 \times 10^3 \delta^2 - 38.8 \times 10^6 \delta^3 + 55.68 \times 10^9 \delta^4 \quad (2.96)$$

Interfacial Shear Stress Relations

Whalley et al. (1974) used the interfacial roughness correlation formulated by Wallis (1970) to calculate shear stresses at the interface of the liquid film and homogeneous liquid-droplet/vapour core:

$$\tau_i = f_i \rho_c \frac{u_c^2}{2} \quad (2.97)$$

$$f_i = f_c \left[1 + 360 \left(\frac{\delta}{d} \right) \right] \quad (2.98)$$

where the core friction factor is determined from turbulent flow pipe-friction correlations, as described in Section 2.1.1, using an equivalent gas core Reynolds number:

$$\text{Re}_c = \frac{G_c d}{\mu_g} = \frac{(G_g + G_{LE})d}{\mu_g} \quad (2.99)$$

However, because the Wallis relation is based on a limited set of air/water flow data at low pressure, Whalley reported an RMS error of 90% in interfacial shear when applied to a wider range of steam flow data. Using a trial and error approach, Whalley and Hewitt (1978) fitted the following modified correlation to take into account some of the pressure effects:

$$f_i = f_c \left[1 + 24 \left(\frac{\rho_l}{\rho_g} \right)^{1/3} \left(\frac{\delta}{d} \right) \right] \quad (2.100)$$

This reduced the error in interfacial shear to about 26% for the tested data set. Saito et al. (1978) use the friction factor of Moeck (1970):

$$\Lambda_i = 4f_i = 0.02 \left[1.0 + 545.0 \left(\frac{2\delta}{d} \right)^{1.42} \right] \quad (2.101)$$

which, contrary to Whalley et al., is independent of Re. They also include the interfacial friction between droplets and vapour (non-homogeneous core) but these terms are neglected in the Whalley model. Sugawara and Miyamoto (1990) used the original Wallis correlation.

The Triangular Relation

To solve the interfacial shear stress, liquid-film mass flow rate and film thickness simultaneously, a triangular relationship relating the three is required. One method would be to solve the film and core momentum equations simultaneously. However, more direct (empirical) methods have been developed:

- Universal Velocity Profile Method
- Shear-Stress Integration Method
- Approximate Thick-Film Analysis

The Universal Velocity Profile Method, presented by Whalley (1990), uses the "law of the wall", as described in Section 2.1.1, to define the liquid-film velocity, replacing the wall shear velocity with the interfacial shear velocity. The resultant non-dimensional velocity profile is integrated to obtain an estimate of the liquid film mass flux:

$$G_{lF} = \frac{4\mu_l}{d} \int_0^{\delta^*} \left[1 - 2 \left(\frac{y^*}{d^*} \right) \right] u^* dy^* \quad \text{Note: } d^* = \frac{du^*}{v} \quad (2.102)$$

This mass-flux must be iterated as a function of film thickness until the desired liquid-film mass flux is obtained. Comparisons between annular flow data and this form of the triangular relation are only accurate in low-pressure air-water flows where the liquid films are thin and consequently, the wall shear stress and interfacial shear stress are almost equal. The inaccurate data invalidate the inherent assumption that shear stress is a constant.

Hewitt (1961) developed the Shear-Stress Integration Method based on the analysis of Dukler (1959) involving the direct integration of the liquid-film shear stress in annular flow:

$$\begin{aligned}
\tau(r) &= -\frac{1}{2} \left(\rho_c g + \frac{dp}{ds} \right) \left(\frac{r_i^2}{r} \right) - \frac{1}{2} \left(\rho_l g + \frac{dp}{ds} \right) \left(\frac{r^2 - r_i^2}{r} \right) \\
&= \frac{1}{2} (\rho_l - \rho_c) g \frac{r_i^2}{r} - \frac{1}{2} \left(\rho_l g + \frac{dp}{ds} \right) r
\end{aligned} \tag{2.103}$$

which has been shown to predict a wide range of annular flows quite accurately. However, the methods were too cumbersome for implementation in any annular flow dryout models (Hewitt and Hall-Taylor, 1970). If the following simplification can be made for the liquid film:

$$\left| (\rho_l - \rho_c) g \frac{r_i^2}{r} \right| \ll \left| \rho_l g + \frac{dp}{ds} \right| \tag{2.104}$$

then a linear shear-stress distribution is obtained for the liquid film:

$$\tau(r) = -\frac{1}{2} \left(\rho_l g + \frac{dp}{ds} \right) r = \tau_i \frac{r}{r_i} \tag{2.105}$$

Similar to the Prandtl friction factor, the logarithmic inner-law:

$$u^+ = \frac{1}{K} \ln(y^+) + B \tag{2.106}$$

can be integrated over the film area to obtain the liquid-film flow rate:

$$\begin{aligned}
G_{lF} = \frac{\mu_l d^+}{d} & \left\{ \frac{1}{K} \left[\ln(\delta^+) \left[1 - \left(1 - \frac{2\delta}{d} \right)^2 \right] - 2 \frac{\delta}{d} \left(2 - \frac{\delta}{d} \right) \right] \right. \\
& \left. + B \left[1 - \left(1 - \frac{2\delta}{d} \right)^2 \right] \right\}
\end{aligned} \tag{2.107}$$

The linear shear-stress distribution ($\tau_w = \tau_i \times r_o / r_i$) permits use of τ_w in the definition of y^+ , instead of τ_i , removing the constant shear-stress limitation of the Universal Velocity Profile Method.

The method used by Whalley (1977) is the Approximate Thick Film Analysis Method developed by Turner and Wallis (1965) from the methods of Armand (1946). It uses a two-phase liquid-film friction multiplier:

$$\phi_{lF}^2 = \frac{(dP/ds)_F}{(dP/ds)_{F,lF}} = \frac{\int_{lF} \left(\frac{1}{2} \rho_l u_{lF}^2 \right)}{\int_{lF} \left(\frac{1}{2} \rho_l V_{lF}^2 \right)} = \frac{\tau_{lF}}{\tau_{lF,o}} \quad (2.108)$$

where $(dP/ds)_F$ is the two-phase frictional pressure drop, $(dP/ds)_{F,lF}$ the single-phase frictional pressure drop if the film were occupying the entire tube, and V_{lF} the superficial film velocity:

$$V_{lF} = u_{lF} (1 - \alpha_c) = \frac{G_{lF}}{\rho_l} \quad (2.109)$$

Hence,

$$\phi_{lF}^2 = \frac{1}{(1 - \alpha_c)^2} = \frac{1}{\left[\frac{4\delta}{d} \left(1 - \frac{\delta}{d} \right) \right]^2} = \frac{\tau_i \left(\frac{r_o}{r_i} \right)}{f_{lF} \frac{G_{lF}^2}{2 \rho_l}} \quad (2.110)$$

Hewitt and Hall-Taylor (1970) found that this method reproduced the results of Hewitt (1961) when a smooth transition in f_{lF} was used from laminar to turbulent flow:

$$f_{LF} = \left[f_{LF, \text{lam}}^2 + f_{LF, \text{turb}}^2 \right]^{1/2} \quad (2.111)$$

where $f_{LF, \text{lam}}$ and $f_{LF, \text{turb}}$ are the single-phase friction factors for laminar flow (i.e., $16/\text{Re}$) and turbulent flow (i.e., Prandtl or Blasius formula), as described by White (1991).

Transition to Annular Flow

Since most evaporative flows begin with a subcooled inlet, some method of handling the different flow regimes (single-phase liquid, bubbly flow, churn, churn-turbulent, annular flow) and the transition between them is required. Most existing dryout models are formulated with three possible flow regimes:

- single-phase flow
- bubbly flow (using homogenous or drift-flux models)
- annular flow (Whalley model)

The first transition from single-phase flow to bubbly flow is normally assumed at the point where the mixture enthalpy reaches that of a saturated mixture ($i=i_g$). Both fluids are assumed to have the same temperature, often referred to as thermodynamic equilibrium. This is not the case in subcooled boiling, where significant void fraction can occur at low pressure with the mixture well below the saturated liquid enthalpy. Since dryout modelling is only concerned with CHF in the positive-quality region, detailed modelling of subcooled or bubbly flow region is not required. However, this limit of applicability does prevent a more unified approach to CHF modelling, covering all the flow regimes.

The transition from bubbly flow to annular flow or onset of annular flow (OAF) has been defined in two ways. Whalley et al. (1974) made the assumption that OAF occurs at an arbitrary flowing quality of 1%:

$$x_{\text{oaf}} = \frac{G_g}{G_l} = 0.01 \quad (2.112)$$

which has proven to be reasonably accurate in predicting CHF for saturated boiling lengths (L_{sat}) as small as 0.1 m, and has been adopted by most dryout models. Sugawara and Miyamoto (1990) proposed a more mechanistic approach to modelling the transition using the Baker flow map for horizontal flow (Baker 1954):

$$\alpha_{g,\text{oaf}} = (P + 0.9/P_o) e^{(-G/G_o)} + (3.1 - P/P_o) \quad (2.113)$$

where $P_o=4.0$ MPa and $G_o=729$ kg/m²·s are reference values. It was assumed that the same transition holds for vertical flow in both tubes and rod bundles. It should be noted that the Baker flow map is for horizontal adiabatic gas-liquid flow in small tubes, and that better two-phase flow maps do exist (e.g., Hewitt and Roberts, 1969 or Taitel and Dukler, 1976). The reference values (P_o , G_o) are for water, as are all the correlations taken from Sugawara and Miyamoto (1990).

The associated entrainment fraction at OAF must also be defined:

$$F_e = \frac{G_{IE}}{G_l} = \frac{G_{IE}}{G_{IF} + G_{IE}} \quad (2.114)$$

Whalley et al. (1974) arbitrarily assumed $F_e=0.99$, while others have varied F_e only to find that for most heated lengths, CHF is insensitive to F_e .

Sugawara and Miyamoto (1990) included a critical maximum film thickness at OAF:

$$\delta \leq \delta_{cr} = \frac{\pi \sigma}{2} \left(\frac{\rho_l + \rho_g}{\rho_l \rho_g} \right) \left(\frac{\rho_g i_{lg}}{q_w} \right)^2 \left(\frac{A_g}{A_w} \right)^2 \quad (2.115)$$

$$\left(\frac{A_g}{A_w} \right)^2 = 2.5 \times 10^{-5} \left(\frac{G}{G_o} \right)^{-0.8} \left(\frac{\rho_l}{\rho_g} \right) \quad (2.116)$$

where A_g/A_w is the sum of projected areas of the vapour columns in the liquid film per unit area of the heated surface, and $G_o=2000 \text{ kg/m}^2\cdot\text{s}$ is a reference value. If the liquid film thickness at OAF is greater than this value, the value of δ_{cr} is used. This suggests that the value of F_c must be adjusted to obtain the proper film flow rate and interfacial shear stress when the critical film thickness is exceeded; however, no further details are provided.

2.2.3 Spacer Models

This section describes a number of spacer models available for CHF in annular flow. Mitsutake et al. (1990) proposed the following empirical spacer model:

$$\begin{aligned} E_{sp} &= \eta_{sf} \left(\frac{\Delta P_{sg}}{\Delta P_s} \right) \left(\frac{d_{sp}}{d_o} \right) G_{IE} & D_{sp} &= \eta_{sp} \left(\frac{A_{sp}}{A_o} \right) G_{IE} \\ E' &= (1 + \eta_{mix,E}) E & D' &= (1 + \eta_{mix,D}) D \end{aligned} \quad (2.117)$$

where the net effect on both entrainment ($E_{sp}+E'$) and deposition ($D_{sp}+D'$) are specified using various spacer parameters (η_{sf} , η_{sp} , $\eta_{mix,D}$, $\eta_{mix,E}$) determined from existing bundle critical power data. ($\Delta P_{sg}/\Delta P_s$) is the ratio of vapour dynamic head to total dynamic head, (d_{sp}/d_o) is the ratio of spacer gap size to subchannel size, and (A_{sp}/A_o) is the spacer blockage ratio. η_{sf} acts as a liquid-film stripping mechanism, η_{sp} as an impingement mechanism, and η_{mix} as a turbulence-enhancement mechanism. No specific relations for η are provided and the comparisons made between the model and bundle experiment are reported in overall statistics, making it difficult to separate the spacer-effects from the other bundle effects.

Nishida et al. (1994) assumed a constant Schmidt number along the length of a conduit:

$$Sc = \left[\frac{v}{\lambda} \right]_{sp} = \left[\frac{v}{\lambda} \right]_o \quad (2.118)$$

and a constant boundary-layer thickness ($l=\Delta y$):

$$\frac{\lambda_{sp}}{\lambda_o} = \frac{k_{sp} \Delta y}{k_o \Delta y} = \frac{k_{sp}}{k_o} \quad (2.119)$$

to adopt the eddy-enhancement model of Lahey et al. (1977) for a bundle spacer:

$$\frac{\lambda_{sp}}{\lambda_o} = \frac{k_{sp}}{k_o} = \begin{cases} \left(\frac{72}{20} \right) \left(\frac{L_c}{d_e} \right) \sqrt{\frac{2}{f_i}} & , \quad 0 < \frac{z}{L_c} \leq \frac{5}{\pi^2} \\ \left(\frac{72}{4\pi^2} \right) \left(\frac{L_c^2}{d_e^2 z} \right) \sqrt{\frac{2}{f_i}} & , \quad \frac{5}{\pi^2} < \frac{z}{L_c} \leq \frac{18}{\pi^2} \frac{L_c}{d_e} \sqrt{\frac{2}{f_i}} \end{cases} \quad (2.120)$$

where L_c is a characteristic length determined from experiment. The downstream profile for

($f = 0.003$)

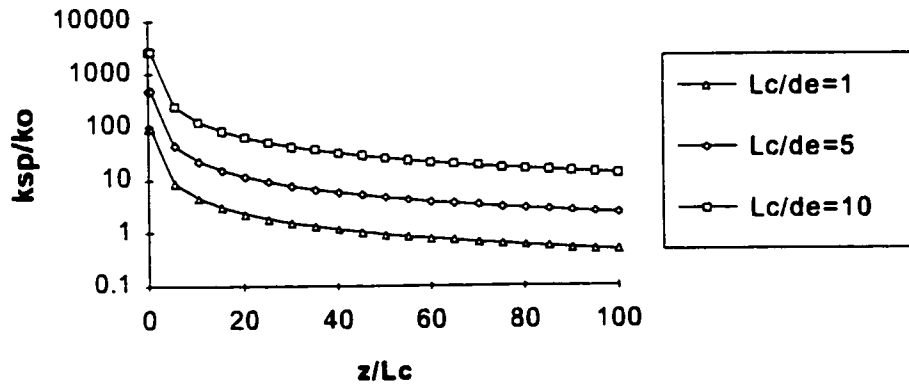


Figure 2.12: Deposition enhancement profile (Nishida et al., 1994).

deposition enhancement using this model is shown in Figure 2.12. In comparison, the single-phase heat transfer enhancement profiles (Nu_{sp}/Nu_o) display a more exponential-type decay. The ratio (k_{sp}/k_o) can diminish below a value of unity, contradicting the results from other experiments (Berger and Hau, 1979).

Knabe and Wehle (1993) hypothesized the following spacer-effect for mass-transfer in annular flow:

- An equal portion of film, from each of the walls surrounding a spacer, is stripped and re-distributed equally over all walls surrounding the spacer. The amount of film stripped is proportional to the degree of contraction of the spacer area and liquid-film thickness (phase re-distribution).
- A local deposition coefficient ($\eta_{E,sp}$) determines the portion of entrained droplets deposited on the wall due to direct interaction with the spacer:

$$\Delta G_{IF} = \eta_{E,sp} G_{IE} \quad (2.121)$$

- A deposition enhancement multiplier ($\eta_{D,sp}$) determines the turbulent enhancement of deposition downstream of the spacer:

$$D' = \eta_{D,sp} D = \eta_{D,sp} k C \quad (2.122)$$

By fitting their spacer model to critical power data from different 3×3 and 7×7 rod-bundles, they obtained the following relations:

$$\begin{aligned} \eta_{E,sp} &= 1.5 - 10\% \\ \eta_{D,sp} &= A_o e^{-8z} \\ A_o &= 4.0 - 8.0 \end{aligned} \quad (2.123)$$

No mention is made of the film-stripping mechanism of the spacer model, leading one to speculate the effects were not considered.

Chu and Shiralkar (1993) compared the COBRAG subchannel analysis code with a spacer model included to the critical power measurements taken at the ATLAS Test Facility of GE Nuclear Energy. The spacer model incorporated the following effects:

- Upstream film thinning: an observation made at GE that CHF often occurs just upstream of a grid-spacer due to scrubbing of the film by a horse-shoe vortex in the stream flow created by the obstruction of the film contact, and the increase of interfacial shear inside the grid-spacer (Shiralkar and Lahey, 1973).
- Downstream turbulence enhancement: turbulence generated by the spacer structure enhances mixing between subchannels and deposition of droplets from the core to the wall sub-regions. Parameters affecting turbulence: distance downstream from the spacer, projected area of the spacer, drag form coefficient, hydraulic diameter of the subchannel, mass flux at the spacer.
- Collection and run-off at spacer: a portion of the dispersed droplets in the core is deposited on the spacer surface as a film, depending on the spacer surface area and geometry. A portion of this liquid film runs off the spacer and is deposited on the neighbouring wall surface.

No further details on the spacer model or its parameters are provided. They did make the following observations on the effect of spacers on CHF:

- Spacer type: CHF with grid-type spacers is 10-15% lower than with tube-type spacers at the same flow conditions. The tube-type spacers which are closer to the rod produce more run-off whereas the grid-type spacers produce higher turbulence (ΔP) but have less of an effect than run-off.
- Spacer thickness and height: both thicker spacers and smaller spacer-to-rod gaps produce slight improvements in critical power.
- Spacer pitch: decreasing spacer pitch increases bundle critical power multiplying the net beneficial effects from each spacer.

Chapter 3 EXPERIMENTAL STUDY

A series of experiments were performed at the Chalk River Laboratories (CRL) of Atomic Energy of Canada Ltd. (AECL), during a 5-month term appointment, to investigate the effect of cylindrical flow-inserts on heat transfer, pressure drop, and CHF inside a tube. The data obtained from these experiments were used to develop and formulate analytical models for both heat transfer and CHF enhancement inside a tube. The following sections describe the experimental test facility, the single-phase experiments, the two-phase CHF experiments, and the results obtained.

3.1 Experimental Test Facility

To investigate the effect of flow obstructions, two different test sections were designed, manufactured, and installed in the multi-fluid MR-7A loop at CRL. The first test section used a single flow obstruction, a series of wall thermocouples, and a differential pressure transducer to measure single-phase heat transfer and pressure drop. The second test section was fitted with a number of flow obstructions ($N_{\text{obs}}=1-5$), each with its own set of wall thermocouples to detect CHF in two-phase flow. The MR-7A loop is shown schematically in Figure 3.1 and consists of a working fluid flowing through two magnetically driven gear pumps connected in series with an electric preheater and test section. The fluid passes through a condenser and subcooler before



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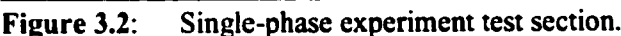
the two-phase experiments, additional experiments were performed using Freon-22 as the working fluid.

3.2 Single-Phase Experiments

3.2.1 Test Section Apparatus

The test section used for single-phase heat transfer and pressure-drop is shown in Figure 3.2, consisting of a vertical 8 mm ID round tube, 1 mm thick, made of Inconel 600, with a heated-length of 2.05 m. A single ring-type flow obstruction was inserted into the test section. The MR-7A flow loop was already instrumented with a differential pressure transducer, connected to pressure taps located before and after the test section ($DP_1 = PT_2 - PT_1$), an inlet and outlet fluid thermocouple (T_{in} , T_{out}), and a wall thermocouple at the test section outlet (TC_{wo}). To more accurately measure the pressure drop across the flow obstruction, another differential pressure transducer ($DP_2 = PT_4 - PT_3$) was connected to two additional pressure taps, located before and after the flow obstruction, spanning a shorter distance (504 mm). This required that two separate test sections, one for single-phase and the other for CHF (to follow), since a number of flow obstructions were studied in CHF at various positions, and this could not be done with the short-length pressure taps in place.

Two different rings were tested, as specified in Sections D.1 and D.2 of Appendix D, both with an 8 mm OD and 6.5 mm in length. One ring had a 7.25 mm ID (18% blockage area) and the other ring had a 6.7 mm ID (30% area blockage). The outer wall surface temperature was measured using two moveable thermocouple carriers (TC_{w1} and TC_{w2} in Figure 3.2). Each carrier was designed to hold three thermocouples, spaced an equal angle (120°) apart, as shown in Figure 3.3. Each thermocouple was mounted through the centre of a bored screw, and fixed to the tube using a small spring, inserted in between the screw and the thermocouple tip. This allowed the thermocouples to be positioned for a particular test configuration, and then fixed for the experiment. These carriers were designed to be moveable for the CHF experiments to



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A novel technique was used to relocate the flow obstruction at different axial locations during the experiment. An annular cobalt magnet, fitted to the outside of the tube, was moved along the tube to position and hold the metal flow obstacle in place on the inner side of the tube. This allowed the effect of axial distance to be studied in detail, without having to know the exact position or magnitude of the effect prior to the experiment.

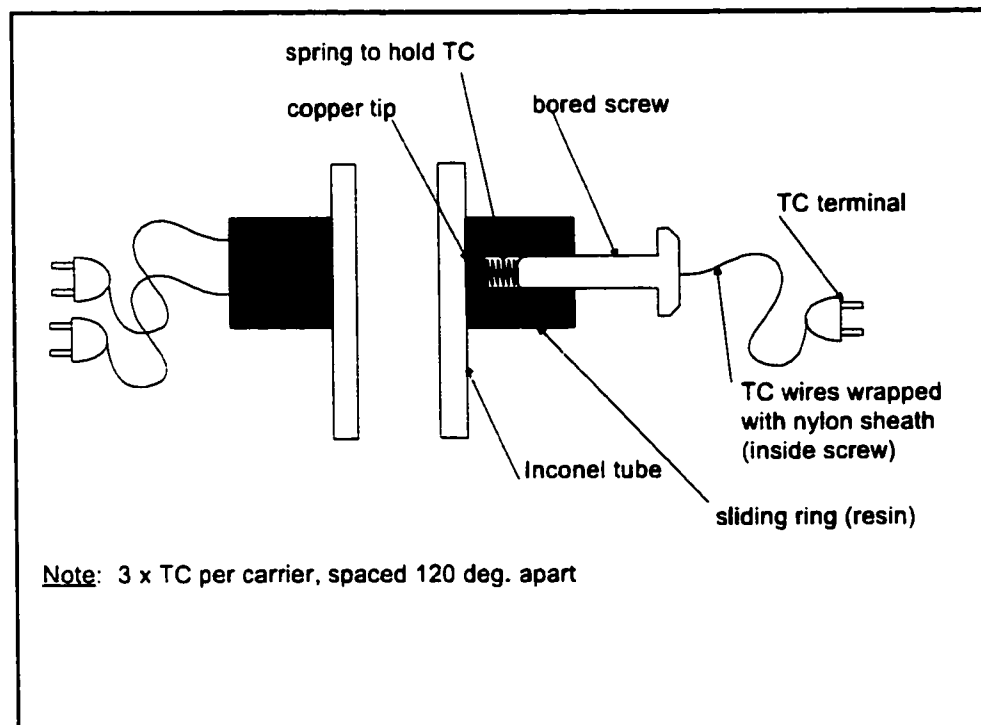


Figure 3.3: Thermocouple carrier configuration.

3.2.2 Experimental Procedures

Preliminary zero-power and reference tube tests with no flow obstruction were performed to check for energy balance and heat losses in the system. These reference test results were also compared with existing empirical tube correlations, to confirm that all components of the system and data analysis were functioning properly. Originally, a test matrix based on two

power settings (2 and 5 kW), two inlet fluid temperatures (6 and 20 °C), and four mass fluxes (1, 2, 4, and 6 Mg/m²·s) was proposed. However, the inlet temperature and power setting were later varied to provide maximum accuracy in heat transfer measurements, by applying a maximum power for each inlet temperature and mass flow. Before applying power to the test section, the desired flow conditions were established, and the test section power was increased until the wall temperature in the vicinity of the downstream PT and TC was near but safely below the saturation temperature of the fluid. At each power setting, the mass flow, outlet pressure, inlet temperature, and wall temperature were monitored to obtain a steady-state condition, and all data were recorded using the DAS. To ensure the repeatability of the results, five measurements were recorded at each data point, and the same procedure was repeated for the following range of parameters: mass flux from 1 to 6 Mg/m²·s, inlet temperature from 3 to 10°C, and power from 4 to 20 kW. The resultant Reynolds number varied from 35,000 to 250,000.

3.2.3 Results and Analysis

Detailed information on the single-phase experimental data is provided in Appendix A, including a full test matrix of tabulated DAS output, and a procedural and error analysis of all the measured and calculated data. The heat transfer analysis is presented first, followed by pressure drop. The first step in analysing the heat transfer data was to assess the heat losses from the test section, since they have a direct impact on the measured heat transfer coefficient. Figure 3.4 shows the calculated heat loss as a function of outer wall perimeter and outer wall-to-ambient temperature difference (AT) defined by the following integral over the surface area of the tube:

$$Q_{loss} = \int_0^L U_o P_{wo} (T_{wo} - T_{\infty}) dz = U_o (AT) \quad (3.1)$$

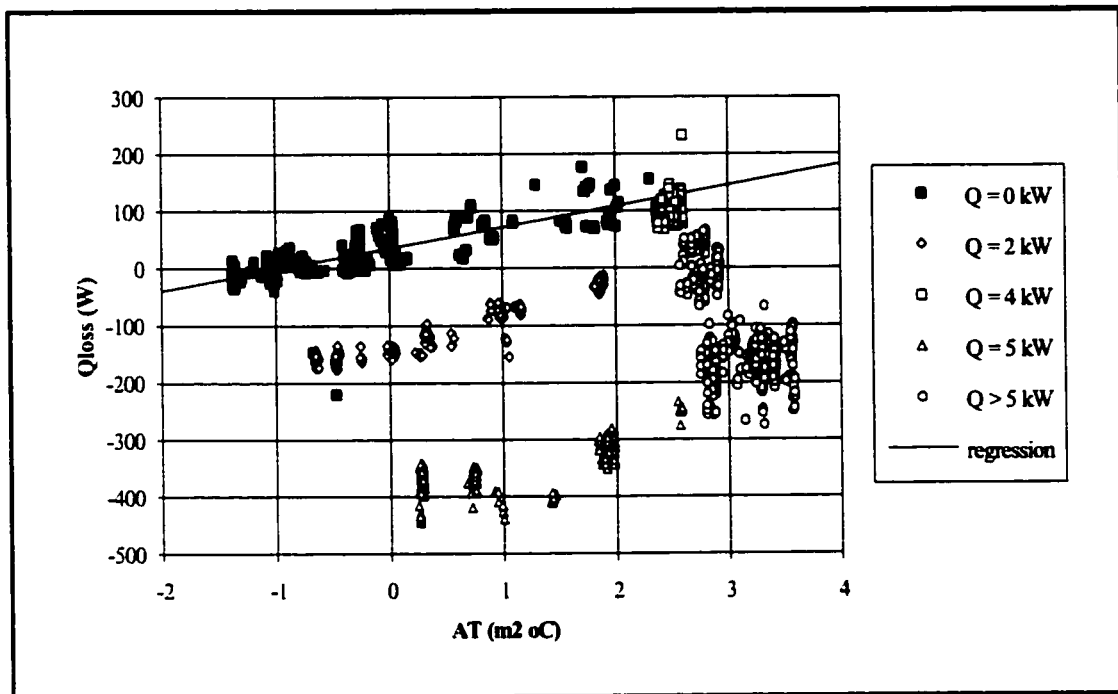


Figure 3.4: Heat loss regression analysis (all data).

The term AT is calculated from the measured outer wall temperatures, as described in Equations (A.2) through (A.4) in Appendix A.3.1. A linear regression to the zero-power Q_{loss} data in Figure 3.4 provides an estimate of the overall heat transfer coefficient on the outside of the tube. Although a positive trend with AT is observed in all the data, large negative offsets (heat gains) are observed when power is applied to the test section. Some of these negative offsets are explained by uncertainties in measured power (ΔQ), mass flow ($\Delta \dot{m}$), and bulk fluid temperature. The RMS error in Q_{loss} is determined using Equations (A.22) through (A.32) in Appendix A.3.2, and used for the abscissa in Figure 3.5 to illustrate most of the heat loss data lie within $\pm 2\sigma$ (i.e., 95% of the normal distribution). Therefore, little significance is given to these measured values of Q_{loss} . Although this error analysis includes all the quantifiable sources of calibration error in the instrumentation, it does not include some of the implementation errors that can arise:

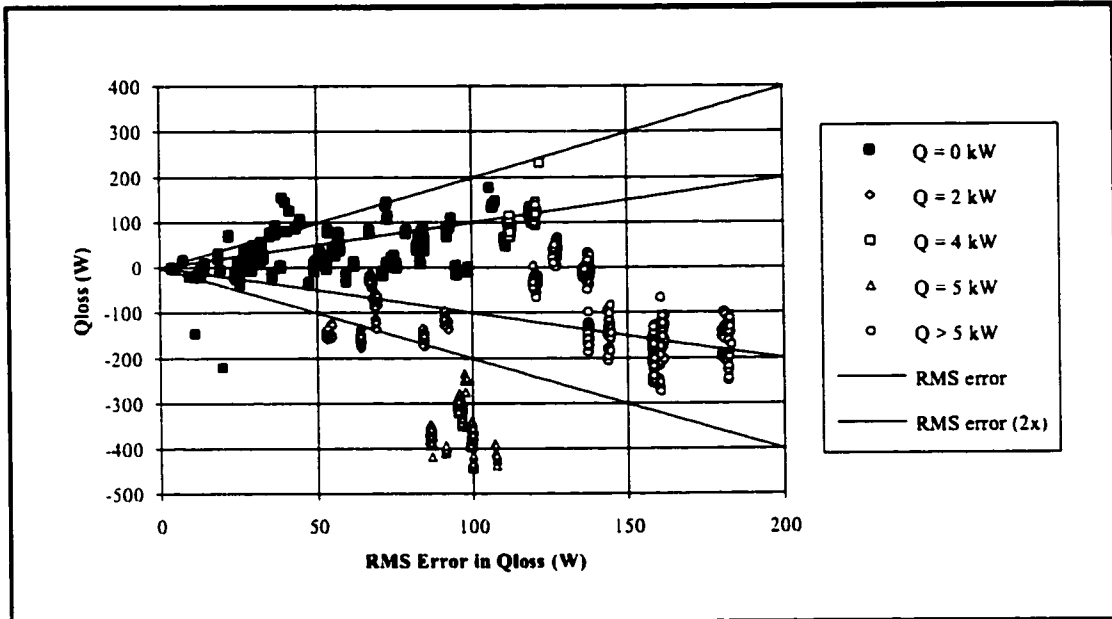


Figure 3.5: Errors associated with heat loss measurement.

- ability of a single thermocouple placed near the exit of the test section to measure the bulk fluid temperature, especially at large heat input rates. It has been suggested that these results might indicate the need to install a mixing chamber at the outlet of the test section,
- ability of the DAS to correct the thermocouple readings for junction temperature. Since thermocouples generate a voltage at both junctions (i.e., one at the measurement tip and the other at the terminal junction), the DAS is equipped to measure the air temperature in the vicinity of the terminal junction and make an internal correction to the thermocouple readings. This method is subject to error when a difference in temperature arises between the air and terminal junction. It has been suggested to connect the inlet and outlet fluid thermocouples (T_{in} , T_{out}) in series, and make a direct measurement of the differential fluid temperature ($T_{out} - T_{in}$), eliminating the need to make a terminal junction correction.

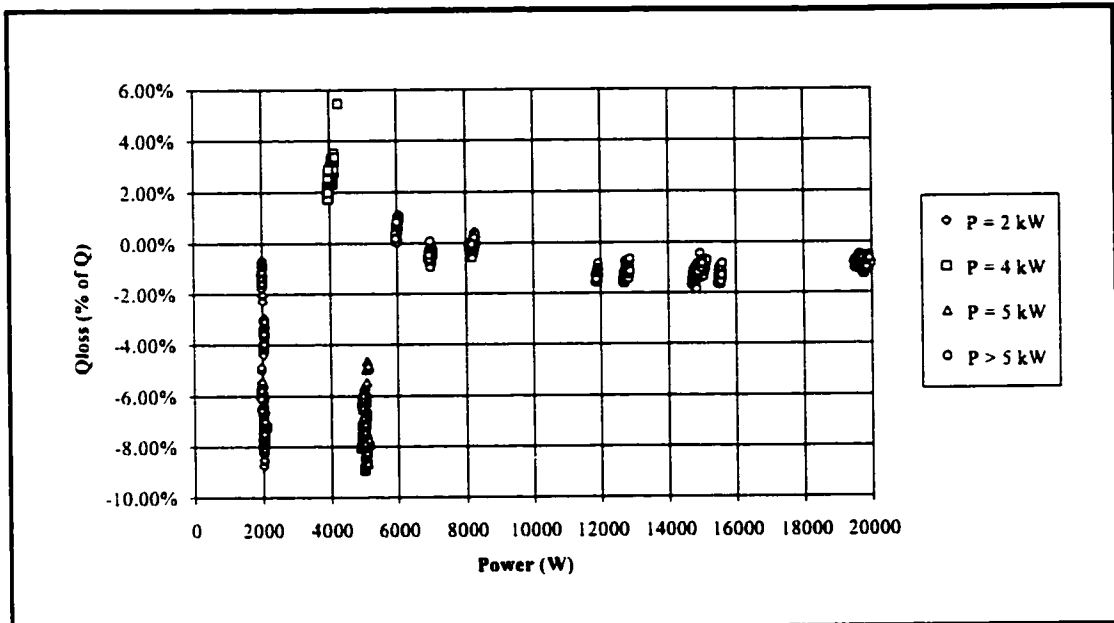


Figure 3.6: Heat imbalance as a function of total power

These suggested apparatus changes were not possible within the present scope of work, and so the heat imbalance was interpreted as follows:

- no corrections were made for heat loss,
- where heat imbalances were larger than the RMS error in heat loss, the actual heat imbalance was used to calculate the error in Power (ΔQ) and the resultant error in heat transfer coefficient,
- as shown in Figure 3.6, only the low-power data ($P \leq 5$ kW) exhibit heat imbalances in excess of 2%-power,

A plot of % Q_{loss} versus mass flow in Figure 3.7 shows the decrease in heat imbalance as the precision of the flow meter is increased at higher flow (i.e., % of full-scale). The apparent offset between the $P \leq 5$ kW and $P > 5$ kW data indicates an offset error in the bulk fluid temperature measurement, as all thermocouples were re-calibrated in between these two data sets. The first set of data are from the reference tube and 18% ring, and the second from the 30% ring.

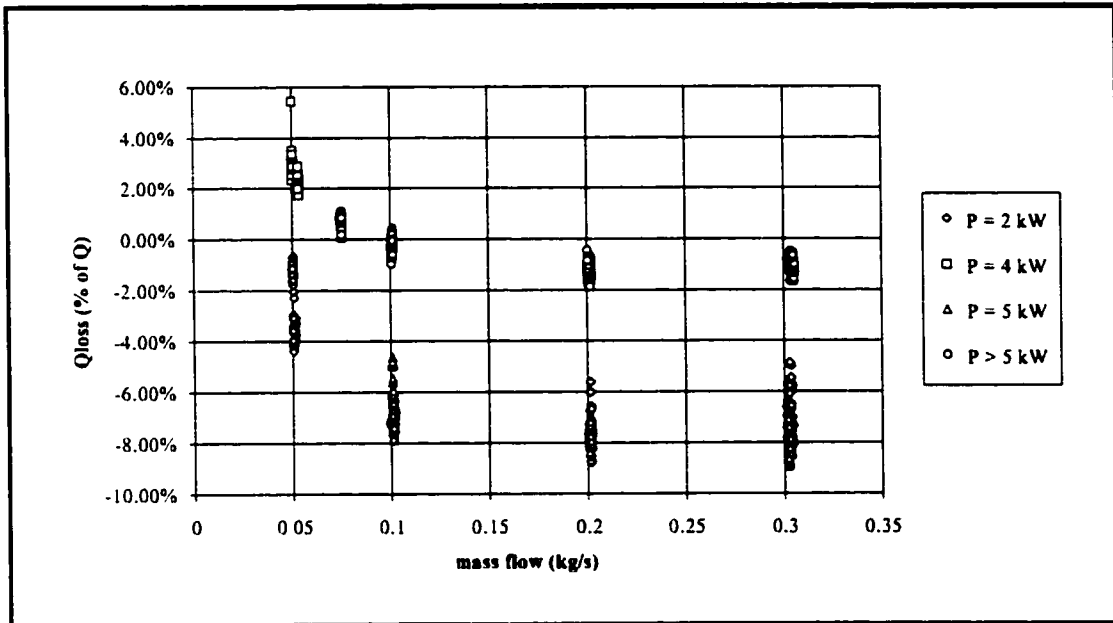


Figure 3.7: Heat imbalance as a function of mass flow.

Although these errors may seem large for the reference tube and 18% ring data ($P \leq 5$ kW), it will be shown that these errors do not limit the interpretation of relative heat transfer enhancement, since both the reference and enhancement values share the same error condition.

The reference tube Nusselt number (Nu) are plotted against three forced convection tube correlations in Figure 3.8, and the associated statistical error analyses are provided in Table 3.1. The errors are within the typical range of accuracy for these correlations, with the Sieder-Tate (1936) correlation showing the smallest prediction error for this particular data set. In assessing the ring obstruction data, as a function of downstream distance from the obstacle (z/d), the Nusselt number measured far away from the rings ($z/d=30$) is used as a reference value for calculating the non-dimensional Nu-enhancement ratio:

$$R_{Nu} = \frac{Nu_{obs}(z)}{Nu(\infty)} \approx \frac{Nu_{obs}(z)}{Nu(z_{max})} = \frac{Nu_{obs}(z/d)}{Nu(z/d = 30)} \quad (3.2)$$

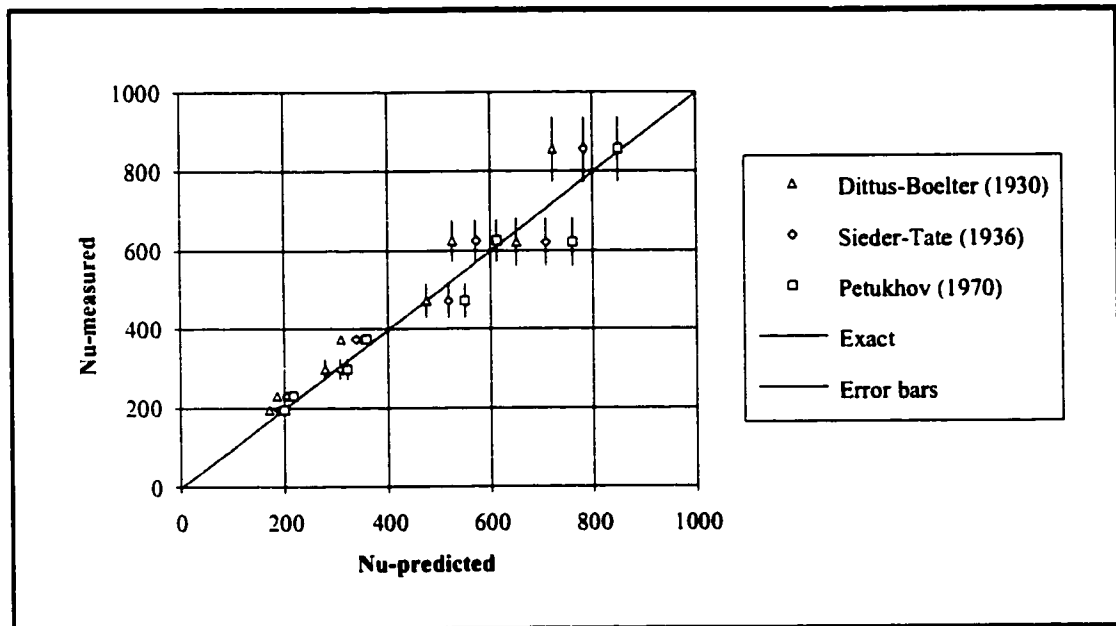


Figure 3.8: Reference tube heat transfer analysis.

Table 3.1: Statistical comparison of reference tube data with correlation.

Difference	Correlation		
	Dittus-Boelter (1930)	Sieder-Tate (1936)	Petukhov (1970)
average	-11%	-2%	4%
RMS	13%	9%	10%
maximum	20%	15%	24%

The Nusselt number enhancement ratios for the two rings, as a function of downstream distance at different Reynolds numbers, are plotted in Figures 3.9 and 3.10, respectively. The results show that heat transfer enhancement only occurs over a short length ($0 < z/d < 10$), and that all values at $z/d > 10$ are essentially those of the reference tube ($R_{Nu}=1$). To confirm the criterion used to establish the reference Nusselt number in the ring-tube data, the Nusselt numbers measured at $z/d=30$ for both rings are plotted against reference values predicted using Sieder and Tate (1936) in Figures 3.11 and 3.12. The results show that all values are within the RMS difference between the correlation and the nominal tube Nusselt numbers ($\pm 15\%$).

Two sets of data are plotted in Figure 3.12. The data obtained using slightly higher power (4–20 kW) had inner wall temperatures very close to the saturated fluid temperature near the outlet (i.e., subcooled boiling may have occurred). The other data (4–15 kW) had inner wall temperatures somewhat below the saturated fluid temperature near the outlet, and appear to diverge less from the reference-tube correlation than the 4–20 kW data. For this reason, the 4–20 kW data were removed from the analysis in favour of the 4–15 kW data. The 18% ring data did not require such an assessment since they were all obtained at low power ($P \leq 5$ kW), where the inner wall temperatures were well below the saturated fluid temperature.

The next step in the analysis was to curve-fit the following functional relation:

$$R_{Nu} = \frac{Nu_{obs}(z)}{Nu_{ref}(\infty)} = \frac{Nu_{obs}(z)}{Nu_{obs}(z_{max})} = 1 + A_o \exp(-bz/d) \quad (3.3)$$

The results for axial distance have already been presented in Figures 3.9 and 3.10 as lines with symbols. The flow effect was derived from a linear regression of the peak Nu-enhancement values, versus Reynolds number, shown in Figures 3.13 and 3.14. The resultant values for (A_o, b) are shown in Table 3.2 and compared with Yao et al. (1982).

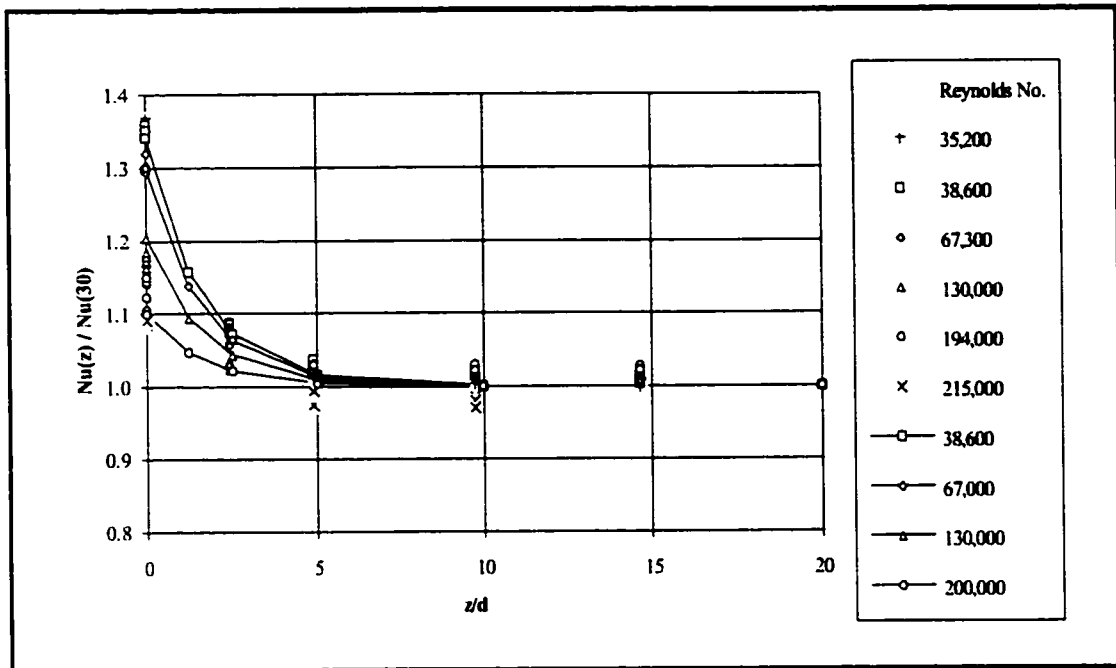


Figure 3.9: Non-dimensional Nusselt enhancement ratio versus z/d (18% ring) – measured (symbols) and curve-fit (lines with symbols) results.

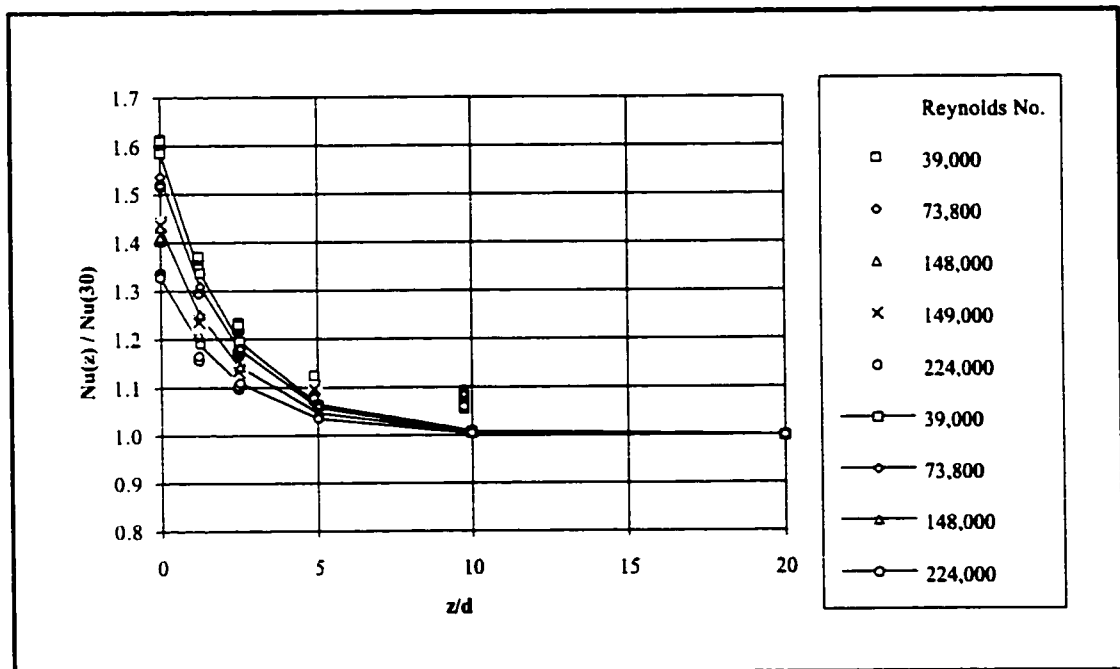


Figure 3.10: Non-dimensional Nusselt enhancement ratio versus z/d (30% ring) – measured (symbols) and curve-fit (lines with symbols) results.

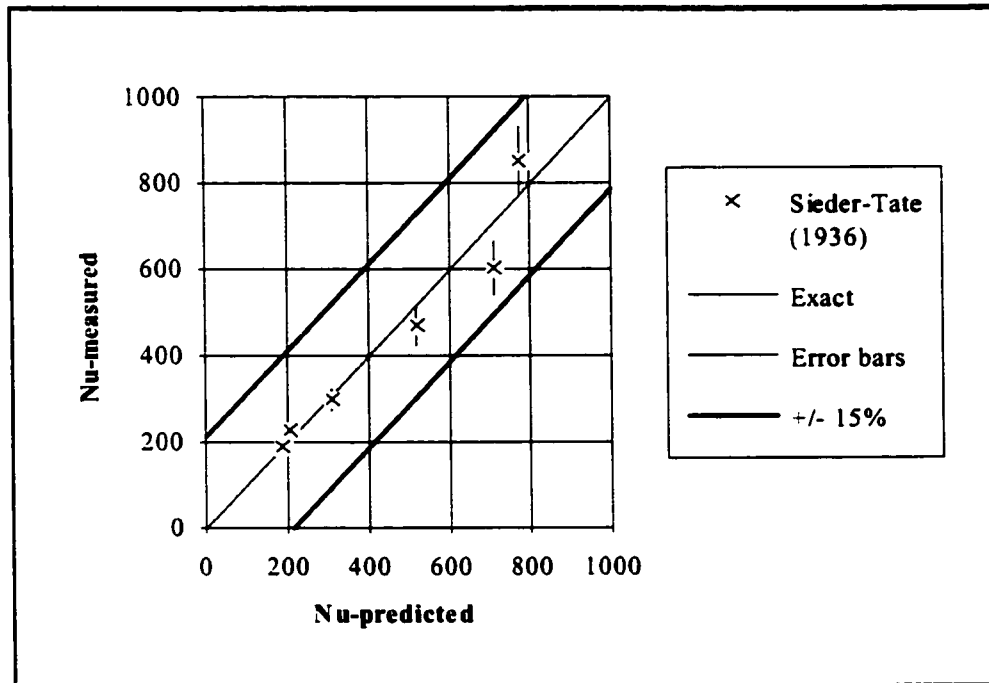


Figure 3.11: Comparison of $Nu(z_{\text{max}})$ with reference-tube correlation (18% ring).

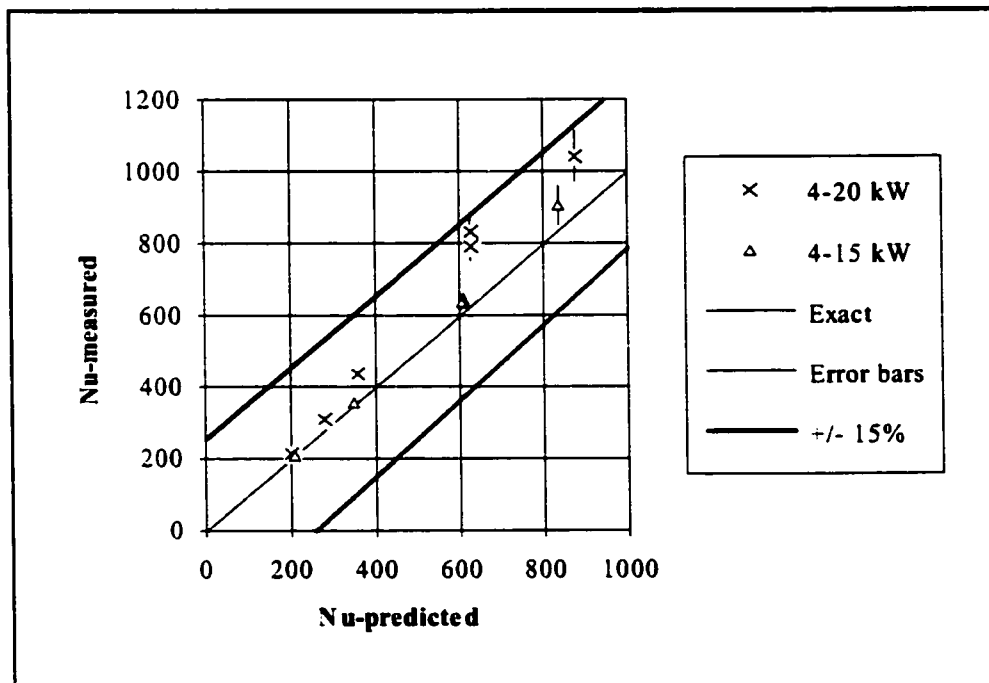


Figure 3.12: Comparison of $Nu(z_{\text{max}})$ with reference-tube correlation (30% ring).

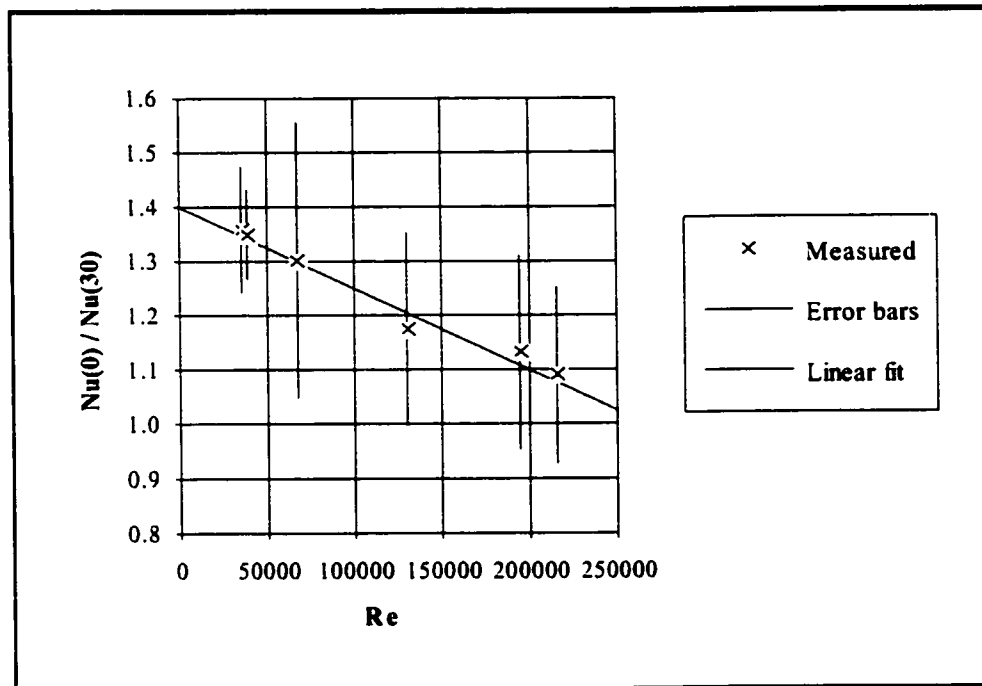


Figure 3.13: Effect of Reynolds number on peak Nu-enhancement (18% ring).

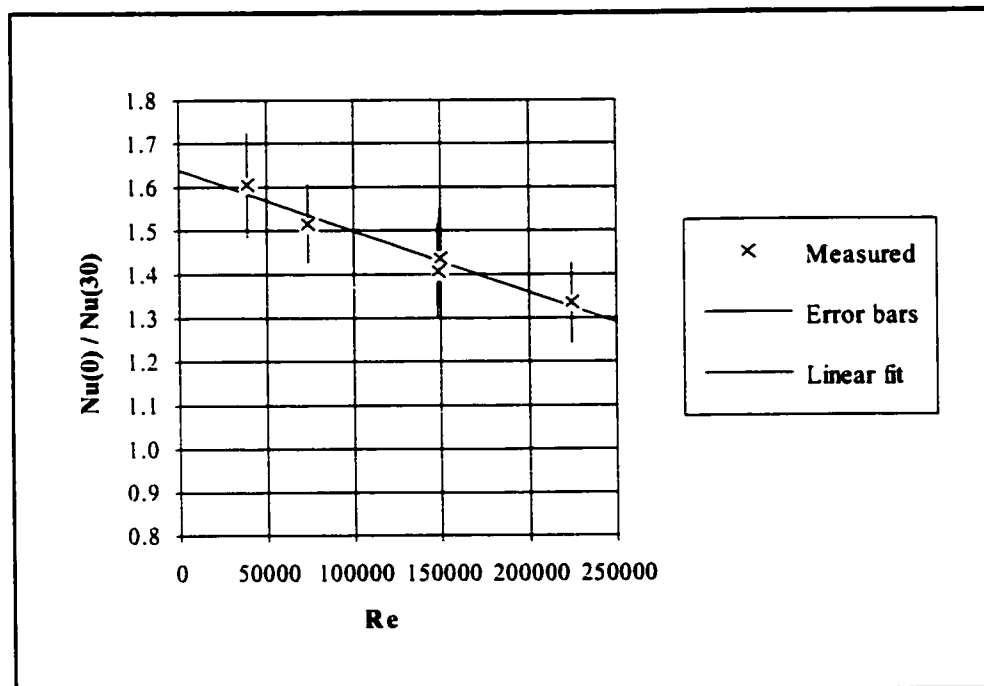


Figure 3.14: Effect of Reynolds number on peak Nu-enhancement (30% ring).

Table 3.2: Measured Nu-enhancement parameters versus Yao et al. (1982).

Flow Obstruction	Present Study			Yao et al. (1982)	
	A_o		b	A_o	b
	Measured	Function			
18 % ring	0.10 – 0.35	$0.40 - 1.5 \times 10^{-6} \cdot Re$	0.62	0.18	0.13
30% ring	0.30 – 0.60	$0.64 - 1.4 \times 10^{-6} \cdot Re$	0.44	0.5	0.13

Although the peak Nu-enhancement values (A_o) are similar to Yao et al. (1982), the decay rate is significantly higher in the present data. This could be explained by the fact that Yao et al. based their correlation primarily on gas-flow data. One would expect the turbulence generated by the flow obstruction to be dissipated much more quickly in liquid than in gas, due to the larger Prandtl number of the liquid. This is similar to the entrance effect for turbulent flow in tubes (Holman, 1981), where higher Prandtl numbers produce a shorter entrance length. The decrease in relative enhancement with higher Reynolds number is in agreement with the results obtained by Berger and Hau (1979) for mass-transfer enhancement. Since the heat and mass transfer are already increased at high Reynolds numbers, the relative impact from the flow obstruction is less. Plots of $Nu(30) - Nu(0)$ versus Reynolds number for the 18% ring and 30% ring are shown in Figure 3.15 and 3.16, respectively. The peak offset in Nusselt number remains more or less constant for the 18% ring, but increases with Reynolds number for the 30% ring. However, there is too little data in the experiment to support a geometrical configuration parameter.

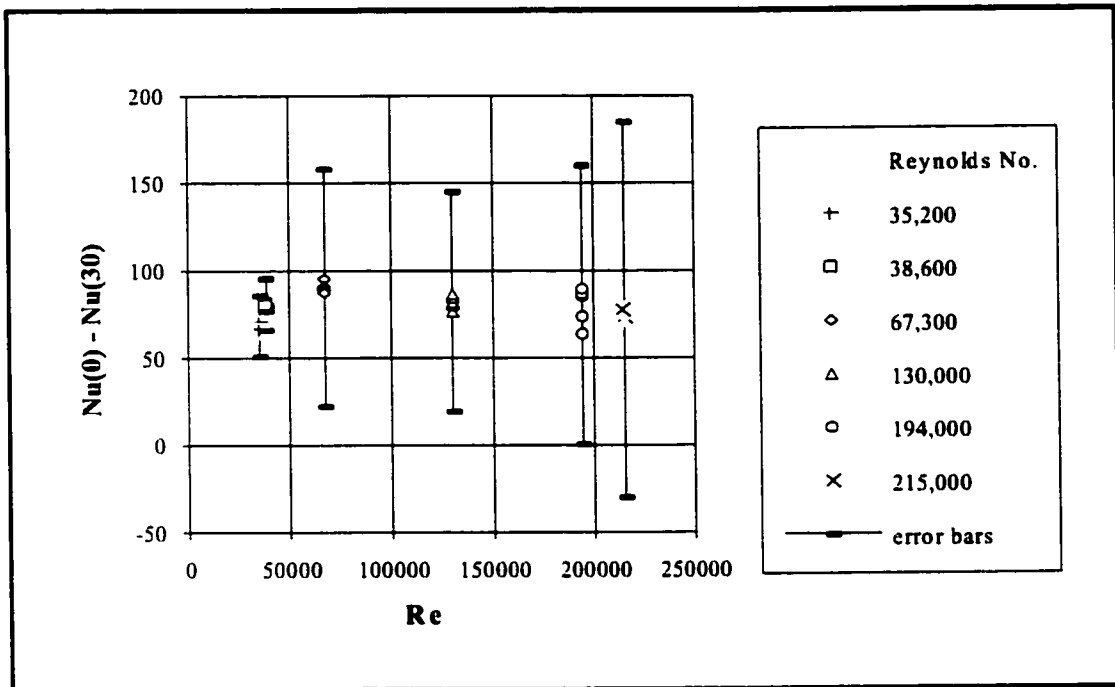


Figure 3.15: Peak offset in Nusselt number with Reynolds number (18% ring).

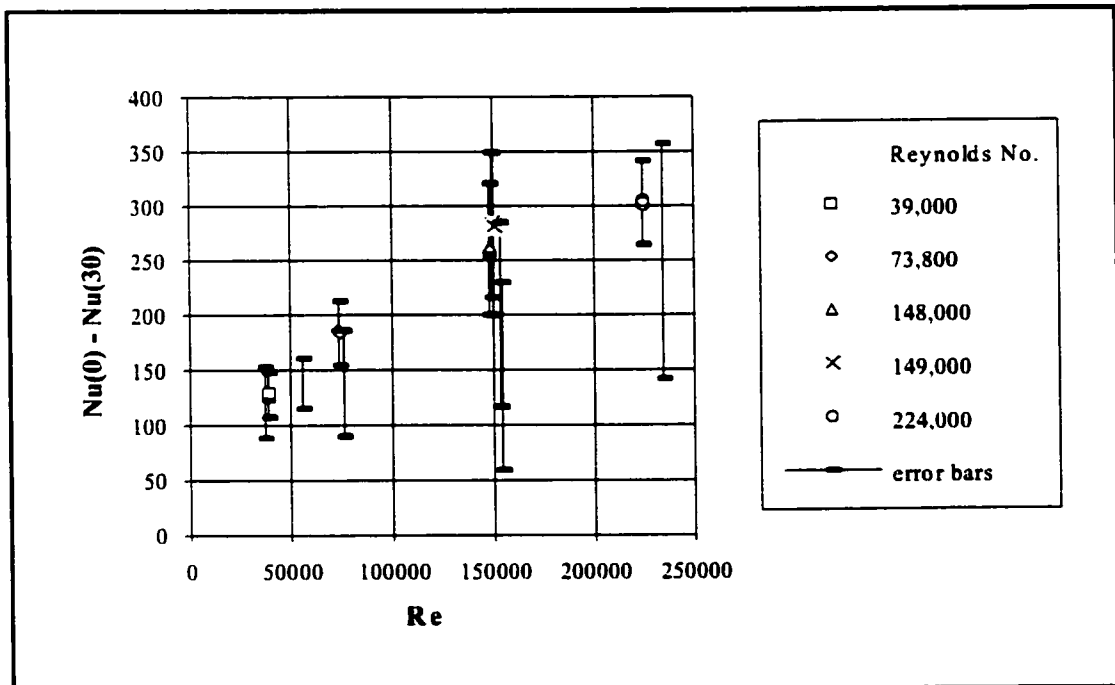


Figure 3.16: Peak offset in Nusselt number with Reynolds number (30% ring).

The pressure drop results were first assessed to compare measured frictional pressure drops from the reference tube (i.e., no obstacle) with predictions from the Prandtl formula (Equation 2.7). The results are presented in Figure 3.17, and show a dead-band region around 3.0 kPa for the DP cell #1 ($L_1 = 2.58$ m) and around 0.60 kPa for the DP cell #2 ($L_2 = 0.504$ m), where the pressure drop measured is insensitive to changes in flow. The dead-band region represents the minimum resolvable pressure drop. Only pressure drop readings lying outside these two dead-bands are going to be reliable and valid. The standard deviation between the reference tube data and the Prandtl formula was computed to be ± 1.2 kPa for DP cell #1, and ± 0.60 kPa for DP cell #2. This RMS difference has a direct impact on the measured head loss coefficients, since the reference tube frictional pressure drop was calculated using the Prandtl formula and subtracted from the total measured frictional pressure drop to obtain the frictional pressure drop associated with the ring:

$$\Delta P_{obs} = \Delta P_{tot} - \Delta P_f = K_{obs} \rho \frac{u^2}{2} \quad (3.4)$$

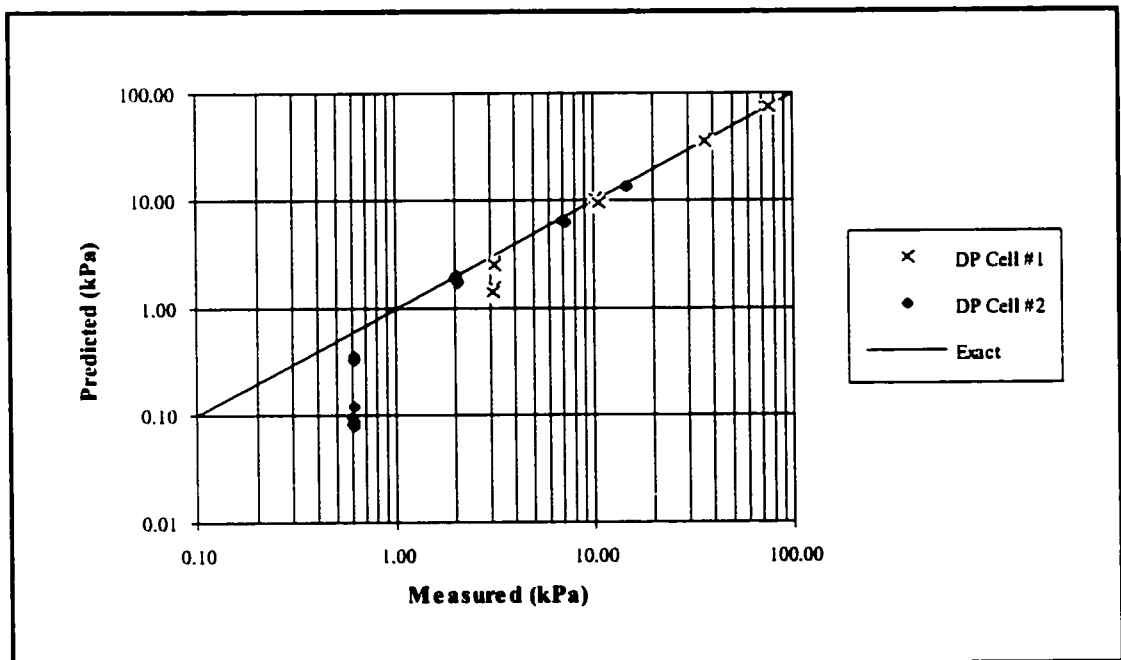


Figure 3.17: Predicted versus measured frictional pressure drop inside the reference tube (single-phase flow, Freon-134a).

Since the resultant ΔP_{obs} only varied from 0 to 2 kPa for the 18% ring, and from 0 to 4 kPa for the 30% ring, only the DP cell #2 data were useable. In addition, only those data with ΔP_{obs} greater than the standard deviation between the measured and predicted pressure drop in the reference tube (i.e., $\Delta P_{\text{obs}} > 0.6 \text{ kPa}$) were considered statistically significant. This further limited the useable data to mass fluxes between 4 and 6 $\text{Mg/m}^2\cdot\text{s}$. The resultant head loss coefficients (K_{obs}) are presented in Figures 3.18 and 3.19 for the 18% ring and 30% ring, respectively. Table 3.3 compares the statistical results obtained for both rings with those predicted by the various relations cited earlier (Table 2.1). In all cases, the measured values were lower than those cited from the literature, by at least a factor of 2. This might indicate that the relative length-to-height ratio of the rings (i.e., $H_{18\%}=0.375\text{mm}$, $H_{30\%}=0.650\text{mm}$, $L=6.5\text{mm}$) is an important factor in defining the overall roughness of the element. Most of the other data from the literature are for very abrupt changes in area (e.g., thin-plate and thick-plate orifices).

Table 3.3: Comparison of measured and predicted head loss coefficients for small ring flow obstructions.

Method	Head loss coefficient (K_{obs})	
	18% ring	30% ring
Present study ($\text{Re} > 1 \times 10^4$)	0.115 ± 0.041	0.260 ± 0.039
De Strodeur (1961)	0.44	1.01
Rehme (1971)	0.21	0.59
Voj (1973)	0.54–0.61	1.01–1.12
thin-plate orifice	0.50 ($C_c=0.813$)	0.89 ($C_c=0.755$)
thick-plate orifice Idel'chik (1966)	0.27	0.66

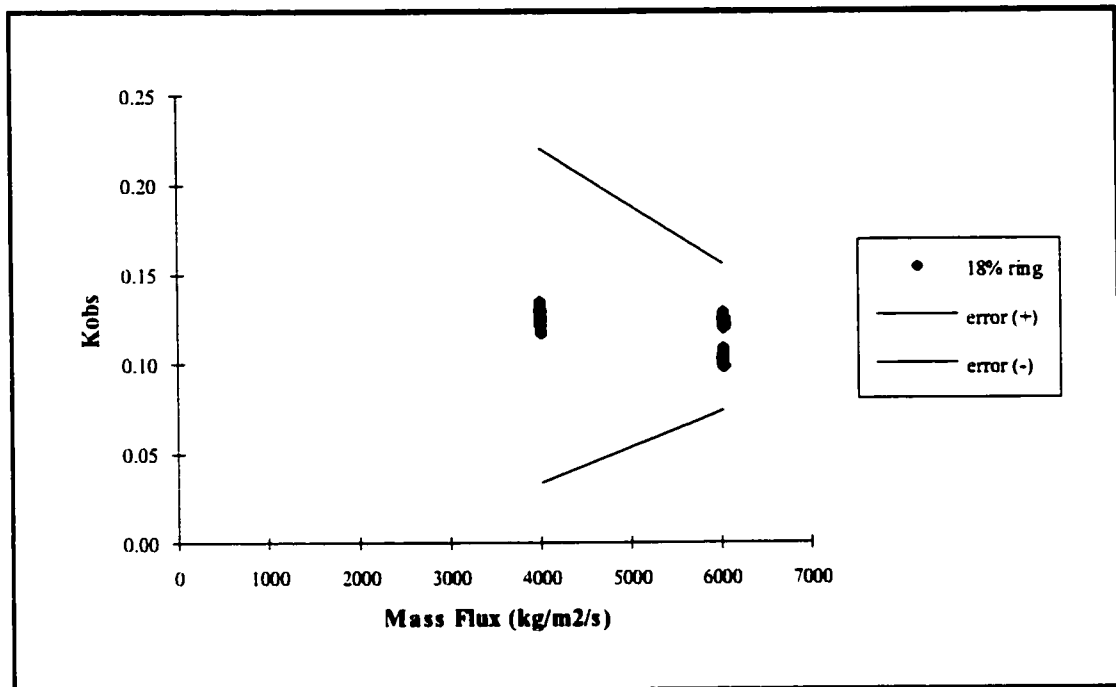


Figure 3.18: Measured head loss coefficients for the 18% ring in Freon-134a (DP cell #2).

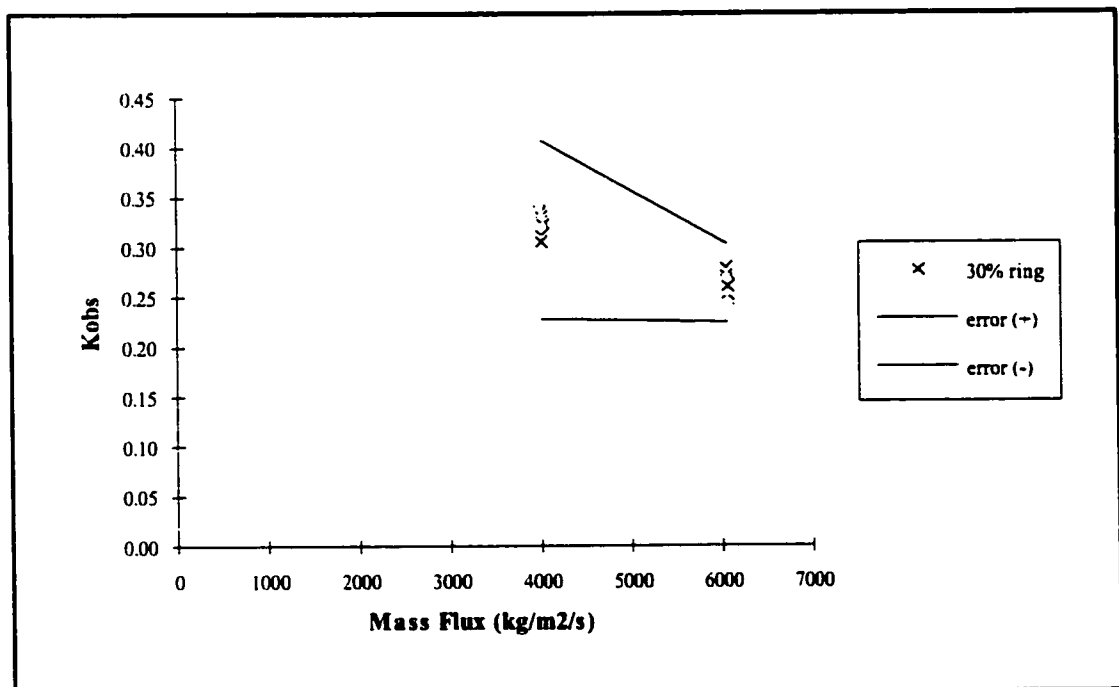


Figure 3.19: Measured head loss coefficients for the 30% ring in Freon-134a (DP cell #2).

3.3 CHF Experiments

3.3.1 Test Section Apparatus

The test section used in the CHF experiments, shown in Figure 3.20, consisted of the same vertical 8 mm ID Inconel 600 tube with a heated length of 2.05 m, except the tube was fitted with multiple flow obstructions of the same type. Each obstacle was paired with a set of wall thermocouple carriers to detect the occurrence of CHF, just upstream of any of the four obstructions, and one additional carrier was used to detect the migration of CHF between the exit and the first flow obstruction. One fixed thermocouple was located at the test section outlet (TCWo) to detect the normal occurrence of CHF.

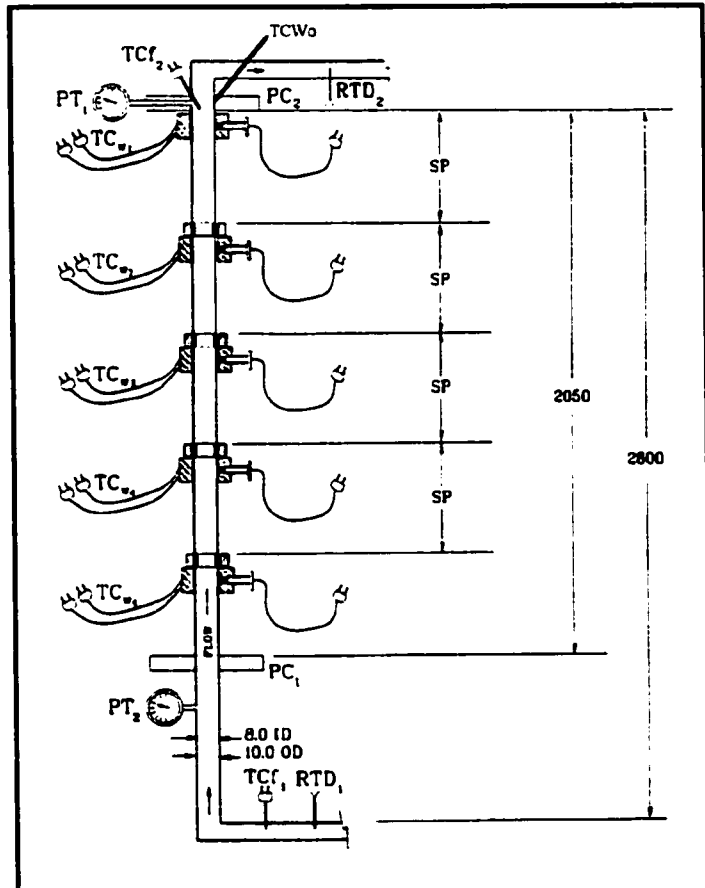


Figure 3.20: CHF experiment test section (four rings installed; dimensions in mm).

The flow obstructions in this case consisted of the same 30% rings, and a new set of 18%-area block-spacers. The block spacer consisted of three separate rectangular blocks located circumferentially and inter-connected radially using a thin strip of spring-steel (see Section D.3 of Appendix D for details). Due to frequent changes in axial position of both flow obstructions

and thermocouple carriers, the test section was left uninsulated. Prior to CHF tests, heat-balance tests were performed to assess the heat loss from the test section, as a function of wall-to-ambient temperature difference.

3.3.2 Test Procedures

All flow obstructions were initially located at the test section inlet to obtain a reference value of CHF (i.e., little or no flow obstruction effect). Although the spacer distance (SP) over which CHF enhancement could be measured was initially unknown, it was later found to be $0 < SP/d < 100$. For the 8 mm tube, this translates to a maximum effective spacing (SP) of 80 cm. After setting the desired inlet condition (i.e., pressure, mass flux, and inlet fluid temperature), CHF was measured by gradually increasing power to the test section until a sudden rise in wall temperature occurred, as illustrated in the sample traces of Figure 3.21. Traces at different times represent several different trials to achieve CHF.

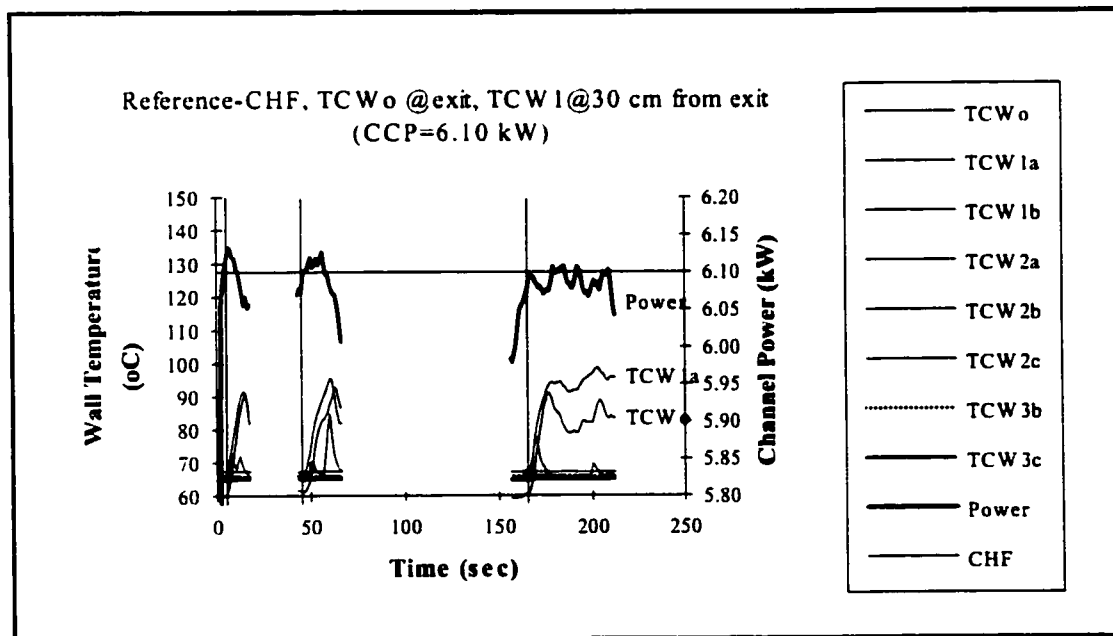


Figure 3.21: Sample thermocouple trace for 30% ring in Freon-134a, all obstructions at the inlet, CHF occurs at the exit and dryout moves upstream to TCW 1a.

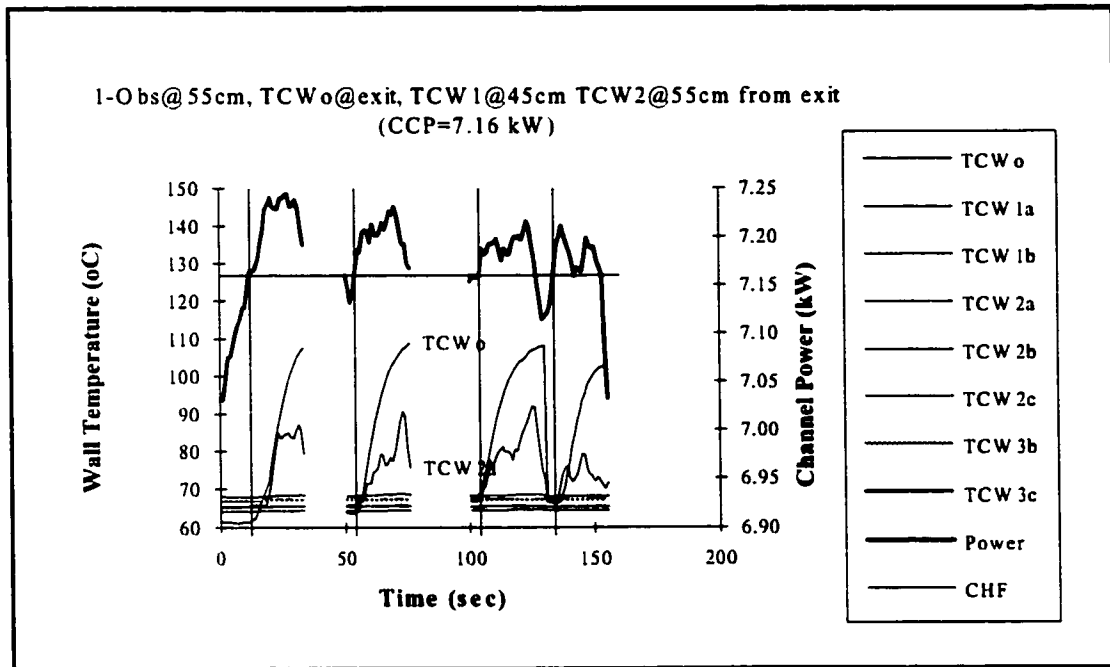


Figure 3.22: Sample thermocouple trace for 30% ring in Freon-134a, 1 obstacle located 55 cm from the exit, CHF occurs simultaneously at both the obstacle and the exit.

The first flow obstruction was then located approximately half-way along the heated length ($SP=100-140$ cm), with one thermocouple carrier located just upstream of the obstacle, and CHF was measured. The obstruction was then moved in steps of 10-20 cm towards the outlet of the test section, and each time the CHF was measured until CHF occurred just upstream of the obstacle. The steps were shortened and the obstruction spacing finely adjusted until CHF was detected simultaneously at both the obstruction and the exit – this is termed the limiting CHF since no further CHF enhancement can be obtained at the exit. Figure 3.22 shows a sample trace where CHF occurs at both the exit and the first obstacle simultaneously, for a critical channel power (CCP) of 7.16 kW and spacing of 55 cm. This is further explained at the end of Section 3.3.3.

A second flow obstruction and its accompanying thermocouple carrier were then moved into place approximately 120-140 cm from the exit. While maintaining an equal spacing

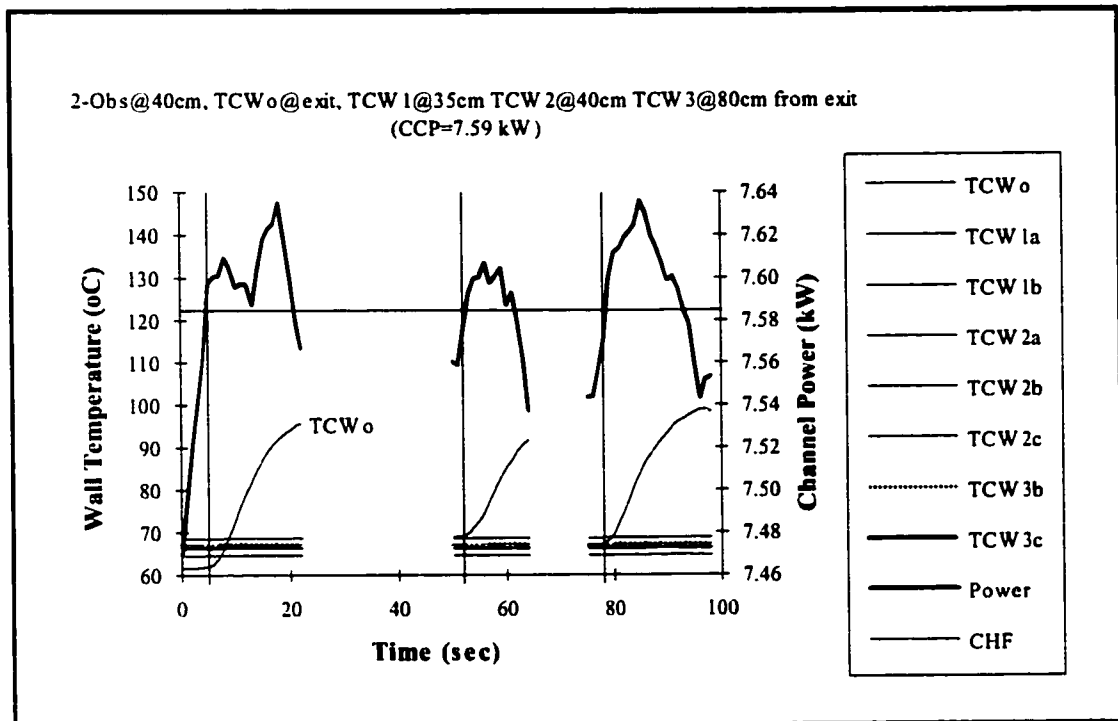


Figure 3.23: Sample thermocouple trace for 30% ring in Freon-134a, 2 obstacles located 40 cm apart, CHF occurs at the exit. between the first and second flow obstructions, and the exit and first flow obstruction (e.g., $SP=60$ cm), the CHF was measured. Again, the flow obstructions were moved in steps of 10-20 cm and the resultant CHF was measured until the limiting CHF occurred. As more flow obstructions were used, higher values of CHF were obtained at smaller obstruction spacings, as shown in Figure 3.23 for two rings located 40 cm apart. It would appear that CHF enhancement inside a tube is only limited by the number and spacing of flow obstructions.

The same procedure was repeated for three and four rings in Freon-134a, one through five block-spacers in Freon-134a, and four block-spacers in Freon-22. For a given pressure and mass-flux, three to five runs were performed at each inlet temperature and obstacle spacing to ensure repeatability of the results. The parameter ranges tested for each obstacle and fluid are listed in Table 3.4.

Table 3.4: Flow obstruction CHF experiment parameter ranges.

Obstruction	Fluid	P (MPa)	G (Mg/m ² -s)	Inlet Temp. (°C)	Dryout Quality	No. of Obstacles	No. of Points
30% Ring	R-134a	1.13	2	40	0.32–0.43	4	11
			4	27	0.10–0.15	4	7
		1.66	3	55	0.21–0.32	1–4	55
			4	11	0.01–0.12	1–4	65
				34	0.06–0.16	1–4	52
				44	0.09–0.22	1–4	63
				53	0.15–0.25	1–4	58
18% Spacer	R-134a	1.66	4	34	0.06–0.15	1–5	67
				45	0.10–0.20	1–5	69
				54	0.16–0.25	1–5	69
	R-22	1.89	3	6–38	0.08–0.30	4	62
			4	7–48	0.04–0.30	4	115
			5	9–42	0.02–0.24	4	56

3.3.3 Results and Analysis

Detailed information on the CHF experimental data are provided in Appendix B, including a full test matrix of tabulated DAS-measured and calculated data. In total, 755 flow obstruction CHF data points were measured, 311 (41%) of which were obtained using the 30% rings in Freon-134a. The 30% ring data were selected for use in analytical CHF modelling, since the single-phase heat transfer was measured for the same flow obstruction, and a large amount of CHF data were obtained for various obstacle spacings and obstacle number, with the same inlet temperature and flow condition. A complete procedural and error analysis was performed on this particular set of data, and the results are presented in Appendix B. The other

test data are presented here, without error analysis, to demonstrate their similar parametric trends. As stated in Appendix B, although these CHF experiments were performed by the author, all the resultant CHF data were tabulated by Doerffer et al. (1995).

CHF Enhancement Ratio

To illustrate the relative enhancement effects of different flow obstruction parameters, a non-dimensional CHF ratio similar to that defined for single-phase heat transfer was used:

$$R_{CHF} = \frac{q_{c,obs}}{q_{c,ref}} \bigg|_{X_c = const} \quad (3.5)$$

based on either the same local quality (above) or the same inlet temperature and heated length:

$$R_{CHF} = \frac{q_{c,obs}}{q_{c,ref}} \bigg|_{T_{in}, L_h = const} \quad (3.6)$$

Since the data span a wide range of inlet and flow conditions, it was necessary to obtain a similar range of reference CHF data for use in the above relation (Equation 3.5).

Reference CHF

Although reference CHF data were obtained before and after each test with all flow obstructions located at the inlet, this corresponded to only one data point per flow condition and inlet temperature (as outlined in Table 3.4). For the 18% block spacer in Freon-22, the inlet temperature varied with spacer configuration (i.e., inlet temperature will tend to rise with increased channel power, unless adjusted using the preheater and/or condenser). For this reason, Doerffer et al. (1995) performed additional reference tests with no flow obstructions and relied on previous data (Doerffer and Groeneveld, 1994) to compute the reference CHF for all CHF

enhancement data, at the same local quality. These reference data were obtained for the same fluid and tube diameter, but with different heated lengths to cover the range of quality required. Table 3.5 lists the parameter ranges for all the reference data used, as well as the correlating constants used by Doerffer et al. (1995) to fit the following empirical formula to the reference data:

$$q_{c,ref} = a P^{n_1} G^{n_2} + b P^{n_3} G^{n_4} x_c^{n_5} \quad (3.7)$$

The data at $P=1.66$ MPa and $G=4$ Mg/m²·s had to be separated into low-quality and high-quality groups to obtain a better fit. The dependent variable in each case was critical quality (x_c), or the quality at which CHF was measured. Figures 3.24 and 3.25 show the variation in CHF with quality, at pressures of 1.13 and 1.66 MPa in Freon-134a, respectively. Figure 3.26 shows the variation in CHF with quality at 1.90 MPa in Freon-22. The two pressures selected for each fluid are equivalent to typical operating pressures in water of 7 and 10 MPa¹, respectively. The solid symbols in each graph indicate the experimental data covering the range of pressure and mass flux shown in the legend. The lines represent the empirical correlation evaluated at the mean pressure and mass flux of each data set. The 1.13 MPa data in Freon-134a (7 MPa water-equivalent) show a slight increase in CHF when the mass flux is reduced from 4.0 to 2.0 Mg/m²·s, whereas the 10 MPa water-equivalent data in both Freon-134a ($P=1.66$ MPa) and Freon-22 ($P=1.90$ MPa) show a slight decrease in CHF when the mass flux is reduced from 5.0 to 3.0 Mg/m²·s. These trends will be discussed later, in comparisons with the analytical dryout models, to predict some of the flow mechanisms responsible for this parametric behaviour. The RMS error for this particular correlation ranges from 3% to 12%, depending on the flow condition and fluid, and has been taken into account in the error analysis of the 30% rings in Freon-134a.

¹

Equivalent pressures are obtained by matching the density ratios (ρ_l/ρ_g) of both fluids – for example, Freon-134a at 1.33 MPa has the same density ratio as water at 7 MPa.

Table 3.5: Reference CHF correlation data (Doerffer et al., 1995).

Parameter Ranges								
Fluid:	Freon-134a					Freon-22		
Pressure†: (MPa)	1.13 (7)		1.66 (10)			1.90 (10)		
Mass Flux: (Mg/m ² ·s)	2	4	3	4		3	4	5
Quality: (dryout)	.13-.37	.01-.28	.01-.25	.01-.11	.15-.24	.08-.28	.05-.27	.03-.26
Correlating Constants								
a	-1.0655	0	75.2733	0.0314	0.89595	0.0703	0.6899	0.4135
n ₁	0.94499	0.70873	-4.4176	-1.3636	6.45803	4.6339	2.1649	4.308
n ₂	5.57447	5.87313	-2.5849	2.2037	-1.3346	-1.3997	0.7151	0.783
b	1.07597	0.20383	-280.06	0	-0.8129	0	-0.7312	-0.4131
n ₃	0.94292	1.2779	-6.0443	-2.3613	6.73069	10.9269	2.16773	4.3461
n ₄	5.56147	-0.678	-3.0081	4.89685	-1.375	-2.2582	0.6665	0.7662
n ₅	0	-0.211	0.17789	0.54477	0.0108	0.48317	0.008	0.002
Statistical Error Analysis (using local quality)								
No. of Points:	52	73	96	90	43	49	35	52
Avg. Error:	-4.5%	-10.5%	-0.1%	-0.7%	-1.5%	0.3%	-0.4%	-1.3%
RMS Error:	7.7%	12.1%	7.8%	2.7%	4.2%	3.7%	3.8%	3.2%
Max. Error:	12.9%	23.8%	16.4%	9.2%	17.2%	7.5%	7.2%	6.2%

† Values in parentheses correspond to equivalent pressures in water.

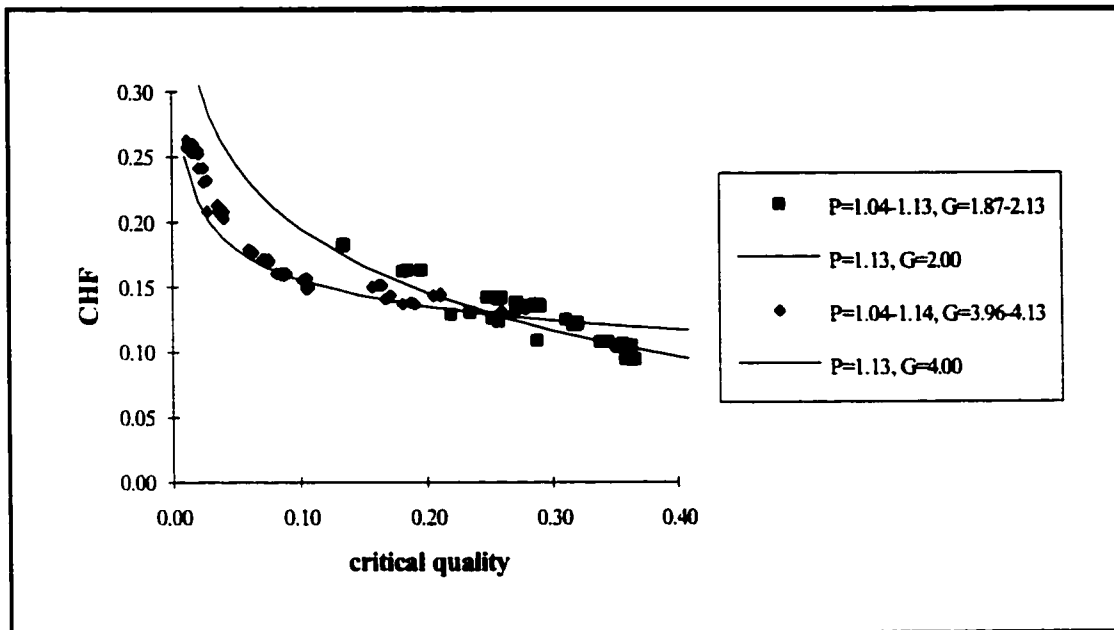


Figure 3.24: CHF (MW/m²) versus quality in Freon-134a, $P=1.13$ MPa, $G=2$ and 4 Mg/m².s.

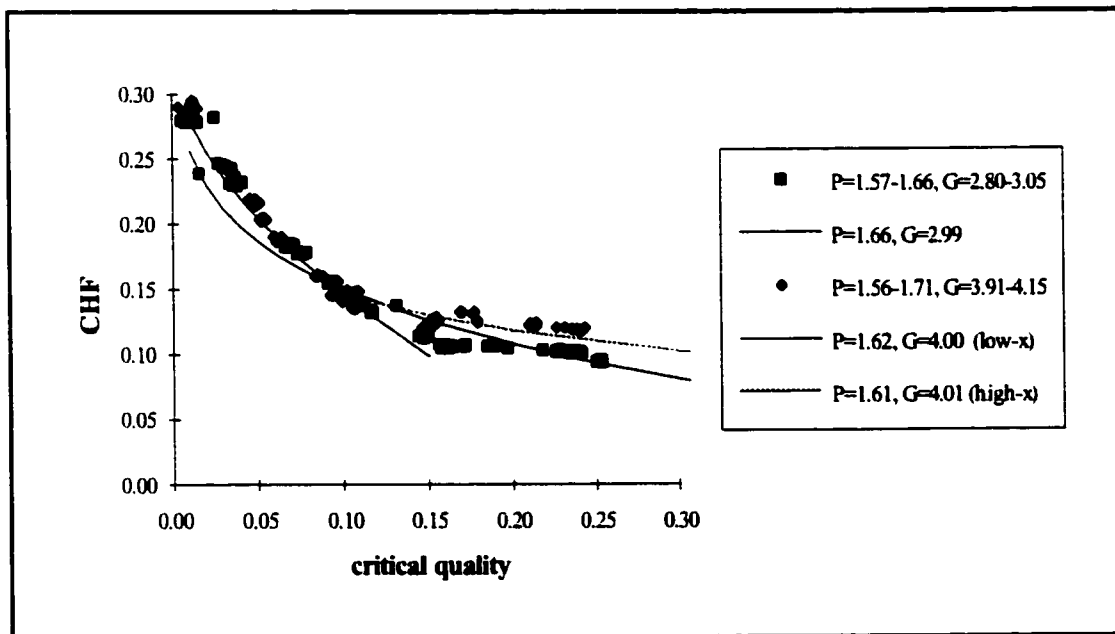


Figure 3.25: CHF (MW/m²) versus quality in Freon-134a, $P=1.66$ MPa, $G=3$ and 4 Mg/m².s.

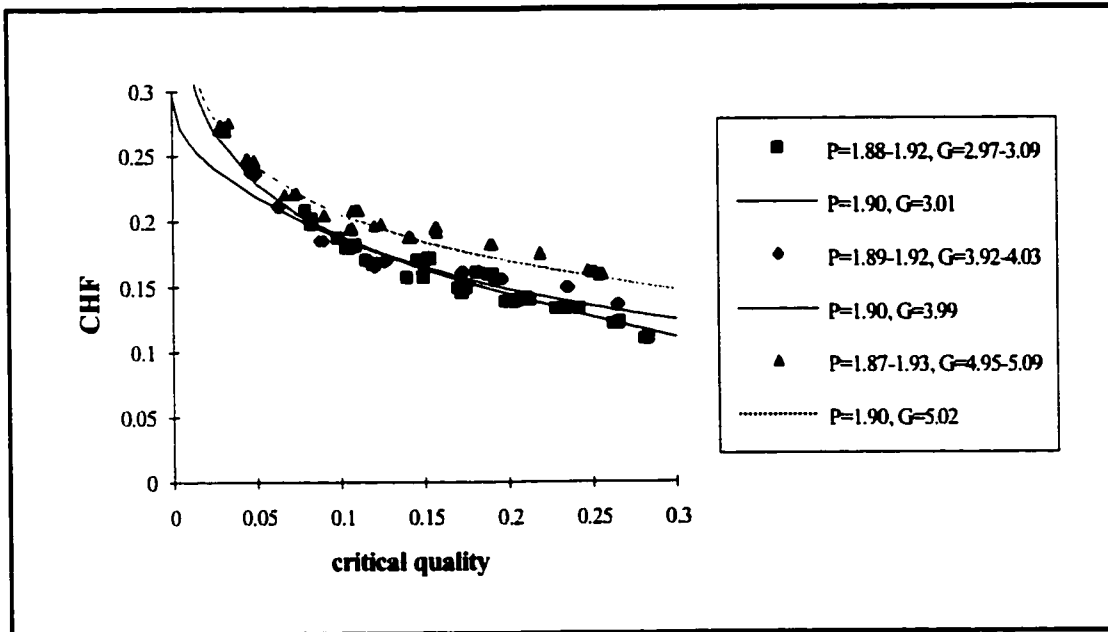


Figure 3.26: CHF (MW/m^2) versus quality in Freon-22, $P=1.90$ MPa, $G=3, 4$, and $5 \text{ Mg/m}^2\cdot\text{s}$.

CHF Enhancement (Same Quality)

The CHF enhancement results obtained based on local quality are presented in Figures 3.27 through 3.30 for the 30% rings in Freon-134a (two pressures), 18% spacers in Freon-134a, and 18% spacers in Freon-22, respectively. The strongest influence on CHF enhancement is the spacing between obstacles (SP/d), and between the last obstacle and the exit, where increases as much as 260% were measured at the smallest spacing. Relative increases in enhancement were also observed as the obstacles were located farther into the high quality region (i.e., higher inlet temperature), as shown in Figures 3.28 and 3.29. Small increases in enhancement were also observed as the mass flux was reduced from 4.0 to $3.0 \text{ Mg/m}^2\cdot\text{s}$ in Freon-134a at 1.66 MPa (see Figure 3.28). The same overall magnitude of enhancement was obtained with the 30% ring and the 18% spacer in Freon-134a, indicating the enhancement is more efficient when the obstacle extends farther into the flow (i.e., for the same blockage area).

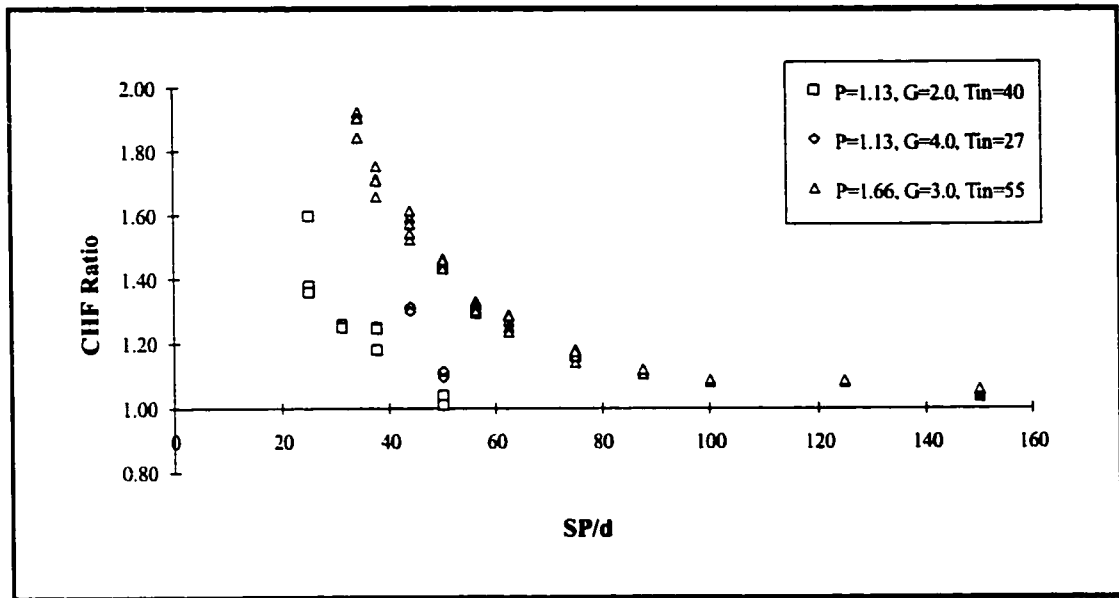


Figure 3.27: CHF enhancement ratio (based on local quality) versus non-dimensional spacing (SP/d) – 30% rings in Freon-134a at $P=1.13$ ($G=2.0, 4.0 \text{ Mg/m}^2\cdot\text{s}$), $P=1.66 \text{ MPa}$ ($G=3.0 \text{ Mg/m}^2\cdot\text{s}$), constant inlet temperature ($T_{in}=27, 40$, and 55°C), and $N_{obs}=1-4$.

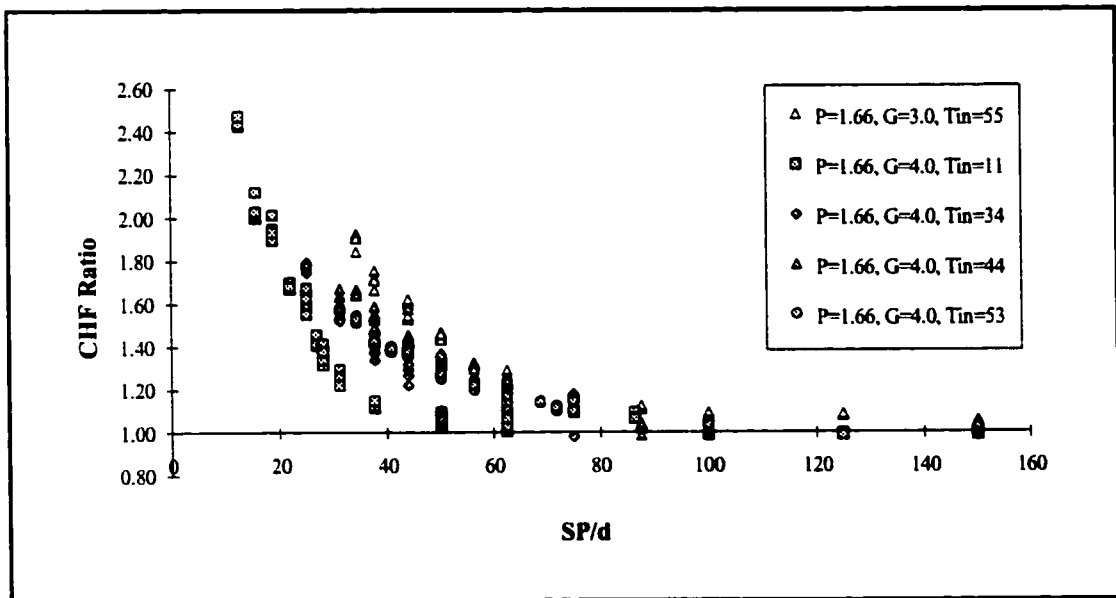


Figure 3.28: CHF enhancement ratio (based on local quality) versus non-dimensional spacing (SP/d) – 30% rings in Freon-134a, $P=1.66 \text{ MPa}$, $G=3.0$ and $4.0 \text{ Mg/m}^2\cdot\text{s}$, constant inlet temperature ($T_{in}=11, 34, 44$, and 53°C), and $N_{obs}=1-4$.

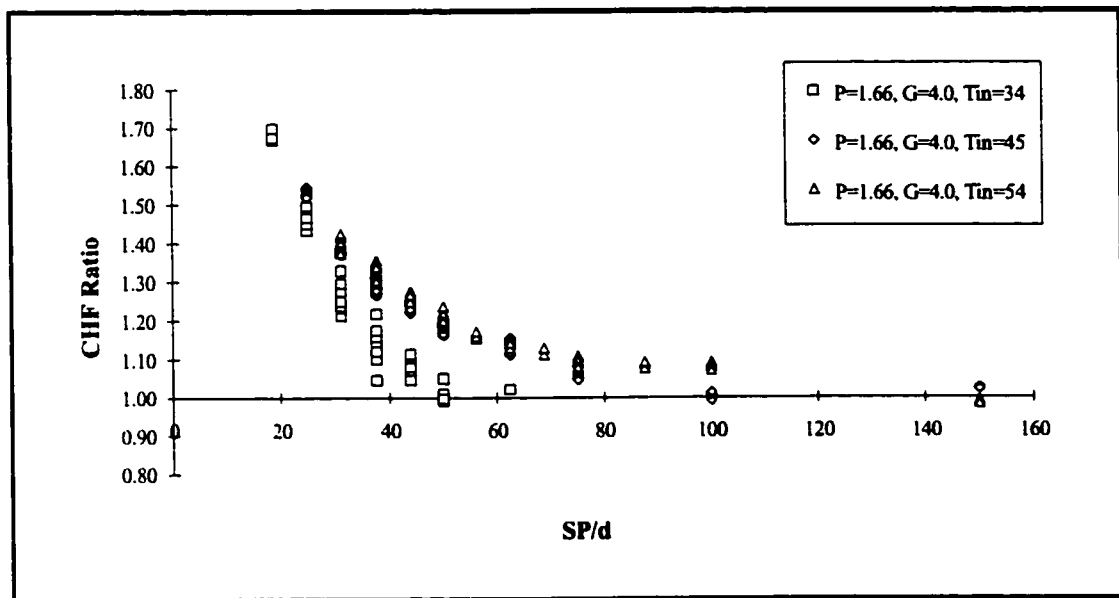


Figure 3.29: CHF enhancement ratio (based on local quality) versus non-dimensional spacing (SP/d) – 18% spacer in Freon-134a, $P=1.66$ MPa, $G=4.0$ Mg/m²·s, constant inlet temperature ($T_{in}=34, 45$, and 54°C), and $N_{obs}=1-4$.

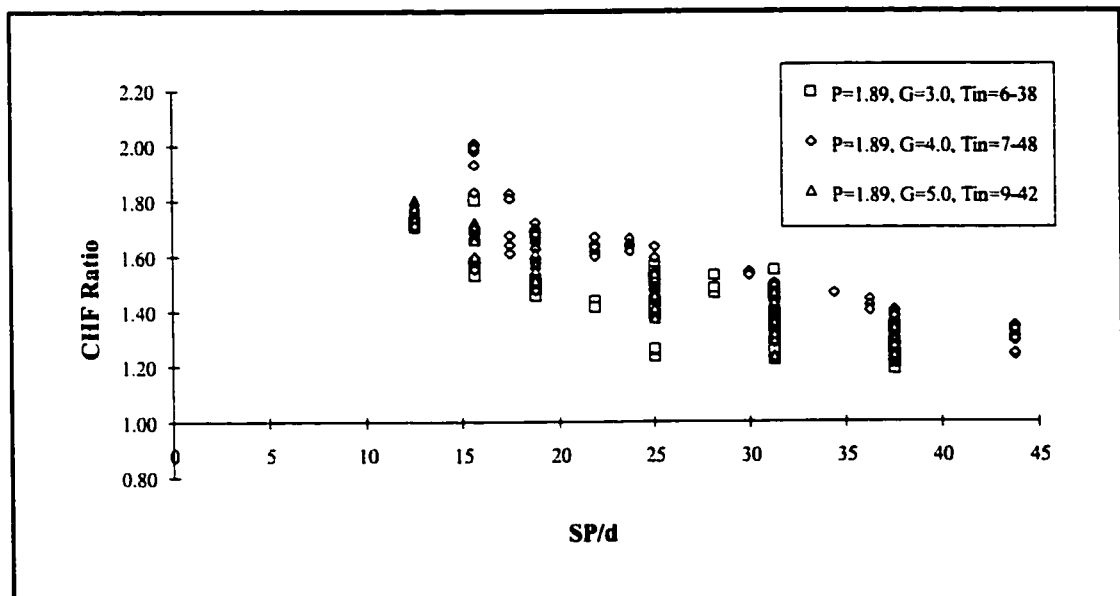


Figure 3.30: CHF enhancement ratio (based on local quality) versus non-dimensional spacing (SP/d) – 18% spacer in Freon-22, $P=1.89$ MPa, $G=3.0, 4.0$, and 5.0 Mg/m²·s, varying inlet temperature ($T_{in}=5-48^{\circ}\text{C}$), and $N_{obs}=4, 5$.

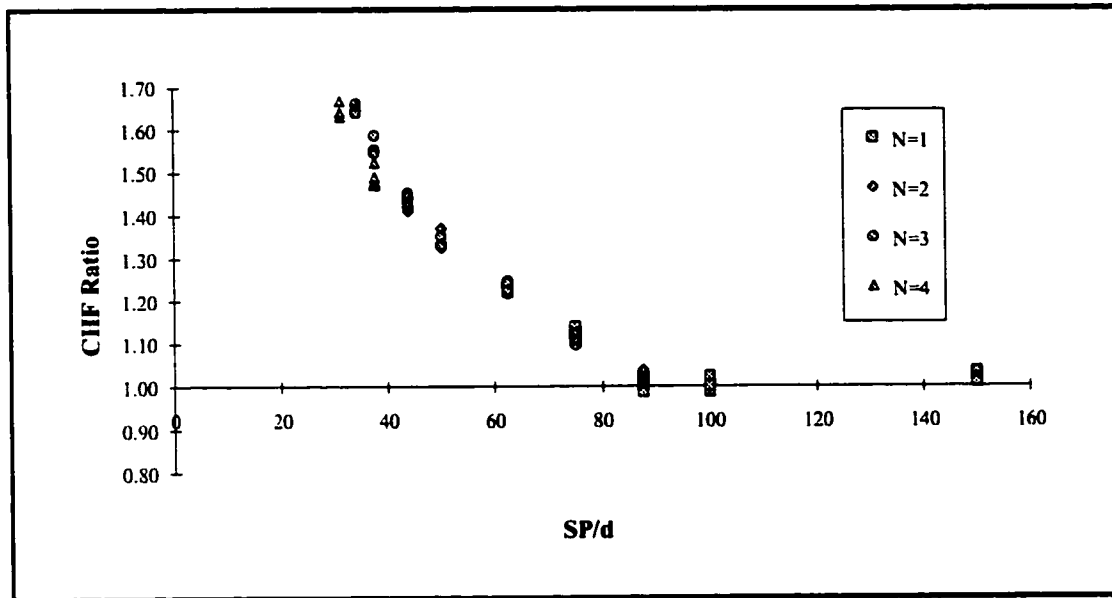


Figure 3.31: CHF enhancement ratio (based on local quality) versus non-dimensional spacing (SP/d) – 30% rings in Freon-134a at $P=1.66$ MPa, $G=4.0$ Mg/m²·s, and $T_{in}=44^{\circ}\text{C}$ for different numbers of flow obstacles ($N_{obs}=1,2,3,4$).

The thickness of the 30% ring is 1.3 mm, whereas the height of each block in the 18% spacer is 1.45 mm. The larger spread of the data for the 18% spacer in Freon-22 shown in Figure 3.30 is due to the large variation in inlet conditions used during the experiment. The intent was to obtain as wide range of data as possible for the 18% spacer in Freon-22, to compare with those obtained in Freon-134a. As indicated by the legend, the inlet temperature was varied from 6 to 48°C for each pressure and mass flow, with very few points obtained at the same inlet temperature.

To illustrate the effect of using more than one flow obstacle, a plot of the 30% ring data in Freon-134a at ($P=1.66$ MPa, $G=4.0$ Mg/m²·s, and $T_{in}=44^{\circ}\text{C}$), differentiated only by the number of flow obstacles (N_{obs}), is shown in Figure 3.31. The data overlap for the same inlet condition and obstacle spacing, indicating there is no cumulative effect from the presence of more than one flow obstacle, within the range of spacings tested. At one point, the CHF moves upstream of the first flow obstacle or occurs simultaneously at more than one flow obstacle. A

comparison was made between the CHF measured upstream of the first obstacle and the CHF measured in the reference tube at the same location (Doerffer et al., 1995) to show that these two values are equivalent (i.e., no degradation in CHF). As CHF is enhanced downstream, a point is reached where the nominal CHF or that of a less enhanced region will become critical — this is referred to as the limiting value of CHF. As more and more flow obstacles are added, the limiting value of CHF increases and higher values of CHF are obtained. Because the maximum number of flow obstacles was limited to either 4 or 5, a minimum spacing of 10 cm ($SP/d=13$) was obtained. If this minimum spacing were reduced by using more flow obstacles, one would expect an optimal spacing to occur where any further reduction in spacing would decrease CHF, due to the truncation of enhancement, as observed in single-phase heat transfer (Okamoto et al., 1993).

CHF Enhancement (Same Inlet Condition)

To facilitate comparisons with the model, the CHF enhancement ratios for the 30% ring data were also computed for the same inlet temperature and heated length (see Figure 3.32). The ratios are slightly lower because the reference value of CHF remains constant for the same inlet temperature, whereas the reference value of CHF will decrease for a constant quality ratio as the CHF increases. The same overall trend still applies. The reference CHF correlations were reassessed using the same inlet temperature and heated length to produce the error results shown in Table 3.6. The errors based on inlet temperature and heated length are typically 50% lower than those based on local quality (see Table 3.5). This reduction in error can be explained by the illustration shown in Figure 3.33. The CHF versus quality curve for a constant inlet temperature follows a constant slope for the same pressure, mass flux, heated length, and fluid. The same curve for a constant quality condition follows

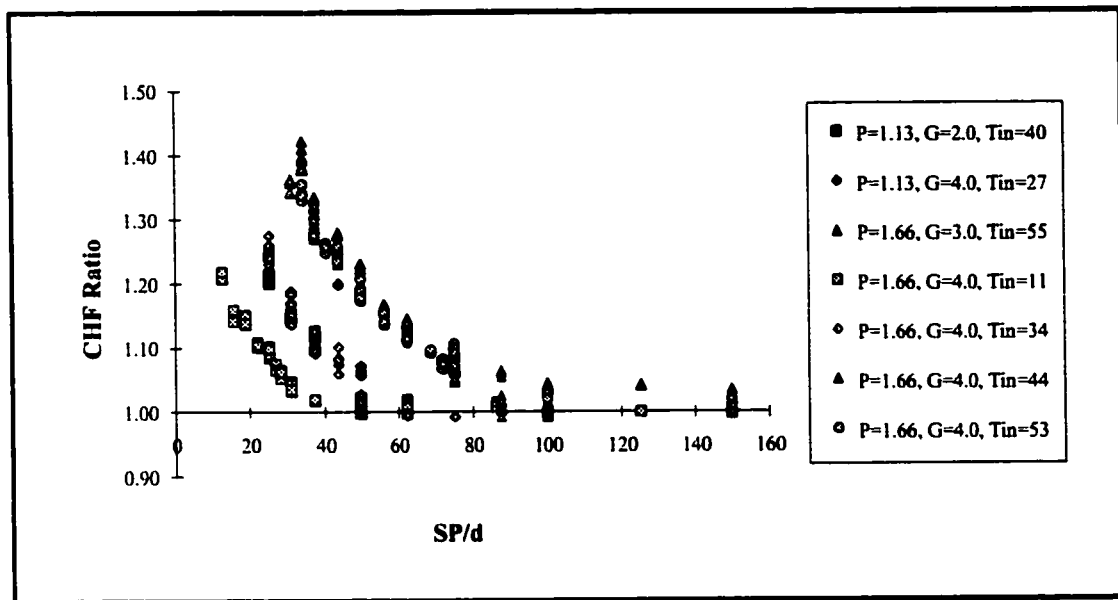


Figure 3.32: CHF enhancement ratio (based on inlet temperature) versus non-dimensional spacing (SP/d) – 30% rings in Freon-134a ($N_{obs}=1-4$).

Table 3.6: Reference CHF correlation errors based on heated length and inlet temperature.

Parameter Ranges					
Fluid:	Freon-134a				
Pressure†: (MPa)	1.13 (7)		1.66 (10)		
Mass Flux: (Mg/m ² ·s)	2	4	3	4	
Quality: (dryout)	.13–.37	.01–.28	.01–.25	.01–.11	.15–.24
Statistical Results					
No. of Points:	52	73	96	90	43
Avg. Error:	-1.9%	-4.9%	0.2%	-0.1%	-1.2%
RMS Error:	3.8%	5.8%	3.4%	0.8%	3.6%
Max. Error:	6.4%	11.9%	7.0%	2.1%	17.3%

† Values in parentheses correspond to equivalent pressures in water.

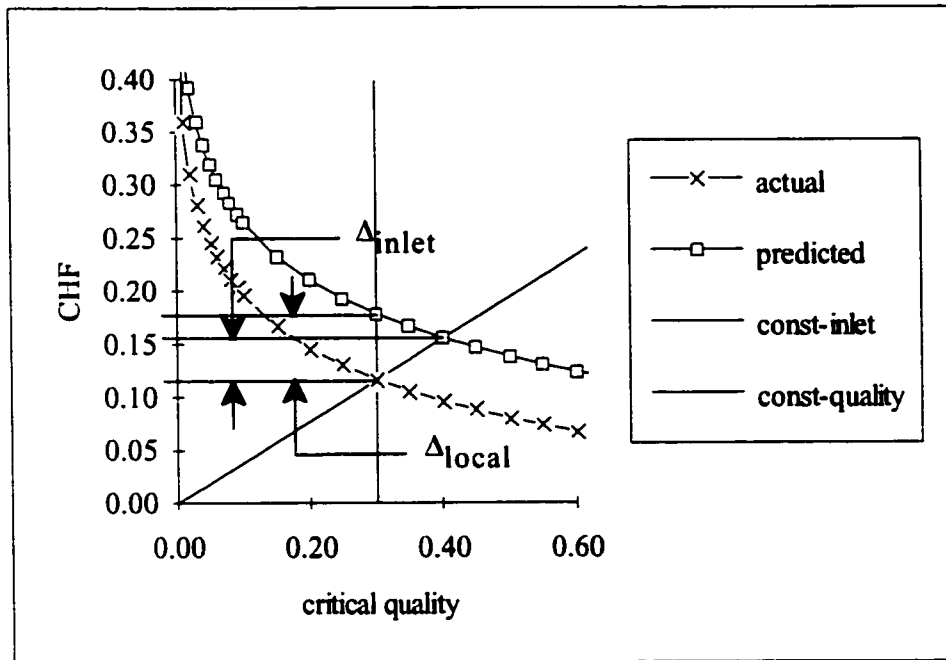


Figure 3.33: Comparison of CHF prediction methods which use local quality versus inlet temperature and heated length.

a vertical line. The error is defined by the difference between the intercept of the actual and predicted CHF curves, using either the constant quality or constant inlet temperature line, and is shown to be a maximum for the constant quality line. It should be noted that local quality is not a measurable quantity, but must be calculated from the measurement of inlet fluid temperature, mass flow, test section power, and the properties of the fluid.

To illustrate the uncertainties associated with the CHF enhancement results for the 30% ring in Freon-134a, the average ratio and associated error are presented in Figures 3.34 and 3.35 for the same inlet condition, spacing, and number of flow obstacles (see Appendix B for details). A large uncertainty exists in the calculation of heat loss due to a combination of measurement errors in fluid temperature and mass flow rate, to produce an uncertainty in measured CHF ranging from 1% to 2.5%. The largest source of uncertainty in the CHF ratio is the prediction of reference CHF using the previously cited CHF correlations, where the errors range from 4% to 12% depending on the pressure, mass flux, and local quality.

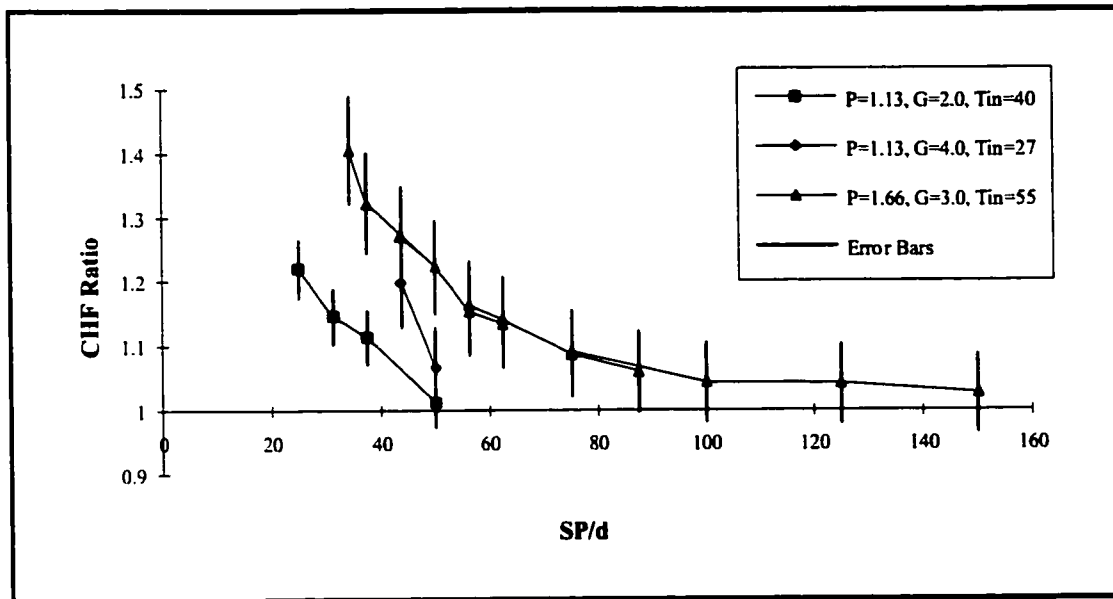


Figure 3.34: Average CHF enhancement ratio (based on inlet temperature), with error bars indicated, versus spacing (SP/d) for the 30% rings in Freon-134a at $P=1.13$ MPa ($G=2.0, 4.0$ $\text{Mg/m}^2\cdot\text{s}$) and $P=1.66$ MPa ($G=3.0$ $\text{Mg/m}^2\cdot\text{s}$).

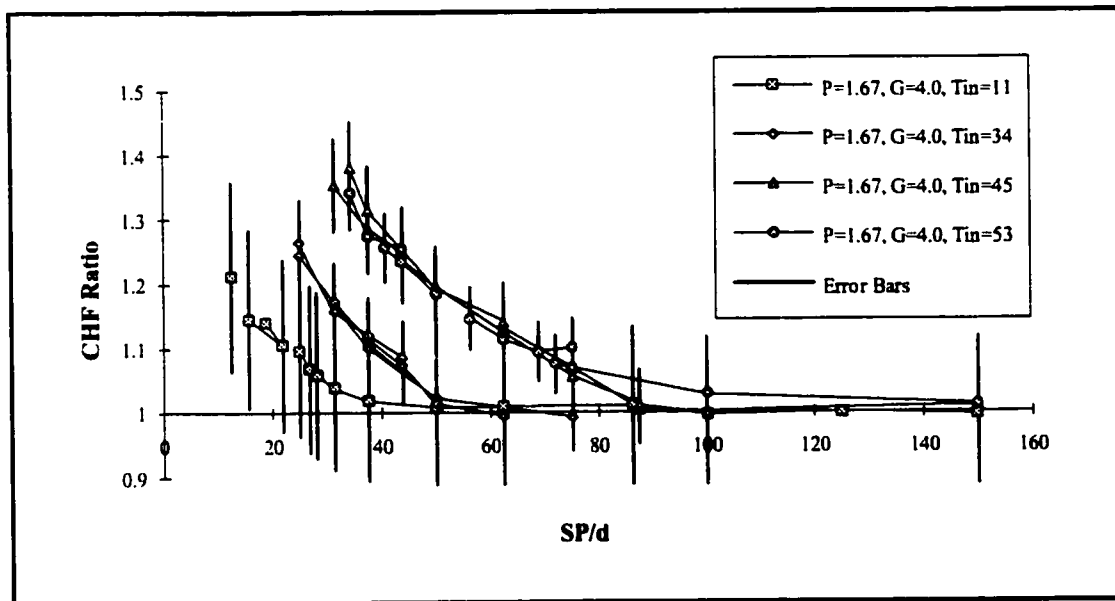


Figure 3.35: Average CHF enhancement ratio (based on inlet temperature), with error bars indicated, versus spacing (SP/d) for the 30% rings in Freon-134a at $P=1.66$ MPa and $G=4.0$ $\text{Mg/m}^2\cdot\text{s}$.

The largest error in CHF ratio is 12% and occurs at $P=1.66$ MPa, $G=4.0$ Mg/m²·s, and $T_{in}=11$ °C. The average error in CHF ratio is around 6%. Although these errors seem large in comparison to the magnitude of the CHF ratio, all the data collapse to within 5% of the nominal CHF value at very large values of spacing (SP/d) — an indication of the true error. It should be noted that the model should not be fit to the data by more than 5%, since any additional precision will be invalid due to the uncertainty in the measured data. This is an important point when considering the estimation of parameters for an analytical model.

Geometry Effectiveness

Since CHF was measured for both rings and blocks in Freon-134a at the same inlet conditions, the effectiveness of these two geometries to enhance CHF can be compared, as shown in Figures 3.36 and 3.37. At the lower quality ($T_{in}=34$ °C), the 30% ring is roughly 20% more effective than the 18% blocks. At the higher quality ($T_{in}=54$ °C), the 18% blocks are shown to be equally effective, even though 40% less flow area is being obstructed. This last result would imply that either the two flow blockages produce the same amount of turbulence (mass transfer enhancement), or that the entrained liquid is more concentrated in the centre of the tube with more liquid impinging the higher obstacle of the same area. Measuring the enhancement of single-phase heat transfer behind the 18% blocks would help identify which of these two mechanisms has a greater influence at high quality. If the 18%-area blocks produces significantly less heat transfer enhancement than the 30% ring, one could conclude that CHF enhancement at high quality is primarily a function of entrained liquid impingement on the flow obstacle, re-directing the droplets to the liquid film.

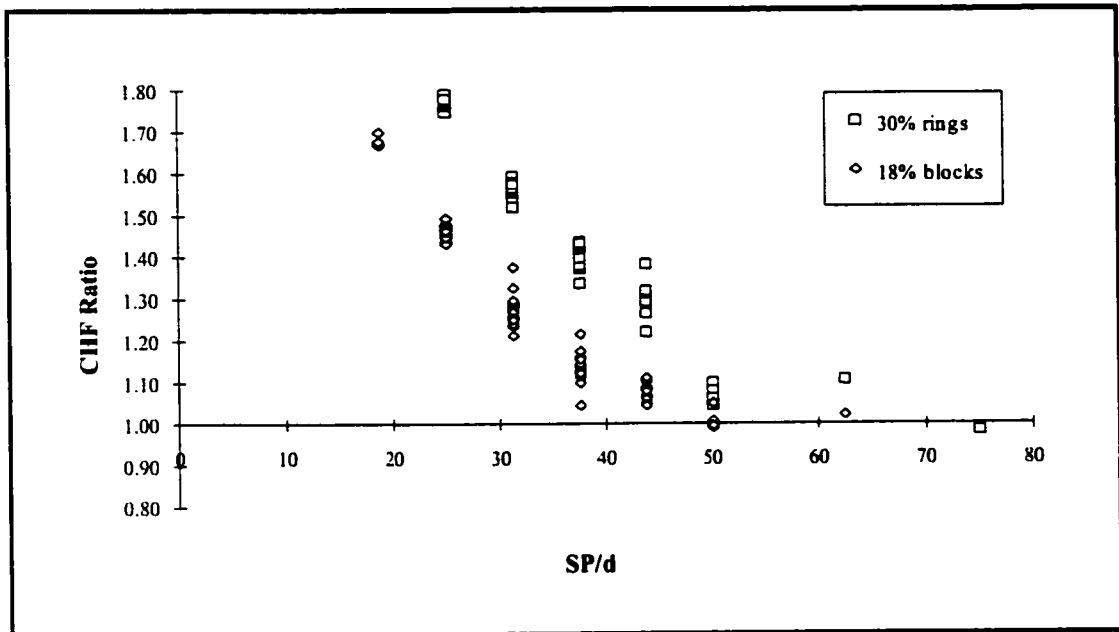


Figure 3.36: CHF enhancement ratio (based on local quality) in Freon-134a – 30% ring versus 18% spacer ($P=1.66$ MPa, $G=4.0$ Mg/m²·s, $T_{in}=34^{\circ}\text{C}$).

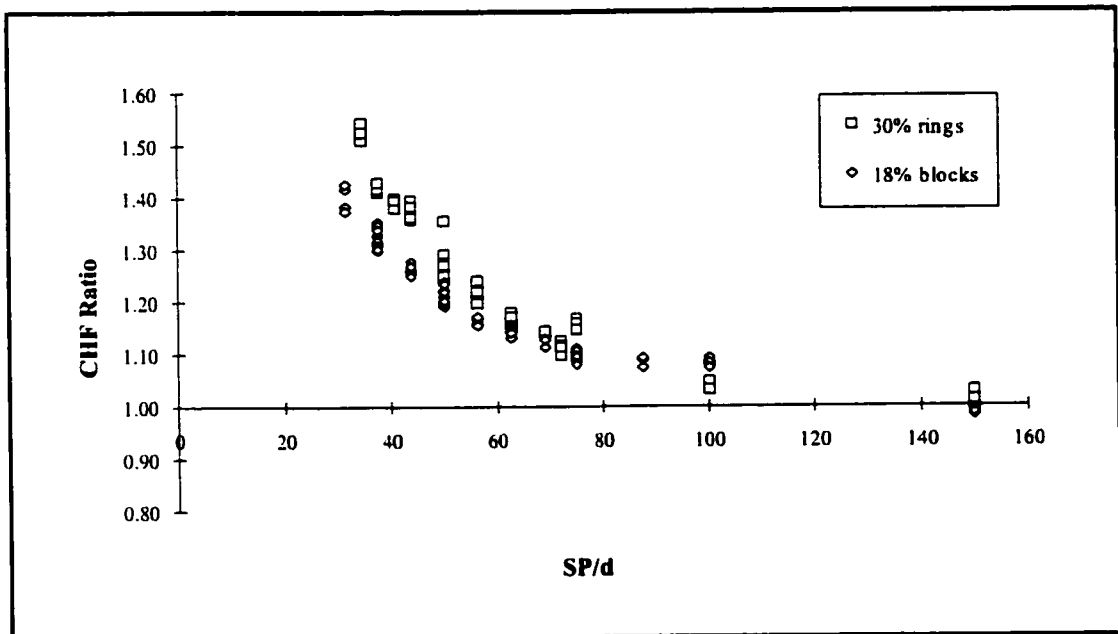


Figure 3.37: CHF enhancement ratio (based on local quality) in Freon-134a – 30% ring versus 18% spacer ($P=1.66$ MPa, $G=4.0$ Mg/m²·s, $T_{in}=54^{\circ}\text{C}$).

Mapping the Effect of Spacing

The previous sections have shown how measured CHF enhancement varies primarily with obstacle spacing and the number of flow obstacles used. To better understand how local increases in CHF (near the flow obstruction) might translate into measured CHF enhancement ratio, various hypothetical CHF versus pipe length curves are presented in Figure 3.38. Based on the results from single-phase heat transfer enhancement, one might expect local CHF enhancement to follow a similar pattern: rapid rise in CHF at or just after the flow obstruction, followed by an exponential decrease in CHF with downstream distance. Three different flow obstruction positions (a, b, c) are now considered to illustrate the following CHF enhancement conditions:

- a) the obstacle is positioned far enough away that the local CHF returns to its nominal (reference tube) value,
- b) the obstacle is positioned closer to the exit, such that the local increase in CHF is enough to cause a measurable increase in CHF at the exit (i.e., for the same inlet condition and heated length),
- c) the obstacle is brought close enough to the exit that the local increase in CHF is enough to match the reference tube CHF just upstream of the flow obstruction,

These three distinct points are identified on the accompanying CHF enhancement ratio curve, to show the range of CHF measured in this experiment. The resultant CHF ratio for the nominal tube at various distances from the exit (i.e., obstacle spacing) serve to illustrate the notion of a limiting CHF, whereby any further decrease in flow obstruction spacing only serves to displace the CHF upstream of the obstacle. It should also be noted that by introducing a second flow obstruction (i.e., upstream of the first), the limiting CHF just before the first obstruction is enhanced to allow greater CHF at the exit, up until the nominal value before the newly added flow obstruction is exceeded. This scenario can be repeated a number of times with the use of more and more flow obstructions near the exit. This same characteristic will be illustrated in the CHF enhancement models to be presented.

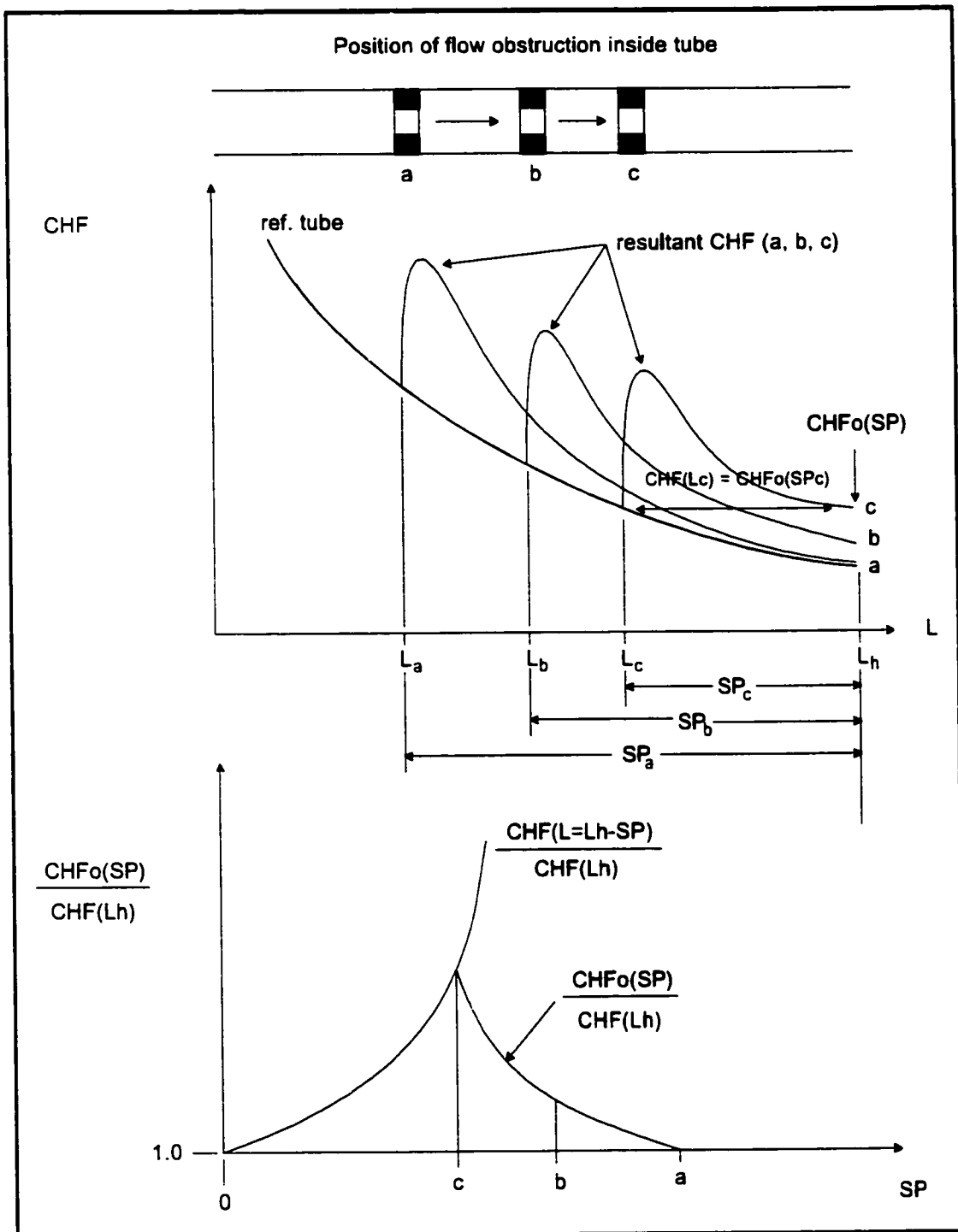


Figure 3.38: Interpreting the effects of flow obstruction spacing on CHF.

Chapter 4 CHF MODEL DEVELOPMENT

A computer software was developed to provide a flexible framework for the simulation of complex physical processes. This chapter will describe the overall software architecture and how it was used to build models of both the reference tube and enhanced tube CHF. These tools are used extensively in the parametric model analysis of Chapter 5 and Chapter 6.

4.1 Object-Oriented Framework

An object-oriented simulation and modelling framework (OSM) was developed using the Borland C++ compiler (v3.1) and Borland ObjectWindows Library (OWL)². Like other object-oriented programming languages (e.g., SmallTalk, Object Pascal, Ada, etc.), C++ uses an object class definition to encapsulate various data and routines within a program. These languages all share one common feature: they can allow or impose classes inheriting from another (base) class to redefine their own methods of dealing with specific object data — this is known as polymorphism. In C++, these specialized base classes are known as virtual (pure virtual) or abstract classes, and form the basis on which OSM was developed. By inheriting

²

Borland C++ and ObjectWindows are registered trademarks of Borland International Inc., Scotts Valley, California.

from base classes in OSM, one can define their own specific process models while still inheriting the system functionality from OSM.

The primary purpose of OSM is to:

- allow the construction of individual component models and inter-connect them at run-time, through specialized data-flow streams, to form a larger system or network model,
- provide a standard method of handling input/output data for each component object and the network, differentiating between different types of data (i.e., configuration, input, output, simulated) through a status specifier,
- define a standard template (name, description, status specifier, default value, and choice of type: text, mode, integer, floating-point, etc.) for each variable accessible within an object,
- automatically scan and connect the network model, generating a list of the minimum input variables necessary to simulate the system and a list of all variables viewable from the system,
- compile, test and simulate the network model through a system of abstract references to monitor the convergence of individual component models, and transfer data between inter-connected components.

Figure 4.1 illustrates the main components of a program called OSMWin which was constructed to carry out the present modelling work. The C++ stream class library is a standard component library, containing the basic I/O functionality of the language. The Borland container class library is a collection of standard container classes (e.g., binary tree, stack, queue, array, sorted array, etc.) which are used by various components of OSMWin to manage the large amounts of data required. The ObjectWindows Library (OWL) encapsulates the data and routines necessary to write any Windows program. Standard interface objects such as windows, dialogue boxes, menus, buttons and other controls are either declared or inherited from OWL,

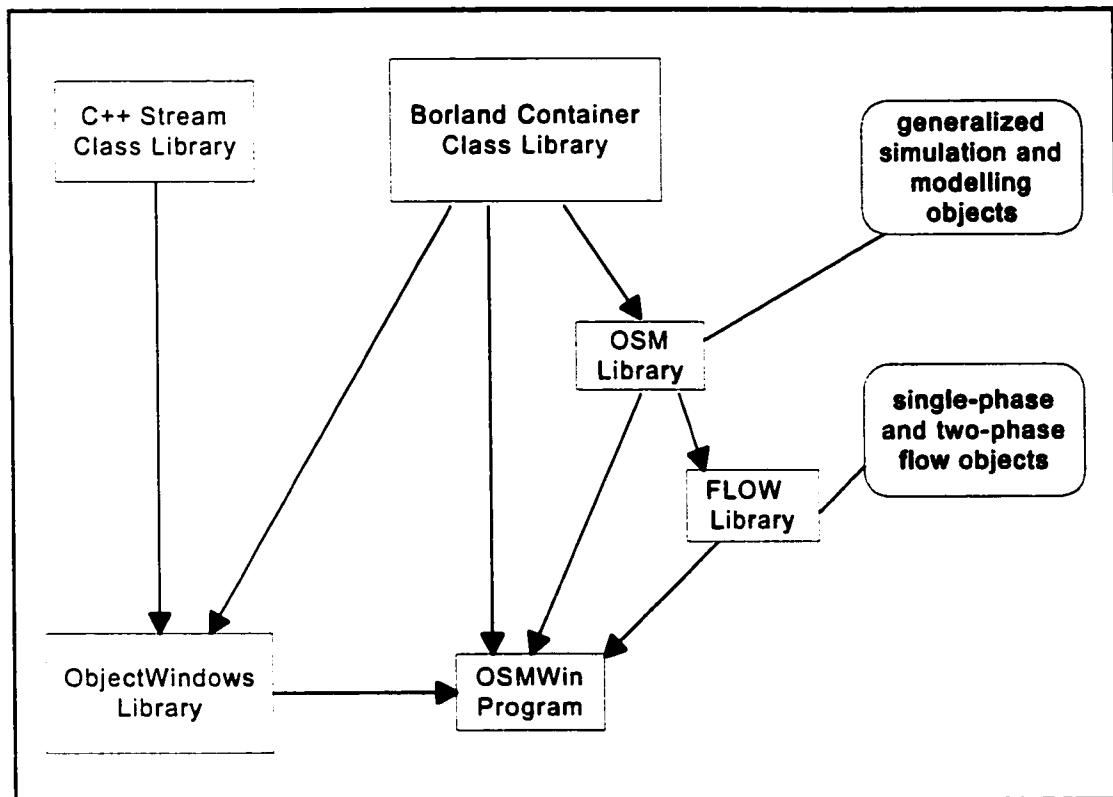


Figure 4.1: Principal components of OSMWin.

and used to build a particular application (OSMWin). OSMWin is linked with both the OSM library and a user-defined FLOW library, providing the standard simulation components to carry out the present modelling study.

The OSM hierarchy of generic simulation and modelling class objects is shown in Figure 4.2. They form the base classes on which specific component models are built. The single-phase and two-phase FLOW library included with OSMWin is an example of how one such component library can be built. Each component object or class in the FLOW library inherits from OSM and provides a unique name, description, and type-specifier (Element, Stream, Data, Network), and has the option of overriding the virtual class member function (getVar) to return a list of its own variables.

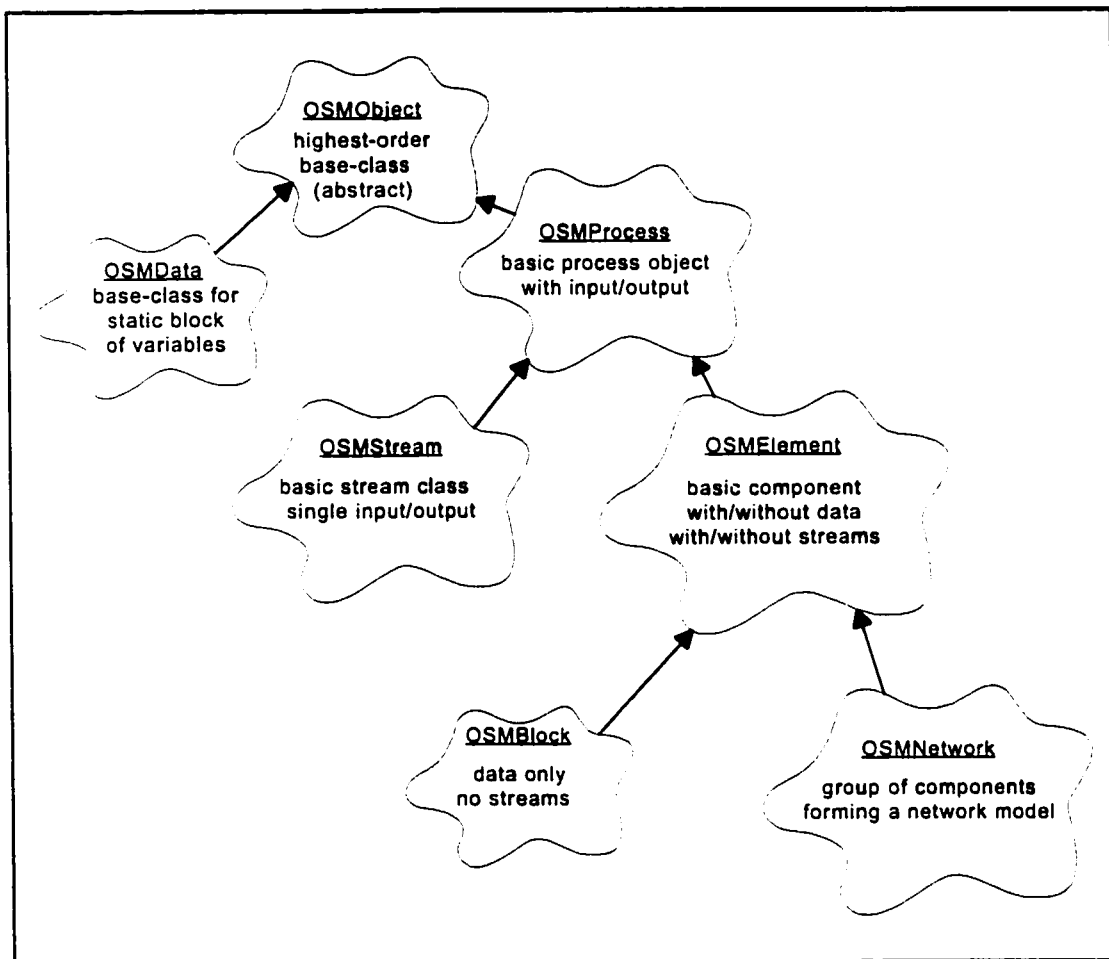


Figure 4.2: The OSM class hierarchy.

OSMDData contains a list of constant variables and associated data, which are loaded using standard read/write member functions, to encapsulate a group of constant model parameters (e.g., the constant properties of a fluid or material). OSMPProcess forms the basis on which any process model is built, encapsulating the input and output streams necessary to connect two individual process components. Each OSMPProcess component has a number of inputs and outputs, and a corresponding list of abstract (high-level) references to its connected elements. OSMPProcess encapsulates the commonality between I/O streams (OSMStream) and component elements (OSMElement). OSMElement is a base class for all component objects,

each containing static (configuration) and dynamic (input, calculated) data, and a reference to each of its OSMStreams. OSMStream is a special sub-class of OSMProcess with only a single input and output stream, to function as a data I/O buffer between two inter-connected OSMElements. OSMStream and its derived classes have no configuration data since they only contain dynamic simulation (buffered) data.

OSMBlock is a special sub-class of OSMElement, conveniently defined for component models with no input or output streams. Objects derived from OSMBlock can only have configuration and simulation (input or calculated) data. Examples of components derived from OSMBlock are the standard CHF prediction methods: Katto (1984), Bowring (1972), and the AECL lookup table (Groeneveld et al., 1995), which have been implemented in OSMWin to compute CHF based on inlet conditions, tube diameter, and heated length.

OSMNetwork encapsulates the group of components forming a network or system model. This class provides most of the overhead functionality, including the loading of multiple (nested) networks, and the compiling, testing, and simulation of the resultant system. Each network uses a system of abstract references to each OSMElement and OSMStream to manipulate data and pre-defined member functions, operating at a very high-level without any inner knowledge of the particular component object.

Based on the above class hierarchy, the following generic functionality has been implemented within each OSMElement inherited class. Each OSMElement has a time and time-step variable, set by the system and used by the component object to model any transients in the system. Although the system was designed for transient modelling, steady-state models are easily simulated using time as a simple run ID, where each time step simply demarcates an independent solution to the system. An ExecStatus variable indicates when a new time step has been launched, when an object still requires iteration, and when an object has converged. A ConfigStatus variable is used by the system to tell the component when new configuration data have been included in the input. This way, objects can be re-configured

during a simulation, without having to reload the static configuration data (e.g., test the effect of diameter or heated length). The read and write routines within OSMElement are used to retrieve, update, and store data for a particular component object, calling on the optional getVars (virtual) function to provide a reference to the object's internal data. A connect routine is used to negotiate a stream connection between two components: an OSMElement can be requested to construct an appropriate stream object (if none exists), or connect with an already existing stream object. In the latter case, the element has a choice to refuse an illegitimate connection. An execute routine is used to define a single iteration of the component object solution. Since the solution of one component is often a function of output from another simulated object, this mechanism allows all objects to be solved simultaneously and iterated in the most efficient way. By breaking up the solution into smaller components, the software has the capability to interrupt the solution temporarily (using what are known as work procedures) without having to terminate the program.

A static global variable ExecObjTable and associated addExecObj routine are used to register component objects within a global database of OSMWin. These are maintained by OSMElement and allow the system software (OSM) to be segregated from the component libraries (FLOW). By using a global registry, component objects can be constructed dynamically at run-time from a user-defined list of objects (network). The object registry also allows other component objects and entire libraries (e.g., FLOW) to be added without having to re-compile either the interface or overhead software. This is an important factor when considering the proprietary nature of software and its future expansion to include third-party component libraries. The overall simulation procedure derived from the OSMNetwork class and used by OSMWin will be described.

4.2 Reference-Tube Test Section Model

The network model for the reference tube CHF is shown schematically in Figure 4.3, and is used here to illustrate the modelling framework. The functionality of each component object is now described. The test section consists of a two-phase flow inlet (TPAInput) and a heated test section (TPAPipe). These two flow elements can simulate both the subcooled (homogeneous) and annular flow regimes. To predict the reference value of CHF, a heat flux must be applied to the wall (q_0) so that dryout occurs at the exit. The exact value of this heat flux is unknown, and must therefore be resolved using some form of numerical solution. The `Iterator` uses a Secant method of solution to iterate a single output value (So) until the error between its dynamic input variable (Si) and an internal set-point value (Sp) is reduced to zero. In this case, the input value provided is the current predicted CHF location (L_c), which could be either within the annular flow pipe (TPAPipe) or estimated somewhere outside the pipe. By specifying a set-point equal to the pipe length, CHF will be obtained at the exit. Two additional inputs, a minimum output value (So_min) and a maximum output value (So_max), are used to limit the output value to within a pre-defined solution domain. For CHF in annular flow, a minimum value of heat flux is required to keep the fluid above the minimum dryout flow condition ($x \geq x(\delta_{peak})$), and a maximum value is used to keep the fluid from becoming superheated ($x \leq 1$). The following theoretical relations are used to define these two limiting heat fluxes. First, a steady-state energy balance on the test section provides:

$$G A_x (i_{out} - i_{in}) = q_w P_w L_h \quad (4.1)$$

where the hydraulic diameter of the tube:

$$d_h = \frac{4 A_x}{P_w} = d_i \quad (4.2)$$

is used to simplify the relation for q_w :

Therefore, K is a constant for a given flow rate and test section geometry. Considering a current set of values (q_w, i_{in}, i_{out}) , and a limiting range of enthalpy values (i_{peak}, i_g) , the following two relations for minimum and maximum heat flux are obtained, respectively:

$$q_{w,min} = \frac{(i_{peak} - i_{in})}{(i_{out} - i_{in})} q_w \quad (4.4)$$

$$q_{w,max} = \frac{(i_g - i_{in})}{(i_{out} - i_{in})} q_w \quad (4.5)$$

where i_{peak} is the fluid enthalpy at maximum (peak) liquid-film thickness, and i_g is the saturated vapour enthalpy. It will be shown in Chapter 5 (see Figure 5.14) that the liquid film thickness increases initially, from the onset of annular flow (OAF), up to a maximum value and then decreases towards dryout. Because the dryout location has to be estimated when the heat-flux is too low, and there still exists liquid-film at the end of the pipe section, the solution domain must be restrained so that the outlet is never in the initial liquid-film growth region of annular flow (i.e., so that numerical iteration will not predict a lower heat-flux to decrease the liquid-film at the outlet). The annular flow model is used to calculate both i_{peak} and i_g (in every pipe section), whereas the enthalpy at the inlet and outlet of the test section are obtained using a special component object (iTrans) to transmit the annular flow mixture enthalpy stream variable at the inlet and outlet of the test section. The ratio itself is computed using a simple SigRatio component block to implement the following generic relation:

$$S_o = \frac{(x_i - x_1)}{(x_2 - x_1)} S_i \quad (4.6)$$

which is identical in form to both Equations (4.4) and (4.5). The AOBank and SigJctx10 objects are simply junctions used to pass a single output variable to more than one component object. In this case, the heat flux is transferred to three different objects (q-min, q-max, and Sect-1). The inlet and outlet fluid enthalpy are both transferred to both SigRatio blocks

($q_{\min}$ and $q_{\max}$). Finally, the flow conditions at the inlet to the test section are controlled by the TPAInput component object, where the fluid pressure, mass flow rate, inlet enthalpy, and optional liquid-film flow rate are specified. The inlet enthalpy can be specified as either a quality, enthalpy, or subcooling.

4.3 Standard Simulation Procedure

A standard simulation procedure has been developed to simulate any model constructed using the OSM framework. The reference tube CHF model, described in the previous section, will be used to illustrate this six step procedure:

- construct the network model
- configure each component element
- compile the network model
- define the input/output variables
- test and run the model
- analyse the model results

4.3.1 Constructing the Network Model

The first step in constructing a network model is to provide a list of components and their associated class-object names, as illustrated in Figure 4.4. In this case, the first component Iter-1 is defined as an instance of the class-object Iterator,

Iter-1	Iterator
Jct-0	SigJctx10
ExpIn	TPAInput
trans1	iTrans
Sect-1	TPAPipe
trans2	iTrans
Jct-1	AOBank
Jct-2	AOBank
$q_{\min}$	SigRatio
$q_{\max}$	SigRatio

Figure 4.4: Network component file (ref-exp.nwk).

Jct-0 as an instance of the class-object SigJctx10, and so on. An instance refers to an actual object constructed from the specified class, each containing its own unique data. Many

objects of the same type or class can co-exist, but not with the same instance name within the same network.

The next file shown in Figure 4.5 contains a connection list, similar to an electronic wiring list, describing the inter-connections between various components in the above network. For example, the 1st output (index=0) of

Iter-1	0	Jct-0	0
Jct-0	0	Sect-1	1
Jct-0	1	q-min	0
Jct-0	2	q-max	0
ExpIn	0	trans1	0
trans1	0	Sect-1	0
Sect-1	0	trans2	0
Sect-1	1	Iter-1	0
Sect-1	3	q-min	3
Sect-1	4	q-max	3
trans1	1	Jct-1	0
trans2	1	Jct-2	0
Jct-1	0	q-min	1
Jct-1	1	q-max	1
Jct-2	0	q-min	2
Jct-2	1	q-max	2
q-min	0	Iter-1	1
q-max	0	Iter-1	2

Figure 4.5: Network component link-list (ref-exp.lnk).

Iter-1 is connected to the 1st input of Jct-0, the 1st output of Jct-0 is connected to the 2nd input of Sect-1, and so on. These two files provide OSMWin with the flexibility to construct the network model at run-time, and allow the user to build complex system models from a basic set of generic component models. The network object itself (OSMNetwork) can also be configured as a component within a network list, in which case the list becomes a parent network, and the component network a child or sub-network of the parent. There is no limit to the number of sub-networks or layers that can be specified. Each sub-network must supply its own appropriate data (i.e., component list and link-list) and those yet to be described. The inter-linking of a sub-network with the other components in a parent network is carried out through an I/O map (e.g., ref-exp.ios). This is defined by the system when the network is compiled, and describes which unconnected input or output of a component object within the sub-network can be used for which input or output of the entire sub-network.

4.3.2 Configuring the Network Elements

steady-state two-phase annular pipe				
Fluid	: name of fluid (property)	: r-134a	: <Text>	: <build>
d	: pipe diameter [m]	: 0.0080	: <Float>	: <config>
L	: pipe length [m]	: 2.0500	: <Float>	: <config>
Zi	: inlet elevation [m]	: 0.000	: <Float>	: <config>
Zo	: outlet elevation [m]	: 2.050	: <Float>	: <config>
NNodes	: no. of fluid nodes [2-500]	: 101	: <Integer>	: <build>
Solve_Type	: FD numerical sol'n method	: Stepl	: <Mode>	: <config>
NodeFile	: File to store Nodal variable values	: sect-1	: <Text>	: <config>
EDType	: entrainment/deposition model option	: Govan	: <Mode>	: <build>
Node_Type	: annular node type option	: Empirical	: <Mode>	: <build>
GLE_frac	: entrainment fraction at ONAF (0-1)	: 0.9900	: <Float>	: <config>

Figure 4.6: Configuration data for the two-phase annular flow pipe (sect-1.cfg).

Once the network has been defined, the next step is to load it into OSMWin: the component objects are constructed, and if their class objects require certain configuration data, the system will look for an associated configuration data file in the network's directory. A sample file is provided in Figure 4.6 for the two-phase annular flow pipe (Sect-1). Each object must supply a set of default values for each variable, and these are put into a configuration file for the object (generated automatically if none exists). The configuration data illustrate the standard variable templates used to define the I/O data. Not only does each variable have a name, description, and default-value, it also has a format-specifier and status specifier. The following variable formats are defined:

- <Text>: a contiguous string of characters
- <Float>: a double-precision floating-point number which can be displayed in either fixed, scientific, or engineering notation
- <Integer>: a signed integer
- <Mode>: an array of pre-defined strings for which an integer is indexed to the string currently being used
- <Array>: an array of variables, consisting of any number of the above variable types

For the variable status, the following states and inherent functionality are defined:

<build>:	required to construct the object and cannot be changed without re-loading the object (i.e., re-constructing it)
<config>:	required to construct the object but can be re-configured during simulation (special case)
<init>:	static configuration variables auto-computed by the component object based on other configuration parameters (e.g., cross-sectional area of a pipe) — if these parameters are sensitive to the configuration data specified, and cannot be controlled by simply limiting the range of the configuration parameters, then a configure routine is required to test the object before its simulation
<input>:	a dynamic parameter requiring input from the user
<exec>:	a dynamic simulation parameter calculated by the component object during a single iteration of its execute routine

As described in the previous paragraph, only **<build>** and **<config>** variables are stored in the object configuration file. The other variable types are used for input and output of the network model, which are described next.

4.3.3 Compiling the Network Model

When a network is compiled, the network is first scanned for unconnected input streams, and if any are found, the associated objects are requested to construct their own input streams. Then, all objects in the network are scanned for the minimum required user input, consisting of all

Iter-1	Element	Sp
ExpIn	Element	P
ExpIn	Element	W
ExpIn	Element	T
ExpIn	Element	WLF

Figure 4.7: Network input variable list (ref-exp.ivl).

variables with status <input> and all variables on the unconnected input streams. This information is stored within the data file shown in Figure 4.7, and later used to define the simulation input data for the system. Finally, the network objects are all scanned for accessible variables, to be used later in the selection of user-specified simulation output. All variables on the output streams, the unconnected input streams, and internal to each specific component element are considered a variable for output. The variables are stored in the file as shown in Figure 4.8.

Iter-1	Element		iniOut	: initial output signal	: <Float>	: <config>
Iter-1	Element		Sp	: controller set point	: <Float>	: <input>
Iter-1	Element		minOut	: minimum output signal	: <Float>	: <exec>
Iter-1	Element		maxOut	: maximum output signal	: <Float>	: <exec>
Iter-1	Stream	Output	0	value	: Analog Stream value	: <Float>
Jct-0	Stream	Output	0	value	: Analog Stream value	: <Float>
Jct-0	Stream	Output	1	value	: Analog Stream value	: <Float>
Jct-0	Stream	Output	2	value	: Analog Stream value	: <Float>
ExpIn	Element		Fluid	: name of fluid (property)	: <Text>	: <build>
ExpIn	Element		Mode	: inlet specification	: <Mode>	: <build>
ExpIn	Element		p	: thermodynamic pressure [Pa]	: <Float>	: <input>
ExpIn	Element		W	: total flow rate [kg/s]	: <Float>	: <input>
ExpIn	Element		T	: fluid temperature [oC]	: <Float>	: <input>
ExpIn	Element		WlF	: liquid film flow rate [kg/s]	: <Float>	: <input>
ExpIn	Stream	Output	0	W	: total flow rate [kg/s]	: <Float>
ExpIn	Stream	Output	0	p	: pressure [Pa]	: <Float>
ExpIn	Stream	Output	0	i	: enthalpy [J/kg]	: <Float>
ExpIn	Stream	Output	0	T	: temperature [oC]	: <Float>
ExpIn	Stream	Output	0	Wl	: total liquid flow rate [kg/s]	: <Float>
ExpIn	Stream	Output	0	Wg	: vapour flow rate [kg/s]	: <Float>
ExpIn	Stream	Output	0	WlF	: liquid film flow rate [kg/s]	: <Float>
ExpIn	Stream	Output	0	WlE	: entrained liquid flow rate [kg/s]	: <Float>
:						
:						

Figure 4.8: Network trend variable list (ref-exp.tvl).

4.3.4 Defining the Input and Output Variables

The user must supply a minimum number of input data to make the simulation resolvable. The order in which these variables are specified, as well as the addition of other non-essential input data (e.g., configuration data), are established

ExpIn	Element	P
ExpIn	Element	W
ExpIn	Element	T
ExpIn	Element	WlF
Iter-1	Element	Sp
Iter-1	Element	iniOut
Sect-1	Element	L
Sect-1	Element	Zo

Figure 4.9: User-defined input variable list (ref-exp.irv).

by the user through a separate input variable file, as shown in Figure 4.9. The file is normally copied from the network input variable list, and selected configuration variables are added to

```

// inputs for REF-EXP.NWK - MR-7A Ref. CHF Data
// original: c:\osmapps\ref-exp\rl14a-5.xls
//
// d = 0.008 m.
// L = 2.05 m.
// Ax = 5.0265E-05 sq. m.
//t [sec] P [Pa] W [kg/s] Tin [oC] WIF [kg/s] Sp iniOut L [m] Zo [m]
//REF_114 Data
1 1662000 0.2036757 52.84 0 2.05 128000 2.05 2.05
2 1665000 0.2050329 52.88 0 2.05 127000 2.05 2.05
3 1665000 0.2020672 53.06 0 2.05 126000 2.05 2.05
4 1622000 0.2063398 53.47 0 2.05 132000 2.05 2.05
5 1665000 0.2058874 53.49 0 2.05 133000 2.05 2.05
6 1665000 0.2077472 53.81 0 2.05 132000 2.05 2.05
7 1660000 0.2024694 54.05 0 2.05 131000 2.05 2.05
//REFX_114 Data
8 1581600 0.2011072 55.38 0 1.6 121200 1.6 1.6
9 1580100 0.1985135 55.05 0 1.6 122100 1.6 1.6
10 1578600 0.1981566 55.02 0 1.6 122100 1.6 1.6
11 1590700 0.2010066 56.11 0 1.6 121500 1.6 1.6
12 1602800 0.2020773 46.25 0 2.8 125000 2.8 2.8
13 1614900 0.2010066 46.17 0 2.8 126100 2.8 2.8
14 1613400 0.2011625 46.32 0 2.8 125600 2.8 2.8
15 1604300 0.2023286 49.69 0 2.8 123200 2.8 2.8
16 1587700 0.202027 49.54 0 2.8 122100 2.8 2.8

```

Figure 4.10: User-defined input data (ref-exp.ird).

it from the network trend variable list file. In this particular case, a set-point for the Iterator, the initial heat flux value, and both length and output elevation of the test section (Sect - 1) are added as input variables. A value for each input variable is provided in the order that they appear in Figure 4.9 for each time step of the simulation, as illustrated in Figure 4.10. The time step is currently determined as simply the difference between consecutive time entries in the file. Double slashes at the beginning of a line (//) denote a comment line. Typically, this file is created using a spreadsheet program and exported as plain text. The output from the simulation is specified in a manner similar to that of the input variables, as shown in Figure 4.11. This output variable list is used by the system to store the values of the selected variables at the end of each time step, which are written to an output file at the end of the simulation.

Iter-1	Element		iniOut	: initial output signal	: <Float>	: <config>
Iter-1	Element		Sp	: controller set point	: <Float>	: <input>
Iter-1	Element		minOut	: minimum output signal	: <Float>	: <exec>
Iter-1	Element		maxOut	: maximum output signal	: <Float>	: <exec>
Iter-1	Stream	Output	0	value	: Analog Stream value	: <Float>
ExpIn	Stream	Output	0	p	: pressure [Pa]	: <Float>
Sect-1	Element		G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
ExpIn	Stream	Output	0	i	: enthalpy [J/kg]	: <Float>
ExpIn	Stream	Output	0	T	: temperature [oC]	: <Float>
Sect-1	Element		dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-1	Element		q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-1	Element		L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-1	Element		x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-1	Stream	Output	3	value	: Analog Stream value	: <Float>
Sect-1	Stream	Output	4	value	: Analog Stream value	: <Float>
trans1	Element		i	: enthalpy [J/kg]	: <Float>	: <exec>
trans1	Stream	Output	0	i	: enthalpy [J/kg]	: <Float>
trans1	Stream	Output	1	value	: Analog Stream value	: <Float>
trans2	Element		i	: enthalpy [J/kg]	: <Float>	: <exec>
trans2	Stream	Output	0	i	: enthalpy [J/kg]	: <Float>
trans2	Stream	Output	1	value	: Analog Stream value	: <Float>

Figure 4.11: User-defined output trend variable list (ref-exp.trv).

4.3.5 Testing and Running the Model

Once the network model has been loaded and compiled, and all user input/output specified, the network is ready for testing and simulation. Whether testing or proceeding with a simulation, the user input variable list is read in and compared with the minimum input variable list to ensure that all necessary input variables have been provided. The associated input data are all read in and stored in memory. During testing, the input data are transferred to the appropriate component models and tested for configuration errors using a standard protocol member function. All data within the input file are tested before terminating. If configuration errors were found, the simulation is prevented from starting until the network has been re-loaded and the input data corrected (i.e., tested successfully). When proceeding with a simulation, data from each of the user-defined output variables are preserved in memory after each time step, and once completed, they are appended to the data file shown in Figure 4.12. A date and time stamp of when the simulation output was stored, as well as the time corresponding to each entry in the input data file appear in the output data file.

4.3.6 Analysing the Model Results

The output data shown in Figure 4.12 are in a standard comma-separated vector (CSV) format. Typically, these output files are renamed (e.g., r134a-5.csv) to correspond with a particular source of input data (e.g., r134a-5.ird), and imported to a spreadsheet program for further analysis and plotting (e.g., r134a-5.xls). These standard methods and procedures were used for all the model analysis in the present thesis.

```
Tue Dec 23 14:21:30 1997
iniOut Iter-1 Element,Sp Iter-1 Element,minOut Iter-1 Element,maxOut Iter-1 Element,value Iter-1
Stream Output 0,p ExpIn Stream Output 0,G Sect-1 Element,i ExpIn Stream Output 0,T ExpIn Stream Output
0,dp Sect-1 Element,q0 Sect-1 Element,L_CHF Sect-1 Element,x_CHF Sect-1 Element,value Sect-1 Stream
Output 3,value Sect-1 Stream Output 4,i trans1 Element,i trans1 Stream Output 0,value trans1 Stream
Output 1,i trans2 Element,i trans2 Stream Output 0,value trans2 Stream Output 1
1,128.0000e3,2.050000e0,66.00130e3,598.5381e3,137.50e3,1.6620e6,4.0520e3,136.43e3,52.84,-92.315e3,137.5
0e3,2.0500e0,0.1696,153.12e3,287.83e3,136.43e3,136.43e3,136.43e3,171.21e3,171.21e3,171.21e3
2,127.0000e3,2.050000e0,67.58153e3,602.3577e3,137.92e3,1.6650e6,4.0790e3,136.49e3,52.88,-92.754e3,137.9
2e3,2.0500e0,0.1684,153.48e3,287.86e3,136.49e3,136.49e3,136.49e3,171.15e3,171.15e3,171.15e3
3,126.0000e3,2.050000e0,65.44745e3,592.4721e3,136.35e3,1.6650e6,4.0200e3,136.79e3,53.06,-91.609e3,136.3
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```

Figure 4.12: Network simulation output (ref-exp.trd).

4.4 Multi-Obstacle Test Section Model

The network model used to simulate the enhanced tube test section, with flow obstructions installed at various locations, is shown schematically in Figure 4.13. The only difference between the enhanced tube and reference tube model is the introduction of additional flow sections, one for each flow obstruction installed. In the illustrated example of Figure 4.13, only one flow obstruction is shown. The pipe section model with a TPAOPipe designation refers to the component object with an inlet flow obstruction, and includes various flow obstruction parameters (K_{strip} , K_{depos} , A_o , and b) to be outlined in Chapter 6. These additional parameters can be found within the configuration data of elements of this type. For a complete listing of all the data files associated with these two network models (`ref-exp.nwk` and `obs-exp.nwk`), as well as a description of each component model object (purpose, internal variables, and stream data), the reader should consult Appendix C. Sections C.2.1 and C.2.2 show how the present illustrated 1-obstacle flow network was expanded to a 5-element, 4-obstruction flow network model.

The numerical iteration and solution of CHF becomes more complex when more pipe flow sections are added. The peak film thickness enthalpy and saturated vapour enthalpy from each pipe section must be compared to account for any film thickness and possible pressure variations along the test section. The largest value of i_{peak} (peak film thickness enthalpy) and lowest value of i_g (saturated vapour enthalpy) are used to calculate the limits for the numerical solution (`SigRatio`), as described in the reference tube CHF model. The maximum and minimum values are determined by the high-value (`HighSig`) and low-value (`LowSig`) component objects, respectively. Since CHF can occur in any of the pipe sections (L_c), the value from each pipe is compared with its own length ($Sp=L$), through an error-signal component object (`SigError`). By giving the error signal a positive bias ($So=Sp-Si$):

- when CHF occurs outside the pipe ($Si=L_c > Sp=L$), a negative signal is produced,

- when CHF occurs inside the pipe ($S_p=L > S_i=L_c$), a positive signal is produced,

and taking the highest value of all error signals (high-e), the lowest possible value of CHF is obtained (i.e., the CHF closest to the exit in any given section). As will be shown in Chapter 6, this solution methodology has been used to successfully resolve CHF in a five-section pipe model, with up to four flow obstructions.

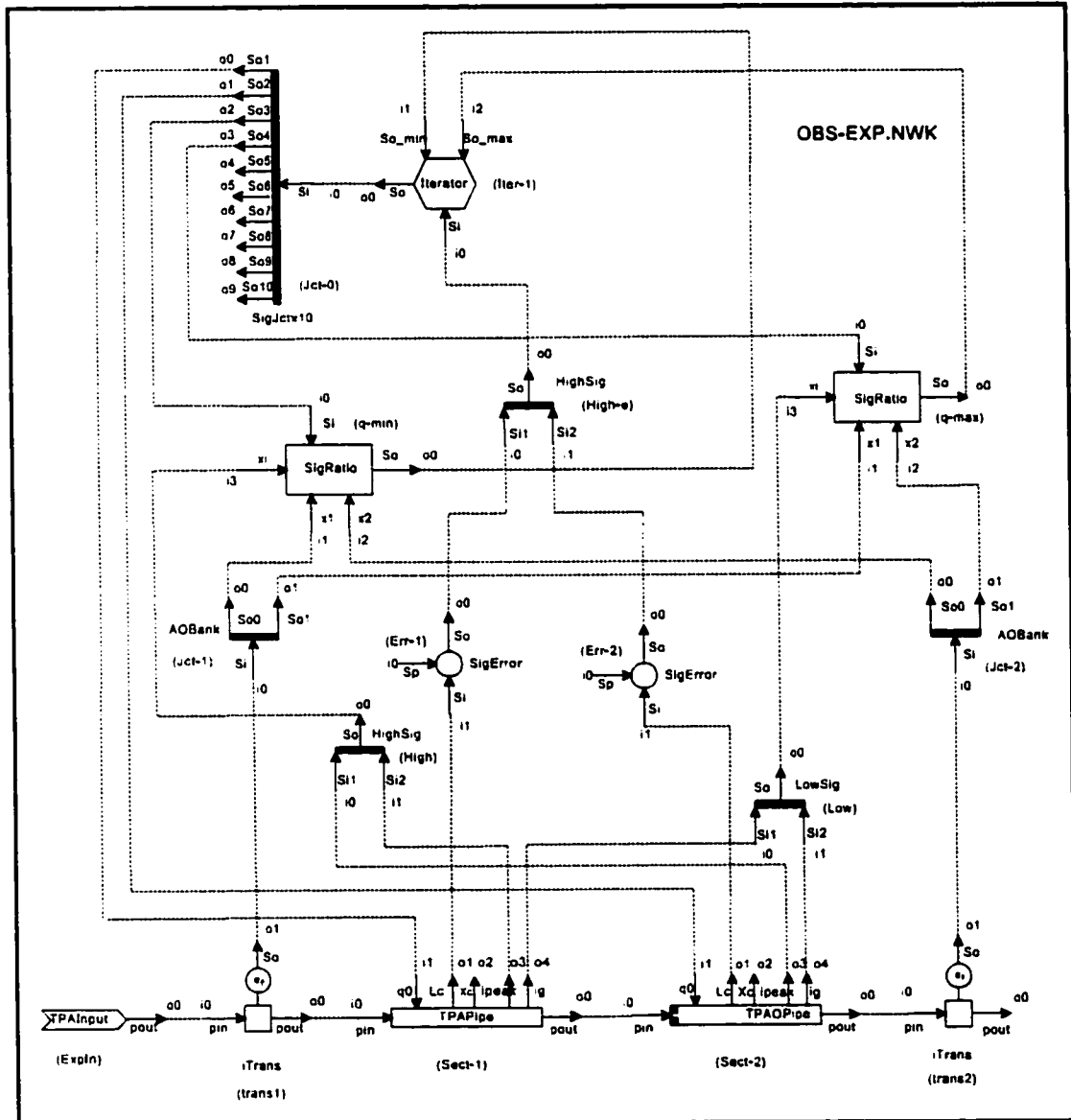


Figure 4.13: Schematic of enhanced tube test section model with one flow obstruction.

Chapter 5 REFERENCE MODEL ANALYSIS

This chapter describes the reference CHF analysis performed on the existing annular flow models (no obstacles) to select an appropriate entrainment and deposition (E/D) model for use in the CHF enhancement analysis. Two resultant E/D models are then reassessed in greater detail, for the working fluid and operating conditions of the CHF enhancement experiments.

5.1 Preliminary Assessment

Four E/D models have been tested both quantitatively and qualitatively against the CHF lookup table of Groeneveld et al. (1995). The lookup table consists of a large database of experimental CHF data, compiled and averaged as a function of pressure, mass flux, and critical quality for a standard 8 mm diameter tube with water as a working fluid. The four E/D models tested were:

- Whalley et al. (1974)
- Whalley and Hewitt (1978)
- Tahir et al. (1987)
- Hewitt and Govan (1990)

The following sub-sections summarize the results of this study to select an appropriate E/D model for use in the CHF enhancement analysis to follow in the next chapter. Further details

on the preliminary model assessment are found in Vaitekunas et al. (1996). Attempts were also made to incorporate the E/D models of Sugawara (1990) and Saito et al. (1978), but failed when applied to Freon-134a, and indicate either an incompatibility with the three-fluid model approach of Whalley et al. (1974) or an inadequate parameterization of the models for the range of fluid properties tested.

5.1.1 Quantitative Assessment Based on Heated Length

Four E/D models are compared quantitatively against the CHF lookup table for a total of 1000 CHF data points, computed for a range of $d=8$ mm, $L_{sat}=0.01\text{--}51.2$ m, $P=0.1\text{--}20$ MPa, and $G=1\text{--}8$ Mg/m²-s. The following methodology was used to predict CHF:

1. Ten (10) incremental pipe lengths ranging from 0.1 m to 51.2 m were specified with saturated liquid conditions at the inlet ($T_{in}=T_{sat}$, $L=L_{sat}$).
2. For each data point (P , G , L), the dryout model was iterated until dryout occurred at the exit (L), with a constant number of solution nodes ($N=100$) to obtain adequate accuracy.
3. The CHF lookup table was iterated and interpolated over (P , G , x) until the L_c obtained, using a steady-state heat balance, was equal to the pipe length ($L=L_{sat}$). Although very small saturated boiling lengths were considered ($L_{sat} = 0.1$ m), the CHF was assumed to be obtained with very large heated lengths ($L_h / d > 100$), using high inlet subcooling. Therefore, none of the heated length corrections, prescribed by Groeneveld et al. (1995) for the lookup table, were applied.
4. A diameter of 8 mm was used which corresponds to the standard diameter used for the data in the lookup table.

Table 5.1: Statistical comparison between the annular flow dryout models and the CHF lookup table (based on heated length).

Method	Max. Diff. [%]	No. of Points	Avg. Diff. [%]	RMS Diff. [%]
Whalley et al. (1974)	± 1	34	0.01	0.67
	± 10	288	-0.63	5.13
	± 25	560	-3.82	12.86
	± 50	809	-9.19	22.87
	ALL	1000	-8.24	40.03
Whalley and Hewitt (1978)	± 1	21	-0.16	0.46
	± 10	95	0.93	4.52
	± 25	182	5.56	13.53
	± 50	329	13.36	26.98
	ALL	1000	59.56	105.73
Tahir et al. (1987)	± 1	18	0.07	0.61
	± 10	179	0.98	5.91
	± 25	421	1.69	13.87
	± 50	666	-3.15	25.03
	ALL	1000	-22.26	48.15
Hewitt and Govan (1990)	± 1	42	-0.15	0.57
	± 10	239	0.20	5.30
	± 25	564	-0.44	13.73
	± 50	889	-5.14	24.58
	ALL	1000	-7.65	31.23

Average and RMS differences between each E/D model and the lookup table are shown in Table 5.1 for different ranges of the absolute maximum difference. For example, 560 out of the 1000 data points obtained using the Whalley et al. model were within $\pm 25\%$ of the lookup table. The corresponding average and RMS difference for these 560 data points was -3.8% and

Table 5.2: Parametric comparison between annular flow dryout models and CHF lookup table (based on heated length).

P [MPa]	G [Mg/m ² -s]	L [m]	No. of Points	Whalley et al. (1974)		Whalley and Hewitt (1978)		Tahir et al. (1987)		Hewitt and Govan (1990)	
				Avg. Diff. [%]	RMS. Diff. [%]	Avg. Diff. [%]	RMS. Diff. [%]	Avg. Diff. [%]	RMS. Diff. [%]	Avg. Diff. [%]	RMS. Diff. [%]
1	1-8	0.1-51.2	50	11.34	55.20	49.32	77.09	-58.00	62.69	-13.45	27.61
3	1-8	0.1-51.2	50	12.81	44.86	35.33	60.92	-51.94	56.89	-9.86	22.59
5	1-8	0.1-51.2	50	8.49	42.95	38.71	65.18	-44.93	51.40	-7.40	19.59
10	1-8	0.1-51.2	50	4.31	23.42	65.07	103.04	-17.04	34.68	6.65	24.90
15	1-8	0.1-51.2	50	-19.30	28.50	68.25	115.29	2.19	35.83	-2.13	32.65
20	1-8	0.1-51.2	50	-45.40	51.59	30.23	124.02	-2.55	70.52	-37.52	48.97
1-20	1	0.1-51.2	60	-5.33	12.65	4.10	48.37	-46.78	60.27	-7.62	25.07
1-20	2	0.1-51.2	60	-1.22	21.60	30.21	60.32	-36.76	55.43	-3.11	32.36
1-20	4	0.1-51.2	60	-2.10	39.64	56.37	89.29	-23.97	47.26	-7.32	31.27
1-20	6	0.1-51.2	60	-4.17	54.89	66.65	110.68	-20.69	47.82	-14.63	31.00
1-20	8	0.1-51.2	60	-10.31	62.41	81.76	134.64	-15.35	56.25	-20.41	34.21
1-20	1-8	0.1	30	46.70	83.49	98.14	140.43	-7.71	57.43	-9.53	29.88
1-20	1-8	0.2	30	20.06	59.87	89.18	127.17	-26.35	59.29	-27.53	33.70
1-20	1-8	0.4	30	3.76	44.15	88.22	120.15	-33.13	61.62	-32.53	37.63
1-20	1-8	0.8	30	-8.24	31.80	79.30	105.44	-33.04	60.71	-30.18	37.57
1-20	1-8	1.6	30	-15.72	29.37	64.55	86.19	-39.67	55.75	-23.35	37.07
1-20	1-8	3.2	30	-18.06	29.19	53.03	77.62	-32.98	52.25	-11.06	34.11
1-20	1-8	6.4	30	-19.53	28.42	33.23	64.01	-30.97	50.49	0.53	32.62
1-20	1-8	12.8	30	-20.20	26.87	11.28	55.52	-27.80	46.40	6.85	24.71
1-20	1-8	25.6	30	-18.11	25.59	-14.64	56.91	-28.36	44.59	10.89	18.07
1-20	1-8	51.2	30	-16.90	28.27	-24.11	57.79	-27.09	44.19	9.73	13.2

12.9%, respectively. To investigate the influence of specific parameters on these differences in CHF, statistics were computed at constant values of pressure, mass flux and boiling length, as shown in Table 5.2. The results show that:

- the Hewitt and Govan model compares best in the 1-10 MPa range, whereas the Whalley et al. model compares best in the 10-15 MPa
- the Whalley et al. model compares best at low flow, while the Hewitt and Govan model compares best at medium to high flow,

- the RMS difference increases for all models as the boiling length is reduced.

From the last observation, one might conclude that the transition to annular flow, and the onset of annular flow ($x_{\text{onf}}=0.01$), is inadequately modelled. As cited by both Whalley et al. (1974), and Hewitt and Govan (1990), these effects will tend to predominate as the CHF location approaches the OAF. To illustrate any OAF effects, the differences between the lookup table CHF and the four E/D models are shown in Figure 5.1 versus dryout quality. Although all four models show large discrepancies near the OAF location ($x_{\text{onf}}=0.01$), large differences are also shown at moderate to high quality, where large boiling lengths occur and the effects of OAF are less significant. These results would indicate that there are other important factors which have not been modelled.

5.1.2 Qualitative Assessment Using Local Flow Conditions

Given the large number of data points obtained from the previous assessment using boiling length, the E/D model results could be interpolated for specified values of dryout quality to produce lookup tables equivalent to that of Groeneveld et al. (1995) based on local flow conditions (P , G , x). Parametric trends in both the E/D models and the lookup table could then be compared as a function of a single parameter (e.g., quality, pressure, mass flux, and diameter) while maintaining all other parameters constant. The following sub-sections will describe each of the parametric trends in CHF obtained.

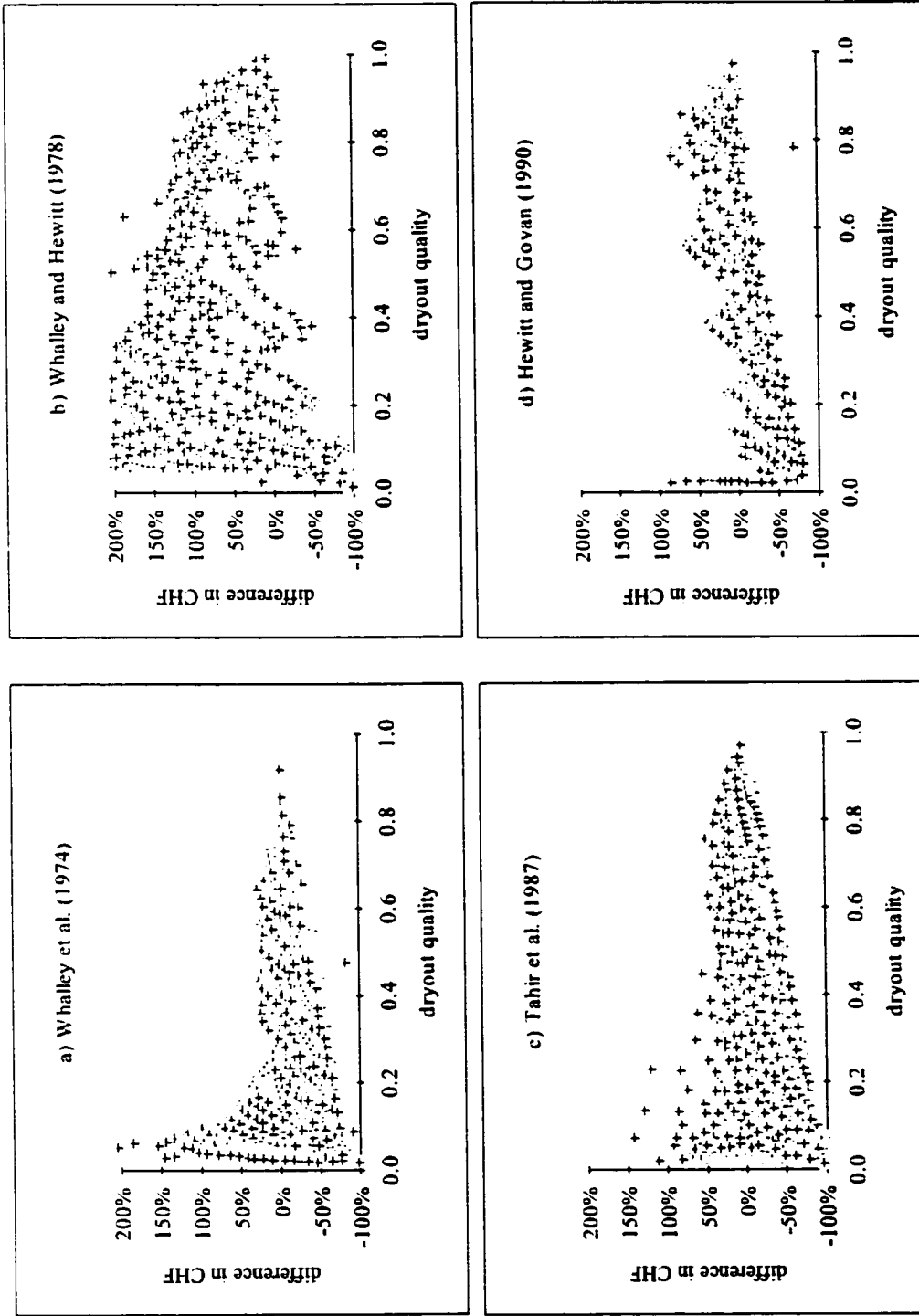


Figure 5.1: Difference in CHF between each E/D model and the lookup table versus quality.

Quality

The results for CHF versus quality are shown in Figure 5.2 for 10 MPa in water at different mass fluxes ($\text{Mg/m}^2\cdot\text{s}$) as indicated by the legend of each graph. The trends in the lookup table can be summarized as follows:

- a consistent decrease in CHF with quality,
- smooth profiles towards high quality, and
- rapid changes in slope and cross-overs between different mass flux curves in the medium-to-low quality region.

All four E/D models predict a similar decrease in CHF with quality. The Whalley and Hewitt model largely over-predicts CHF, while both Whalley et al., and Hewitt and Govan display a characteristic “hump” in CHF at low flow and high quality, similar to that observed in the lookup table. None of the E/D models show any cross-over between the mass flux profiles, as demonstrated by the lookup table. The increase in CHF at high mass flux and moderate quality is most likely associated with “wispy” annular flow. According to the Hewitt and Roberts (1969) flow map for vertical upflow in a tube (see Whalley, 1990), at high momentum flux (G_l / ρ_l), the entrained droplets appear as wisps of elongated droplets, and perhaps this increases turbulent deposition overall.

Pressure

The results for CHF versus pressure are shown in Figure 5.3 for $4.0 \text{ Mg/m}^2\cdot\text{s}$ and different values of dryout quality as indicated by the legend in each graph. The following trends are demonstrated by the lookup table:

- a maximum CHF in the 0–5 MPa range, depending on flow and quality, and
- a second maximum in CHF at 15–20 MPa as the dryout quality is increased.

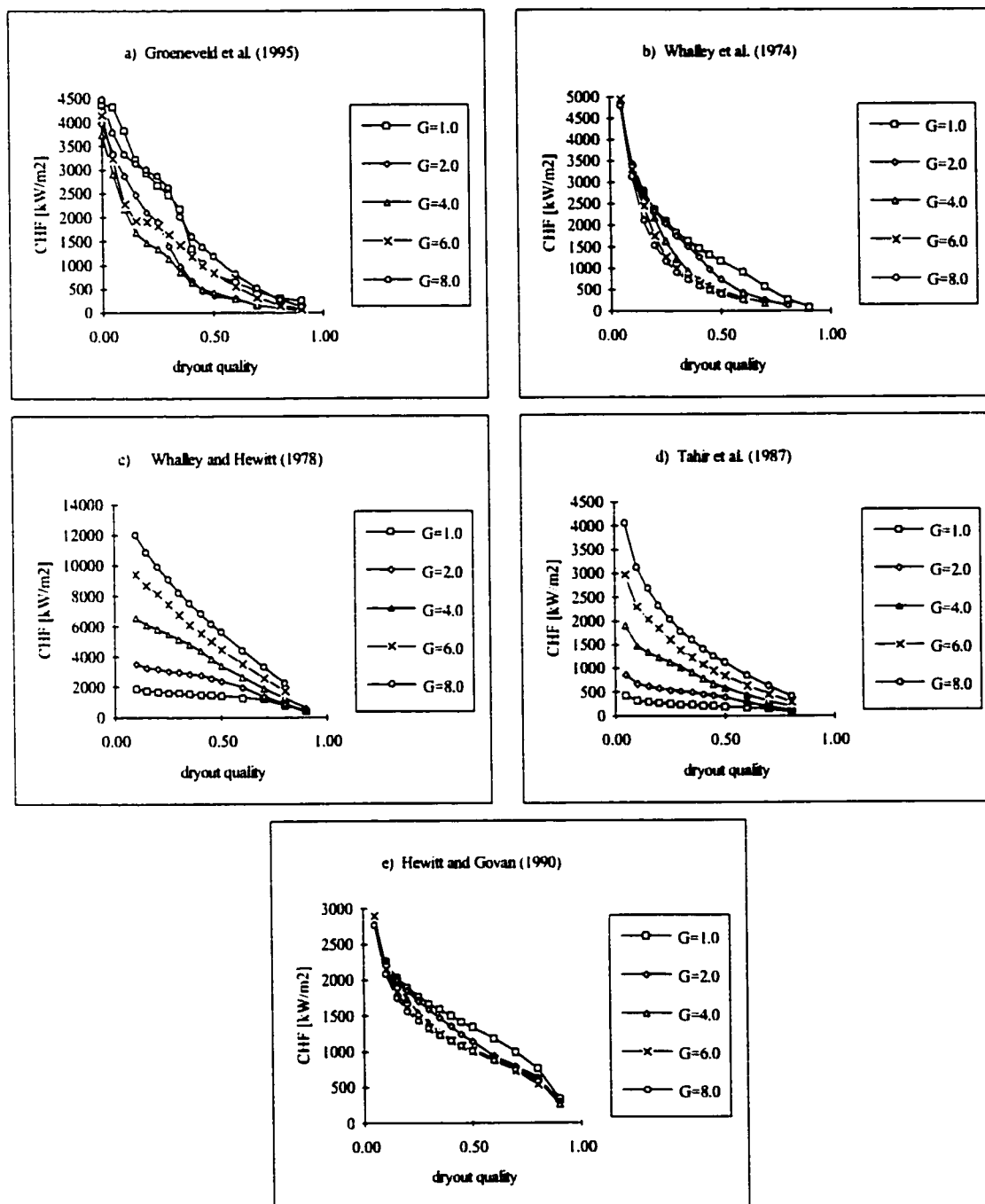


Figure 5.2: CHF versus quality at 10 MPa and various mass fluxes (G) in $\text{Mg/m}^2\cdot\text{s}$.

Only the Whalley et al., and Hewitt and Govan models predict the maximum CHF in the 0–5 MPa range. The Whalley and Hewitt model predicts a rapid decrease in CHF followed by an almost constant CHF for moderate to high pressures. Tahir et al. predicts a continuous increase in CHF with pressure.

Mass Flux

The effect of flow on CHF is demonstrated by Figure 5.4 at a pressure of 10 MPa for different values of dryout quality. The lookup table demonstrates a consistent decrease in CHF with increased mass flux up to 4.0 Mg/m²·s, and then reverses with an increase in CHF up to 8.0 Mg/m²·s. The E/D models of both Whalley et al., and Hewitt and Govan show only a small decrease in CHF with mass flux, while both Whalley and Hewitt, and Tahir et al. show only large increases in CHF with mass flux. The latter would indicate that perhaps these two E/D models were designed for high mass flux “wispy” annular flows.

Diameter

To demonstrate the effect of tube diameter, a subset of CHF data points was calculated for a pressure of 10 MPa and mass flux of 5 Mg/m²·s, using different boiling lengths ($L/d=12.5\text{--}6400$) and tube diameters ($d=2\text{--}20$ mm) to produce the results shown in Figure 5.5. All E/D models show a similar decrease in CHF with increased diameter, which agree with the relation proposed by Groeneveld et al. (1986) for the lookup table:

$$\left. \frac{q_c(d)}{q_c(8)} \right|_{x_c} = \left(\frac{d}{8} \right)^n \quad (5.1)$$

where d is in millimetres and n varies from $-1/2$ to $-1/3$. The ratios calculated using Equation 5.1 range from peak values of 1.6 to 2.0 at the minimum d (2 mm), to minimum values of 0.6 to 0.8

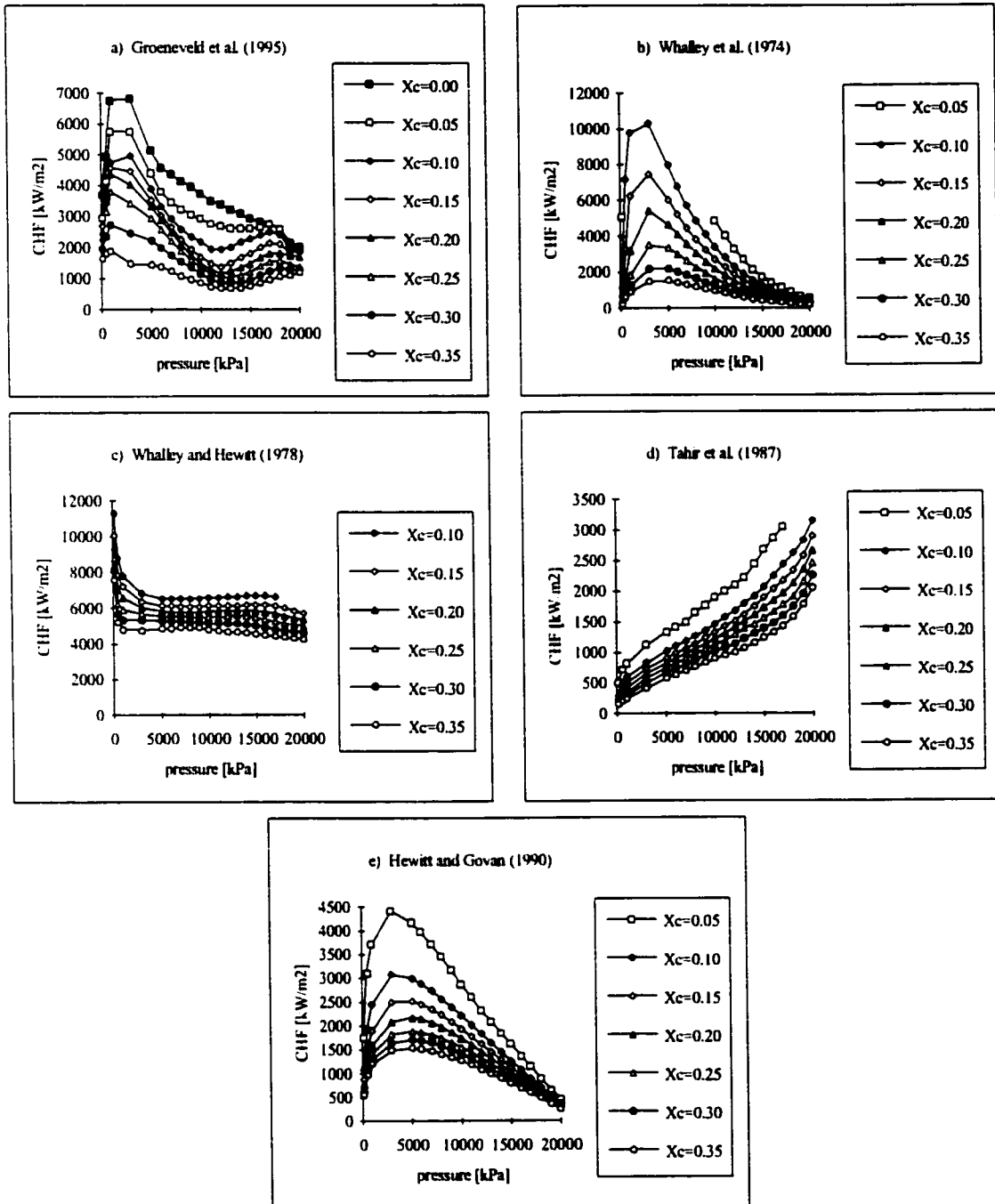


Figure 5.3: CHF versus pressure at $4.0 \text{ Mg/m}^2\text{-s}$ and various qualities.

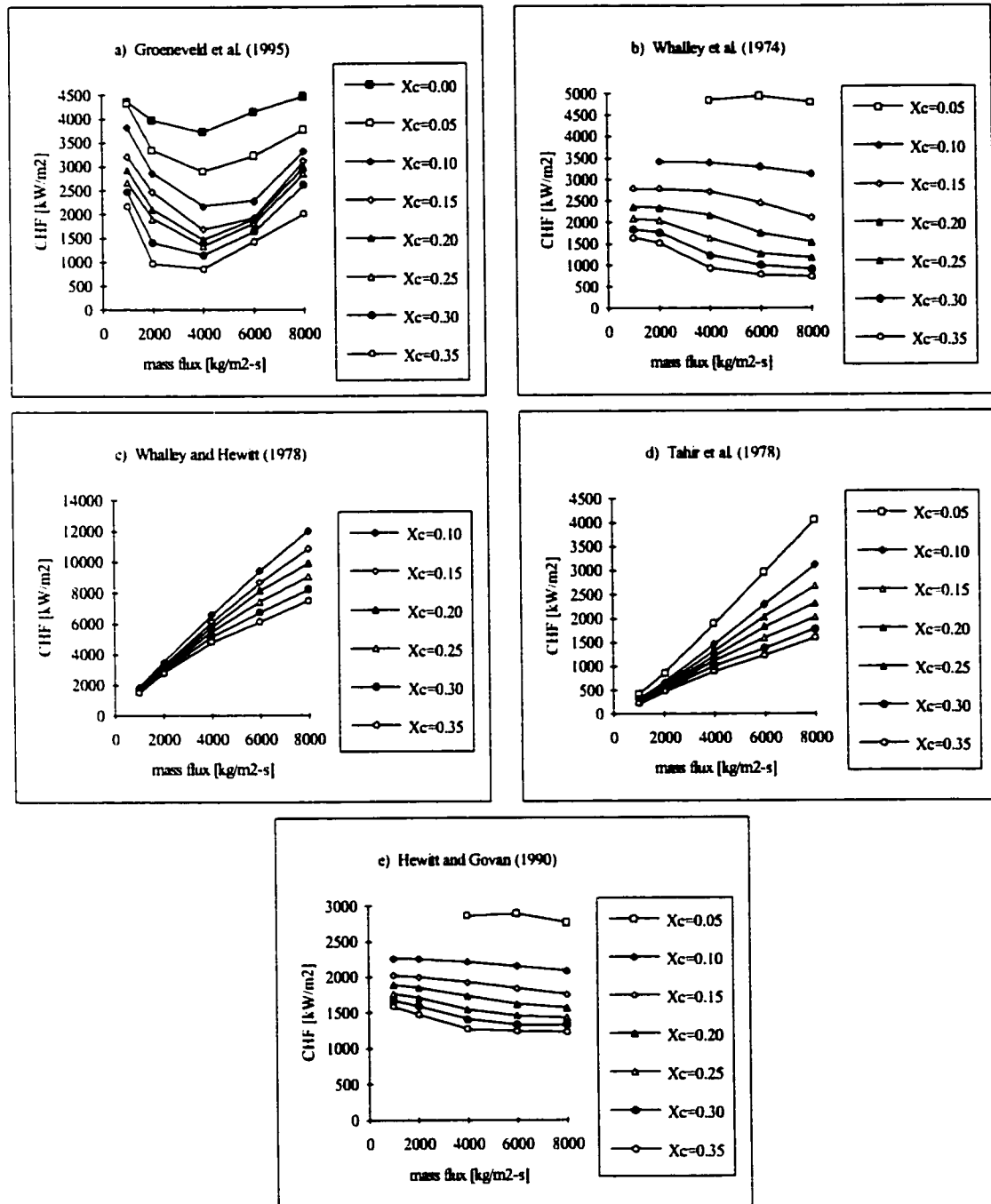


Figure 5.4: CHF versus mass flux at 10 MPa and various qualities.

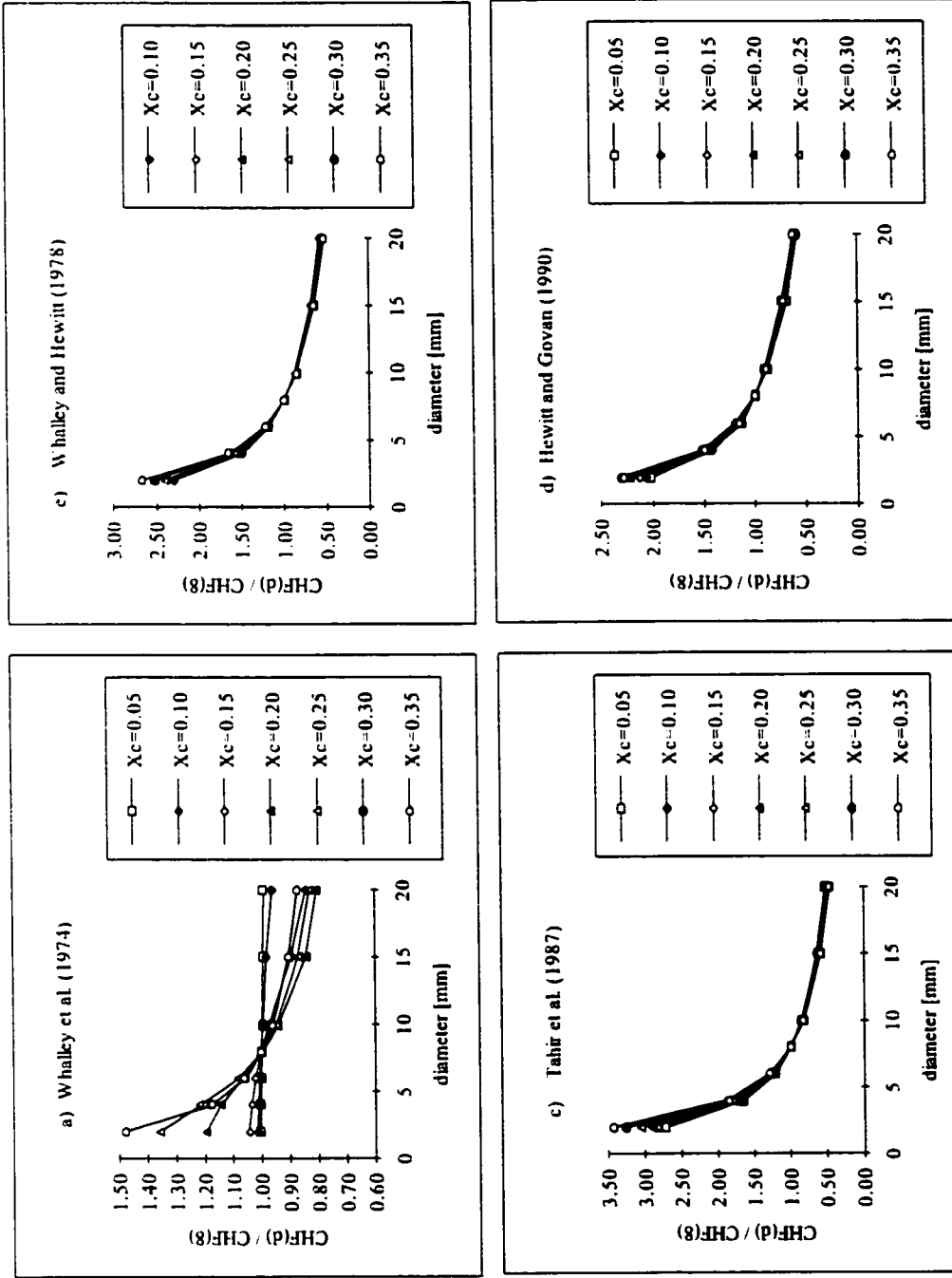


Figure 5.5: CHF relative to 8 mm diameter versus diameter at 10.0 MPa and 5.0 Mg/m²·s.

at the maximum d (20 mm). These ratios are very similar to those obtained from the E/D models, except for Whalley et al. (1974), which tends to predict a smaller diameter effect (i.e., values of n closer to zero).

5.1.3 E/D Model Selection

Based on the previous assessment using the lookup table for water, two of the four E/D models were selected for use in the reference tube and enhanced tube model analysis to follow: Whalley et al. (1974), and Hewitt and Govan (1990). The results of this preliminary assessment are summarized as follows:

- Hewitt and Govan (1990) is in closest agreement with the lookup table of Groeneveld et al. (1995), with RMS differences of 5%, 14%, 25%, and 31% for 239, 564, 899, and 1000 data points, respectively.
- Whalley et al. (1974) demonstrated slightly larger RMS differences of 5%, 13%, 23%, and 40% for 288, 560, 809, and 1000 data points, respectively.
- Whalley et al. (1974) show a higher sensitivity to the OAF condition than that of Hewitt and Govan (1990).
- Both models show the correct trend in CHF with pressure and quality as demonstrated by the lookup table, but only show a small decrease in CHF with mass flux.
- Hewitt and Govan (1990), and to a lesser extent Whalley et al. (1974), show the correct trend in CHF with diameter.

5.2 Detailed Model Assessment

The two selected entrainment and deposition models are now evaluated for a range of inlet conditions and fluid properties for which both reference and obstructed CHF were

measured experimentally, namely the 30% ring data in Freon-134a. A statistical comparison, sensitivity analysis, and tube length profile analysis are all used to ascertain the accuracy and physical properties of the model under these very specific conditions.

5.2.1 Comparison with Experiment

Using the experimental data of Doerffer et al. (1995), and Doerffer and Groeneveld (1994), the following statistical comparison was made for both the Whalley et al. (1974), and Hewitt and Govan (1990) models, based on heated length and inlet temperature. The results are summarized in Table 5.3 for average, RMS, and maximum errors within each of the five groups of data for which the empirical correlations were derived (see Table 3.5). The empirical correlations and the Hewitt and Govan model produce similar results, while the Whalley et al. model produces RMS errors twice as large on average.

A histogram for the error in CHF over the entire data set (N=359) for these two models is shown in Figure 5.6. A smaller error-band centred about +10% is obtained for the Hewitt and Govan model, while a larger and more skewed error-band (centred about +15%) is obtained for the Whalley et al. model. Similar to the results obtained for water, better overall predictions are

Table 5.3: Statistical results of the Whalley et al. (1974), and Hewitt and Govan (1990) reference CHF models, based on inlet conditions and heated length.

Data Set			Empirical Correlations			Whalley et al. (1974)			Hewitt and Govan (1990)		
P	G	N	Avg	RMS	Max	Avg	RMS	Max	Avg	RMS	Max
1.13	2	52	-1.9%	3.8%	6.4%	1.7%	6.9%	13.2%	7.3%	3.6%	15.1%
1.13	4	73	-4.9%	5.8%	11.9%	17.4%	14.3%	34.3%	12.8%	6.4%	21.0%
1.66	3	96	0.2%	3.4%	7.0%	12.9%	9.0%	26.9%	14.1%	7.2%	28.1%
1.66	4.0 (low-x)	90	-0.1%	0.8%	2.1%	11.6%	8.3%	24.1%	8.3%	3.1%	15.6%
1.66	4.0 (high-x)	43	-1.2%	3.6%	17.3%	-3.1%	8.1%	15.6%	3.2%	4.5%	15.7%

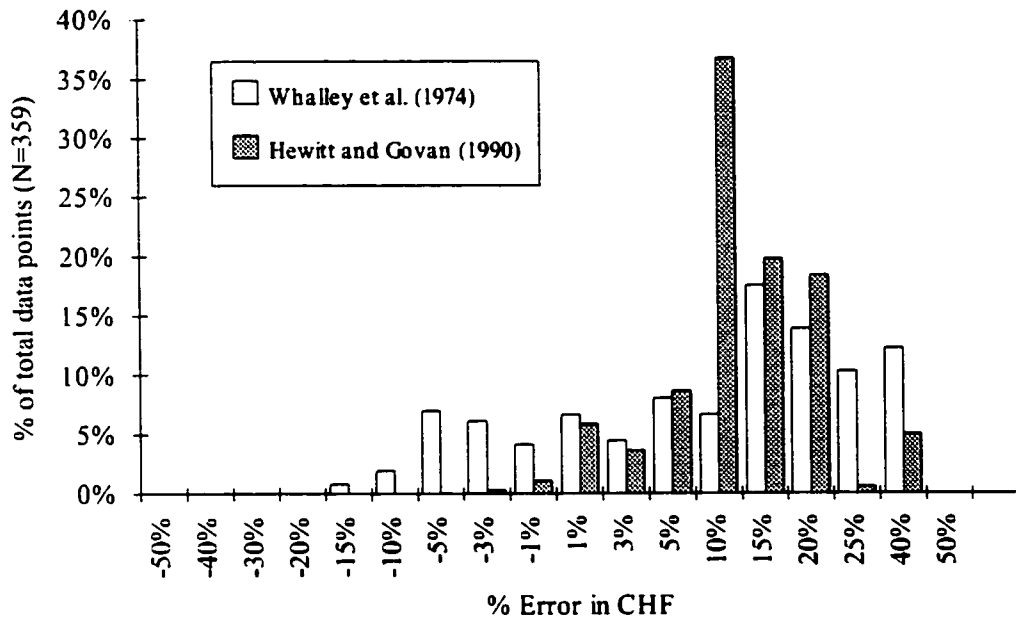


Figure 5.6: Comparison of CHF error histograms between Whalley et al. (1974), and Hewitt and Govan (1990).

obtained using Hewitt and Govan (1990).

Similar to the empirical correlations of Doerffer et al. (1995), the CHF versus quality data are presented for each group of pressure and mass flux data, as shown in Figure 5.7. The Whalley et al. model is shown to over-predict CHF at low quality while under-predicting CHF at high quality. The Hewitt and Govan model tends to predict a lower CHF at low quality and higher CHF at high quality, in comparison to the Whalley et al. model, and provides a much better estimate of CHF.

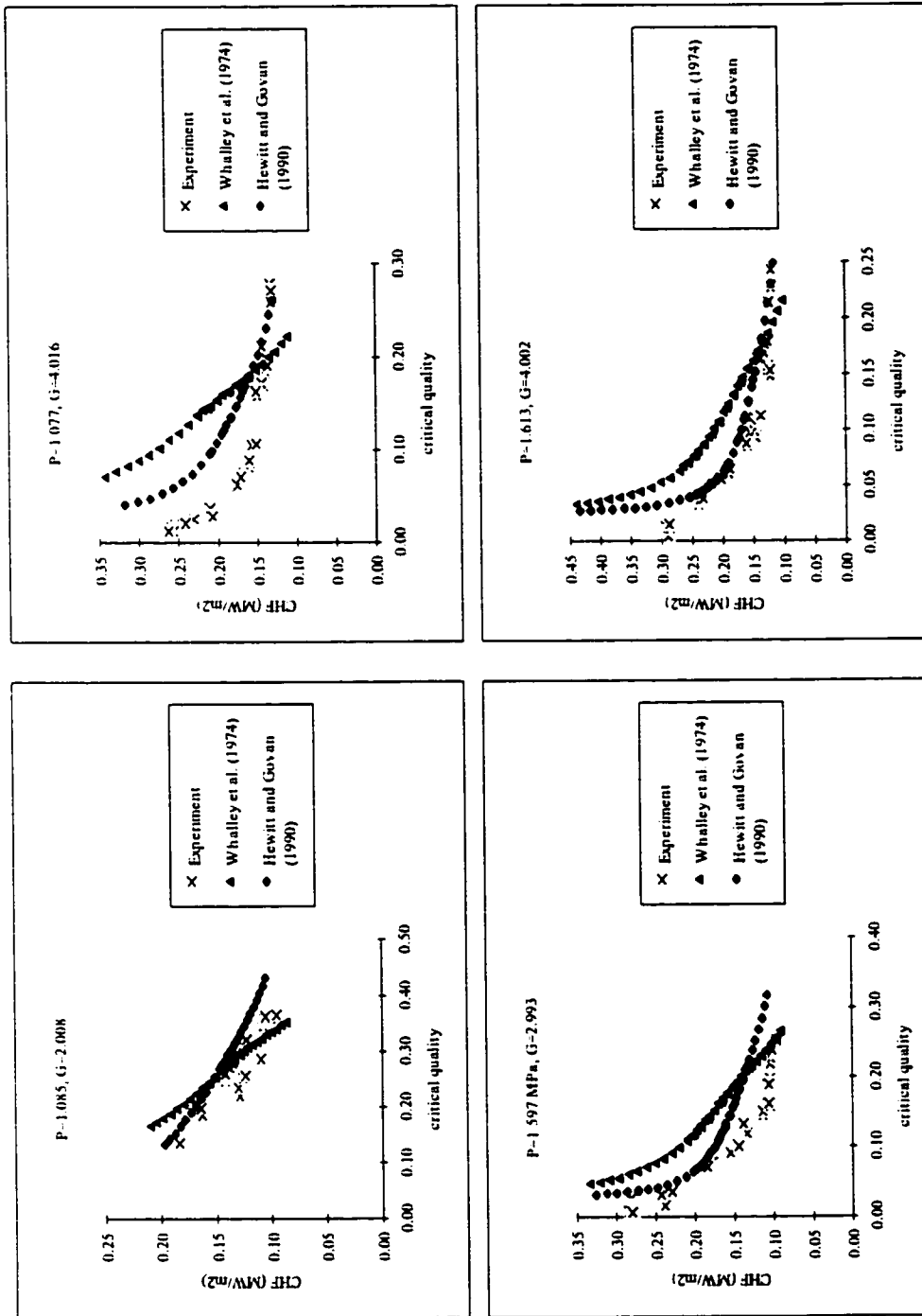


Figure 5.7: Reference CHF versus quality in Freon-134a at different pressure (MPa) and mass flux (Mg/m²·s) — comparing the two E/D models with experimental data.

5.2.2 Sensitivity Analysis

The overall sensitivity of the E/D models to the inherent uncertainty in the empirical correlations used to describe them, is studied through the following analysis of each independent variable: entrainment, deposition, and initial entrainment liquid fraction.

Entrainment and Deposition

The overall sensitivity of the Hewitt and Govan model to uncertainties in the governing entrainment and deposition correlations was determined by fitting an upper and lower limit of each correlation to the data in Figures 2.9 and 2.11. As illustrated in Figure 5.8 and 5.9, the following relations were used to define a limiting range for the entrainment and deposition correlations presented by Hewitt and Govan (1990):

$$k \sqrt{\frac{\rho_g d}{\sigma}} = \begin{cases} A_1 (C/\rho_g)_{\min}^{b_1} & , \quad (C/\rho_g) \leq (C/\rho_g)_{\min} \\ A_1 (C/\rho_g)^{b_1} & , \quad (C/\rho_g) > (C/\rho_g)_{\min} \end{cases} \quad (5.2)$$

$$(E/G_g) = A_2 Y^{b_2} \quad , \quad Y = (G_{\text{IF}} - G_{\text{IFc}})^2 \frac{d}{\sigma \rho_g} \left(\frac{\rho_l}{\rho_g} \right) \quad (5.3)$$

The associated parameters in Table 5.4 define a set of minimum, maximum, and mean values for each correlation, used to obtain the CHF results shown in Figure 5.10. Most of the measured CHF fall within the range of uncertainty of these two governing entrainment/deposition correlations. Some of the predictions for minimum and maximum CHF fall outside the general trend, and are the result of non-convergent CHF solutions. These non-convergent solutions lie outside the physical limits of the model, indicating the need for both physically realistic limits and correct parametric trends in these governing relations if they are to be used over a wide range of operating conditions and fluids.

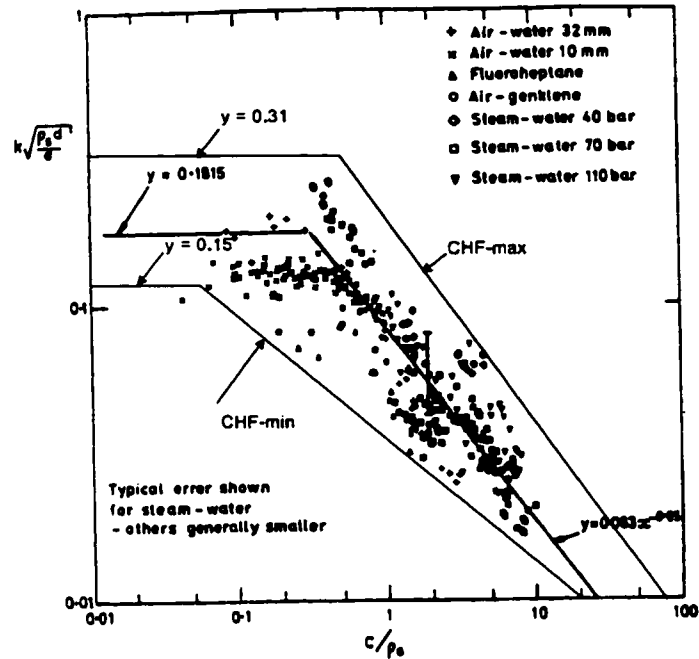


Figure 5.8: Range of uncertainty in deposition model, adapted from Hewitt and Govan (199) with permission of Elsevier Science.

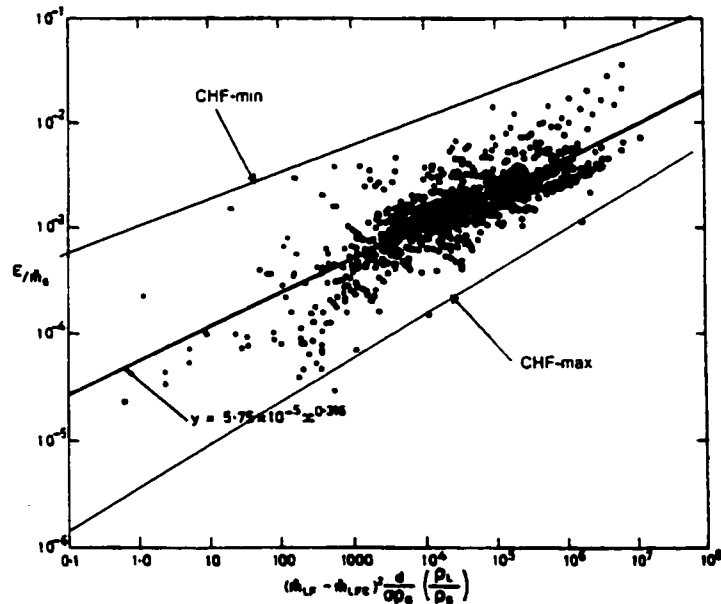


Figure 5.9: Range of uncertainty in entrainment model, adapted from Hewitt and Govan (1990) with permission of Elsevier Science.

Table 5.4: Approximate parameter ranges for the Hewitt and Govan (1990) model.

parameter	CHF _{min}	CHF _{max}	Mean
A_1	0.039	0.18	0.083
b_1	-0.42	-0.6	-0.65
$(C/\rho_g)_{\min}$	0.04	0.4	0.3
$A_1 (C/\rho_g)_{\min}^{b_1}$	0.15	0.31	0.18
A_2	8.69×10^{-4}	3.21×10^{-6}	5.75×10^{-5}
b_2	0.255	0.465	0.316

Similarly, the entrainment model, developed by Hutchinson and Whalley (1973) and used by Whalley et al. (1974), was fitted to the following relation:

$$C_E = \begin{cases} AS^2 & , \quad S \leq S_c \\ 10^{mS+b} & , \quad S > S_c \end{cases} \quad S = \frac{\tau_i \delta}{\sigma} \quad A = \frac{10^{mS_c+b}}{S_c^2} \quad (5.4)$$

with the parameters shown in Table 5.5 providing the upper, lower, and mean values of the correlation, as illustrated in Figure 5.11.

Table 5.5: Approximate parameter ranges for the Hutchinson and Whalley (1973) model.

parameter	CHF _{min}	CHF _{max}	Mean
m	2.19	2.18	2.22
b	0.62	-0.27	0.33
S_c	0.3	0.27	0.3
A	110.09	28.57	210.26

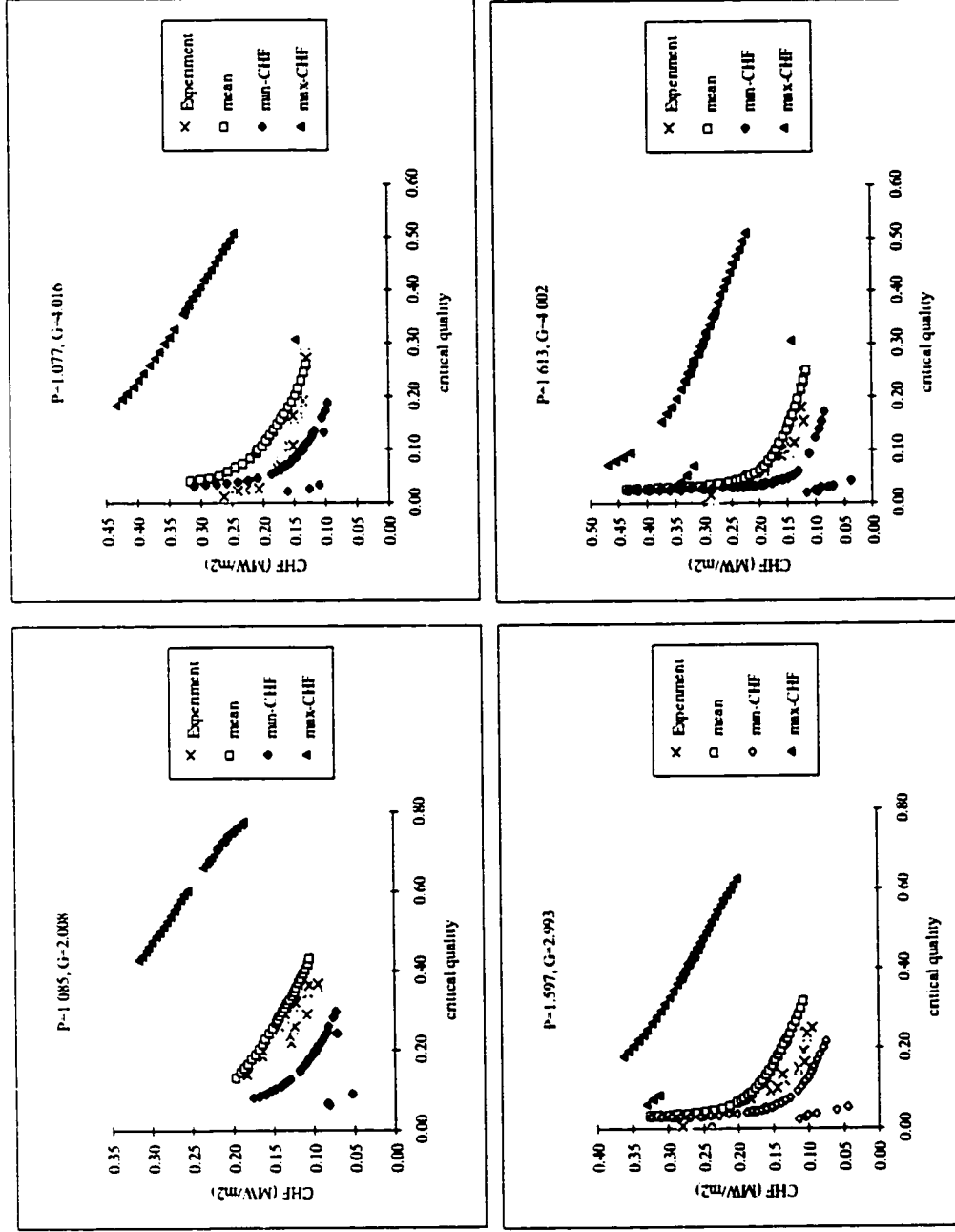


Figure 5.10: Sensitivity of Hewitt and Govan (1990) model to uncertainty in the entrainment and deposition relations, at selected pressures (MPa) and mass flux ($\text{Mg/m}^2\text{s}$).

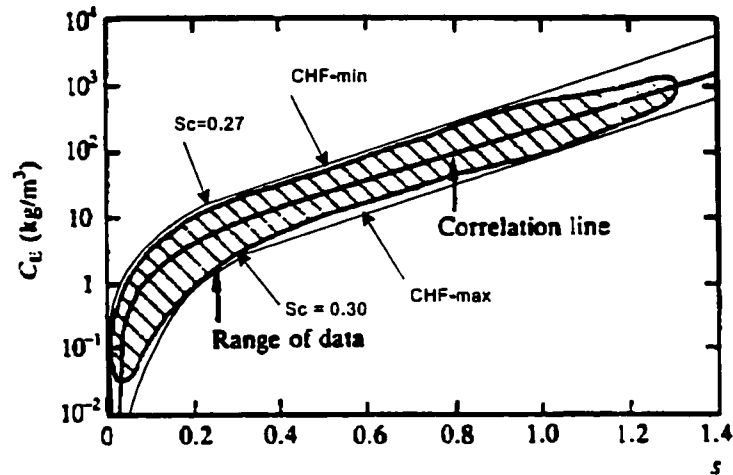


Figure 5.11: Range of uncertainty in the Hutchinson and Whalley (1973) entrainment correlation, adapted from Whalley (1990) with permission of Oxford University Press.

Unfortunately, the same approach could not be used to define an upper and lower limit for the k -values of the Whalley et al. model, since only a few data points exist (see Figure 2.8). Instead, the effect of varying the mass transfer coefficient was analysed, with the results provided in Figure 5.12. No single k -value for a given pressure and mass flux is sufficient to model all the CHF data points. More importantly, the results indicate a lower value of k is required at low quality, and a higher value of k is required at high quality. One flow variable which typically denotes the level of turbulence exchange in a flow is the Reynolds number, and this will be studied later during the assessment of tube length profiles.

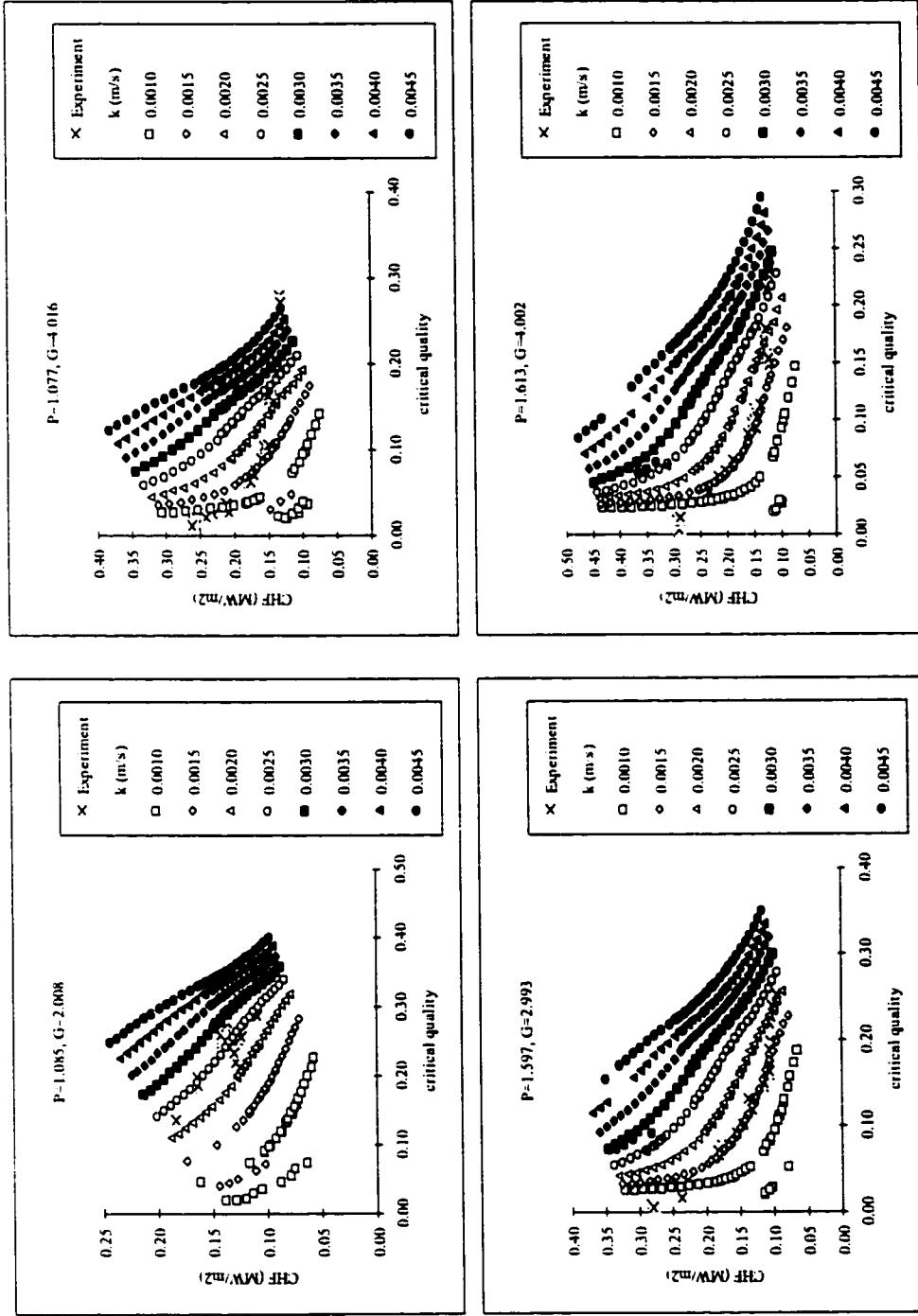


Figure 5.12: Sensitivity of Whalley et al. (1974) model to variations in the mass transfer coefficient (k), at selected pressures (MPa) and mass flux ($\text{Mg/m}^2\cdot\text{s}$).

OAF Condition

To study the effects of the onset of annular flow condition, values of the initial entrained liquid fraction $(G_{IE}/G_I)_{\text{oaf}}$ were varied from 0 to 1. The results for the Hewitt and Govan model are shown in Figure 5.13, and show that only high values of initial entrainment fraction can predict the correct trend in CHF with quality. Lower values of $(G_{IE}/G_I)_{\text{oaf}}$ produce much higher values of CHF and eventually reverse the trend with quality. These results also indicate a strong correlation between the current E/D models and their associated OAF condition, as best results are obtained with $(G_{IE}/G_I)_{\text{oaf}}=0.99$.

5.2.3 Tube Length Profiles

To illustrate the mechanistic behaviour of the annular flow model, various tube length profiles are plotted against quality to assess their shape and relative magnitude in relation to the operating condition. Each of seven inlet conditions tested during the CHF enhancement experiment with 30% rings in Freon-134a are used.

Liquid Film

Figure 5.14 shows the variation in liquid film thickness and liquid film fraction, as a function of quality for each inlet condition (P, G, T_{in}). Both E/D models predict a similar profile for the same inlet condition, but values obtained using the Hewitt and Govan E/D model are 40–50% lower than those obtained using the Whalley et al. E/D model. Only a small portion of the total flow (2–10%) is predicted in the liquid film, producing very small liquid films (40–140 μm). The absolute magnitude of the liquid film is not as important as the relative change in film thickness along the length of the tube in predicting the CHF at the correct dryout location and quality. In these models, dryout is simply defined as the location where $G_{\text{IF}}=0$, regardless of the magnitude of the film thickness obtained. The film thickness before the OAF

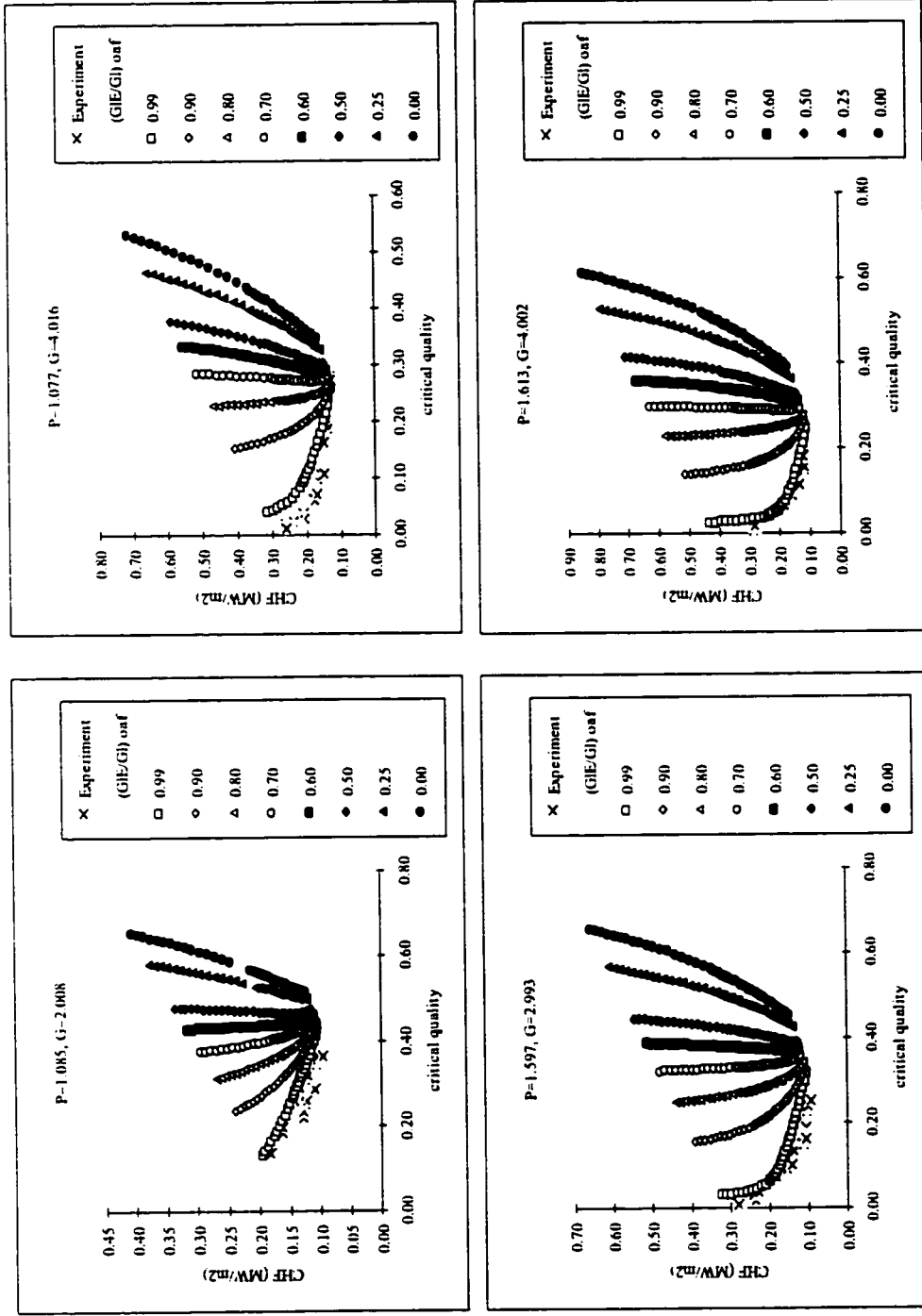


Figure 5.13: Sensitivity of the Hewitt and Govan (1990) model to changes in the initial entrained liquid fraction (G_{IE}/G_I)_{oaf} at selected pressures (MPa) and mass flux (Mg/m²·s).

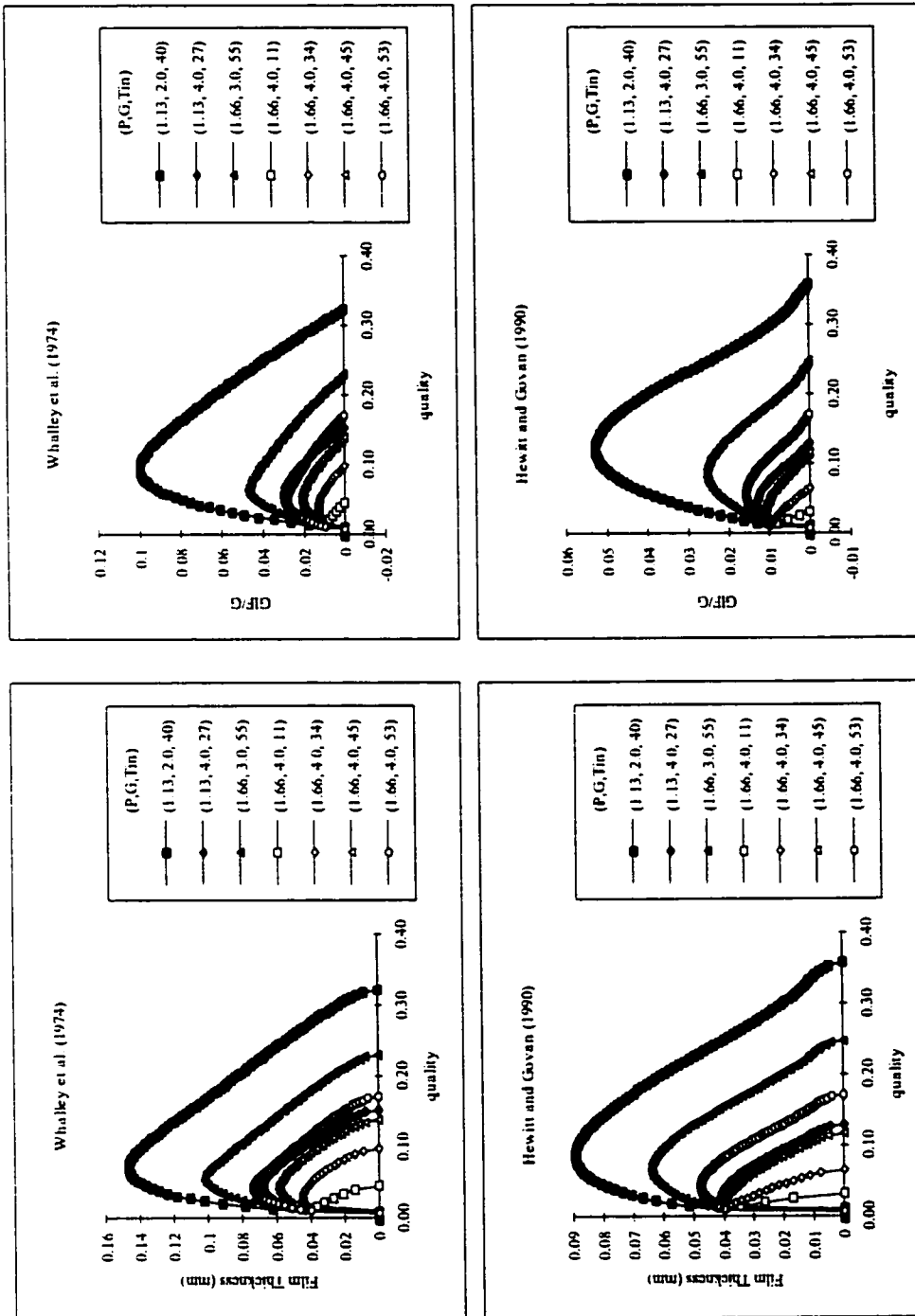


Figure 5.14: Liquid film thickness and liquid film fraction versus quality for selected values of pressure (MPa), mass flux ($\text{Mg/m}^2\text{-s}$), and inlet temperature ($^{\circ}\text{C}$) in Freon-134a.

($x_{\text{osf}} < 0.01$) is undefined and is therefore plotted as a zero in Figure 5.14.

Core Volume

The profiles for the entrained liquid fraction and non-dimensional droplet concentration (C/ρ_g) are shown in Figure 5.15 for both E/D models. The models predict almost identical droplet concentrations, but because the liquid film fractions are lower in the Hewitt and Govan model, the corresponding entrained liquid fractions are higher.

Entrainment and Deposition

The profiles for the predicted ratio of entrainment to deposition, and the mass transfer coefficient (k) are plotted in Figure 5.16. The peak value of entrainment relative to deposition is a result of the following modelling process governing the liquid film: increases in liquid film thickness and interfacial shear (core velocity) increase the overall rate of entrainment, while decreases in droplet concentration with tube length reduce the rate of deposition. As the liquid film begins to thin from evaporation, the entrainment rate tends to zero at the dryout location.

The main difference between the two E/D models is their formulation of the mass transfer coefficient. As described in Chapter 2, the Whalley et al. model uses a k -value which is only a function of surface tension, and therefore remains a constant for a given pressure, mass flux, and fluid. The Hewitt and Govan model relates k to a set of non-dimensional parameters involving the fluid properties, geometry, and droplet concentration. The end result is a linear function of quality for a given geometry and operating pressure, as shown in Figure 5.16 (i.e., curves overlap for same pressure and quality). By increasing k with quality, the previously observed deficiency in the Whalley et al. model (i.e., inability to model all CHF data with a single k -value) has been eliminated, which is largely responsible for the improved accuracy of the Hewitt and Govan model. The increase in k with quality also causes the peak ratio in E/D

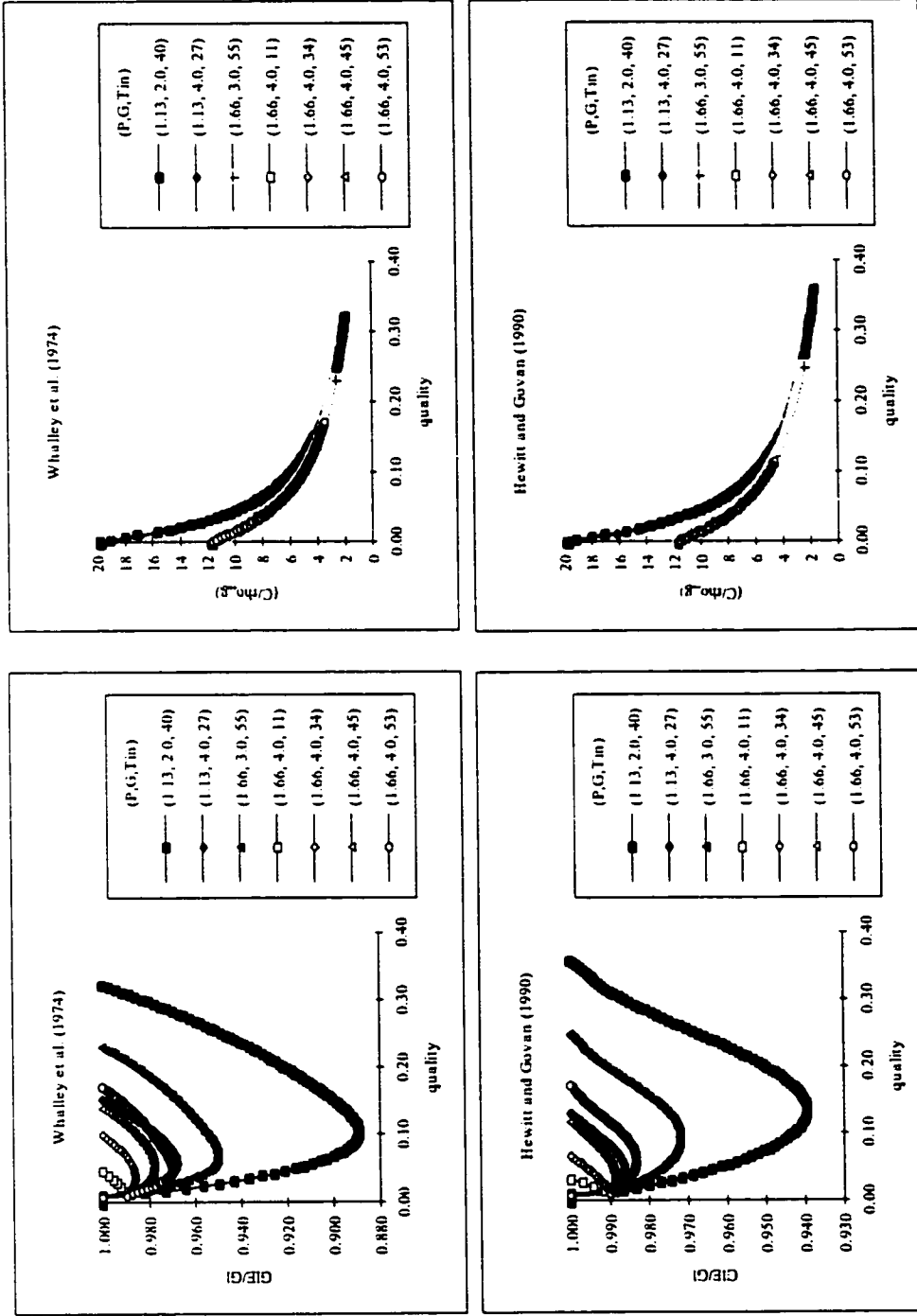


Figure 5.15: Entrained liquid fraction and core volume concentration versus quality for selected values of pressure (MPa), mass flux ($\text{kg/m}^2\cdot\text{s}$), and inlet temperature ($^\circ\text{C}$) in Freon-134a.

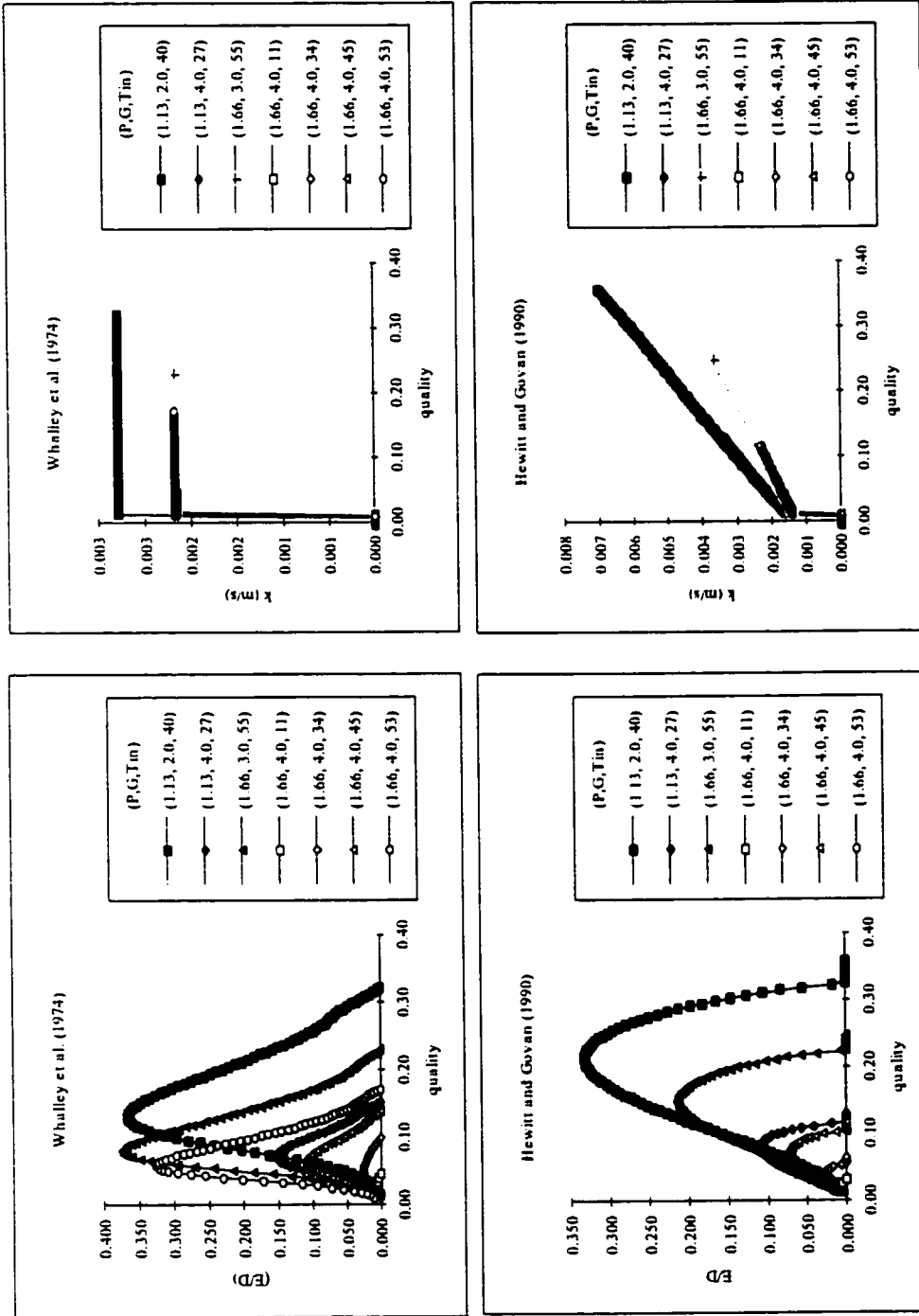


Figure 5.16: Ratio of entrainment to deposition and mass transfer coefficient (k) versus quality for selected values of pressure (MPa), mass flux ($\text{Mg/m}^2\text{-s}$), and inlet temperature ($^{\circ}\text{C}$) in Freon-134a.

to skew towards higher quality, as shown in Figure 5.16, and increase in magnitude when the inlet subcooling or mass flux are reduced.

Entrained Liquid Reynolds Number

Analogous to single-phase heat transfer, the turbulent mass transfer of the entrained liquid to the liquid film should increase with the core flow. The Reynolds number of the entrained liquid in the core can be defined as:

$$Re_{IE} = \frac{\rho_l u_c d}{\mu_l} = \frac{\rho_l G_{IE} d}{\mu_l \rho_l \alpha_c (1 - \alpha_{gc})} = \frac{G_{IE} d}{\mu_l \alpha_c (1 - \alpha_{gc})} \quad (5.5)$$

which is plotted against quality in Figure 5.17 for each inlet condition (P, G, T_{in}). The linear increase in Reynolds number with quality is identical to the linear increase in mass transfer with quality, as given by the Hewitt and Govan model. However, Re_{IE} also varies with mass flux, which is not present in the k -relation of Hewitt and Govan. Comparing Re_{IE} with that of the vapour:

$$Re_g = \frac{G_g d}{\mu_g \alpha_c \alpha_{gc}} \quad (5.6)$$

one can conclude that both Re_{IE} and Re_g will increase with mass flux (G), but Re_{IE} will increase with pressure while Re_g will decrease with pressure – due to variations in both liquid and vapour viscosity as a function of pressure (see Figure 5.18). Since the core is a mixture of both liquid and vapour, a mixture viscosity may be more appropriate. Further investigation of the core flow Reynolds number may provide a better correlation for droplet mass transfer, to take into account changes in both fluid pressure and mass flux.

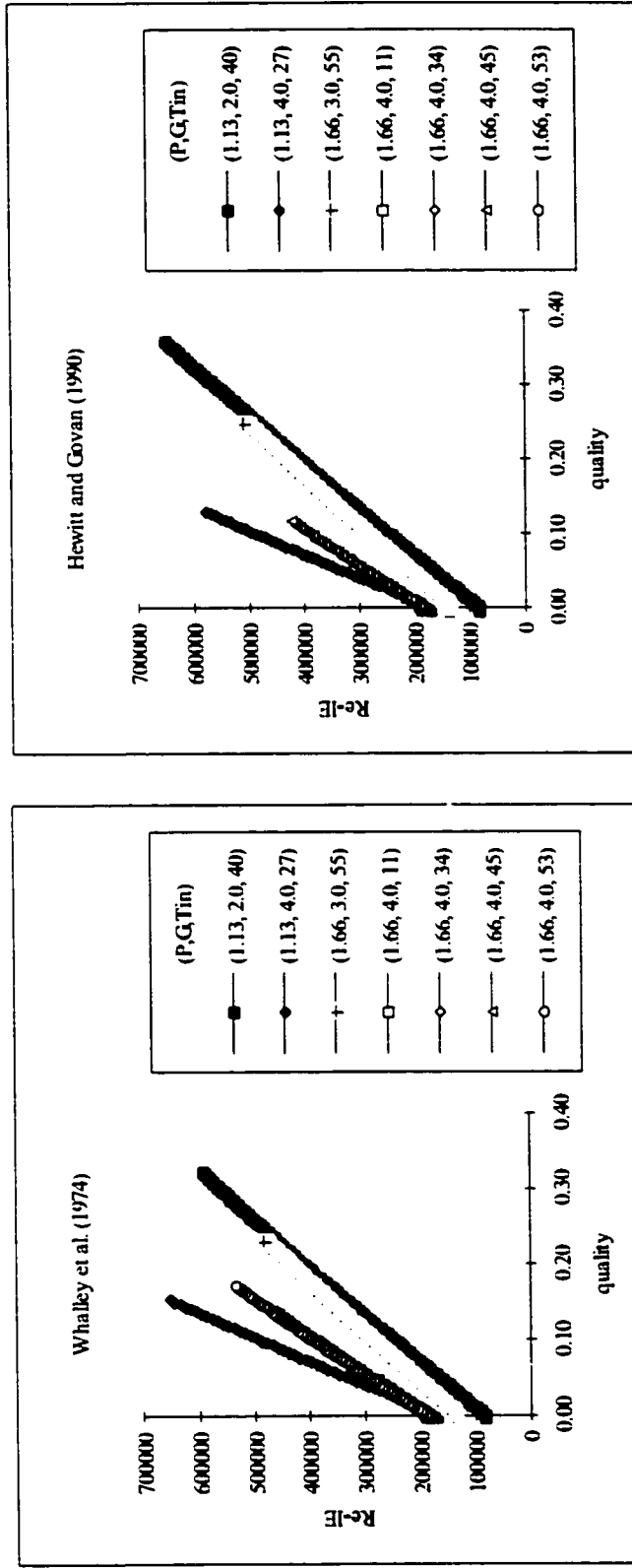


Figure 5.17: Reynolds number for the entrained liquid versus quality for selected values of pressure (MPa), mass flux ($\text{Mg/m}^2\text{s}$), and inlet temperature ($^{\circ}\text{C}$) in Freon-134a.

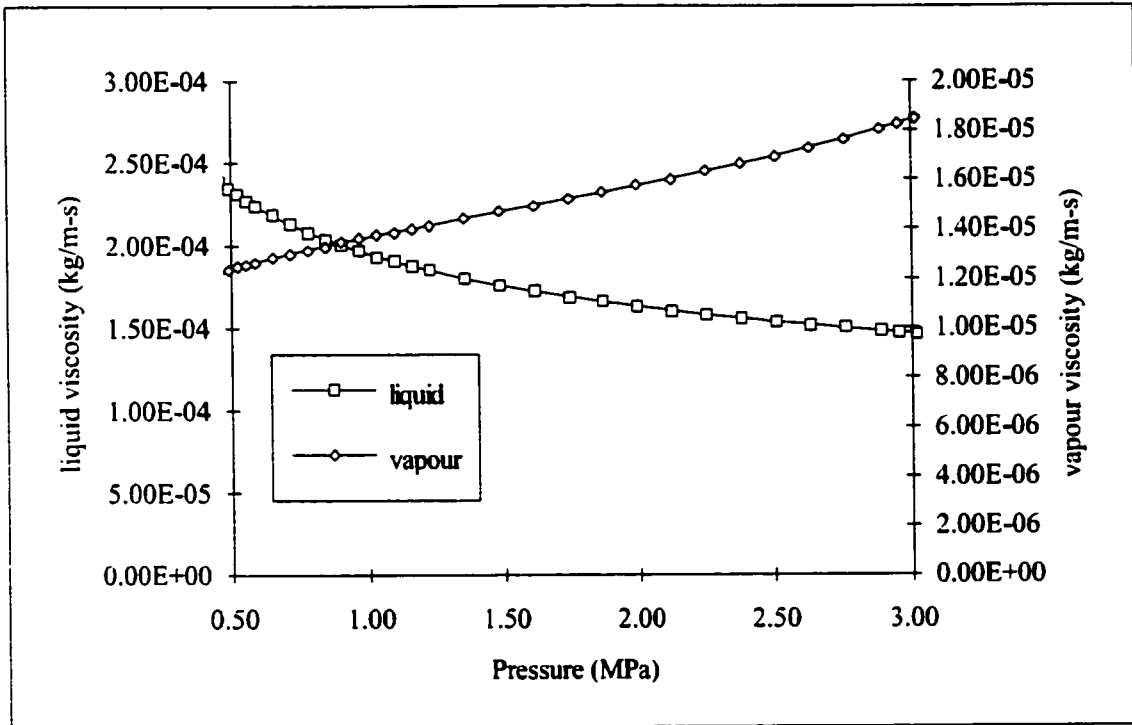


Figure 5.18: Dynamic viscosity of saturated liquid and vapour Freon-134a as a function of pressure.

5.3 Discussion

The entrainment and deposition models by both Whalley et al. (1974) and Hewitt and Govan (1990) have been shown in Section 5.1.2 to produce the correct parametric trends in CHF with quality and pressure. The Whalley et al. model predicts the experimental CHF data presented for Freon-134a to within $\pm 15\%$ (RMS), while the Hewitt and Govan model predicts the CHF to within $\pm 7\%$ (RMS). The improvements made by Hewitt and Govan consist primarily of a mass transfer coefficient which increases linearly with quality. Both models rely on large initial entrainment fractions $(G_{IE}/G_I)_0$ at the OAF. Any reduction in the initial entrainment fraction below 70% results in a reversal of the trend in CHF with quality. From inspection of the CHF versus quality curves, and the associated sensitivity analysis of k and $(G_{IE}/G_I)_0$, one can conclude that the annular flow model is divided into two main regions:

- high droplet concentration/low-quality
- deposition-controlled/high-quality

In the high droplet concentration region, the magnitude of C/ρ_g is so large that the CHF versus quality curve is essentially controlled by the initial entrainment fraction $(G_{IE}/G_I)_o$ and the mass transfer coefficient (k). As $(G_{IE}/G_I)_o$ is reduced, the slope of the CHF curve is not only increased but the entire curve shifts towards higher dryout quality. This steep rise in CHF in the low quality region is comparable to that reported by Piro et al. (1999), where the limiting critical quality or rapid decline in CHF for the same quality is postulated to be a transition point between DNB-type CHF and annular flow dryout. Depending on the pressure and mass flux, the transition point can be quite high ($x_c > 0.3$) and the change in slope quite noticeable (in water: $3 < P < 16$ MPa and $G < 2.5$ Mg/m²·s), or not noticeable at all (in water: $P < 3$ MPa or $P > 16$ MPa and $G > 2.5$ Mg/m²·s). Interestingly, as k is reduced the slope of the CHF curve also increases at low quality (nearest the OAF), as shown by Figure 5.12, and may be further evidence that k should be proportional to Re. At high quality, the magnitude of CHF is a strong function of the mass transfer coefficient (k), and k must increase with quality to fit the data, as shown by the results using Hewitt and Govan (1990). This is referred to as the deposition-controlled region, and the OAF location is far enough away that CHF is relatively insensitive to $(G_{IE}/G_I)_o$. Once the dryout model has been adjusted to fit the experimental CHF data in both these regions, the maximum value of CHF for which the model still fits the data can be used to define a transition point between low quality DNB-type and annular flow dryout-type CHF. As mentioned in Sections 5.1.2 and 5.2.3, the effect of mass flux is not well modelled by either the Whalley et al. or Hewitt and Govan models. The cross-over in CHF versus quality curves of Groeneveld et al. (1995) in Figure 5.2a may be the result of limiting critical quality or a transition from annular to “wispy” annular flow. Any small flow dependencies which do occur in the model are most likely due to the arbitrary limits set for both k ($C/\rho_g \leq 0.3$), C_E ($S < 0.3$), and G_{IF} ($G_{IF} < G_{IFC}$) at low flow and high quality. A more detailed parametric assessment of the annular flow model parameters (Re_{IE} , C/ρ_g , $\rho_g d/\sigma$, $(G_{IE}/G_I)_o$, k) could result in further improvements to the annular flow model.

Chapter 6 ENHANCEMENT MODEL ANALYSIS

This chapter describes the assessments performed on both a single and multi-obstacle CHF enhancement model, derived from the reference models of Whalley et al. (1974), and Hewitt and Govan (1990), and modified to include various flow enhancement mechanisms. The first section will describe the mathematical form of these flow obstruction effects and show some preliminary results for water, which are then used to determine which of the proposed flow enhancement mechanisms are most likely to augment CHF. The remaining sections will describe the detailed assessments performed on the 30% ring data in Freon-134a. This particular CHF data set was used since a large number of data points were obtained for the same inlet and flow conditions, which makes it ideally suited for parameter estimation.

6.1 Proposed Enhancement Mechanisms and Preliminary Results in Water

To account for the observable trends in CHF enhancement, measured during the experiments in Chapter 3, the following physical flow mechanisms were postulated:

- liquid film stripping
- liquid droplet impingement with run-off to the liquid-film
- turbulent deposition enhancement

and applied to the existing dryout models to account for the effect of flow obstructions on CHF inside a tube.

Liquid-film stripping is modelled by the discrete removal of a portion of the liquid film flow ($0 < K_{strip} < 1$) at the obstacle location (z_{obs}):

$$\begin{aligned} G_{lF}(z_{obs}) &= (1 - K_{strip}) G_{lF}(z_{obs}) \\ G_{lE}(z_{obs}) &= G_{lE}(z_{obs}) + K_{strip} G_{lF}(z_{obs}) \end{aligned} \quad (6.1)$$

and associated transfer to the entrained liquid flow (G_{lE}). The associated rise in droplet concentration (C), increase in deposition, and decrease in entrainment (i.e., reduced film flow, G_{lF}) could cause CHF to rise. Results from the simulation of CHF in water using one flow obstacle are shown in Figure 6.1, and indicate that as larger portions of the liquid-film are removed ($K_{strip} = 0.25, 0.50, 0.75$, and 1.00), a proportional decrease in CHF occurs, with no

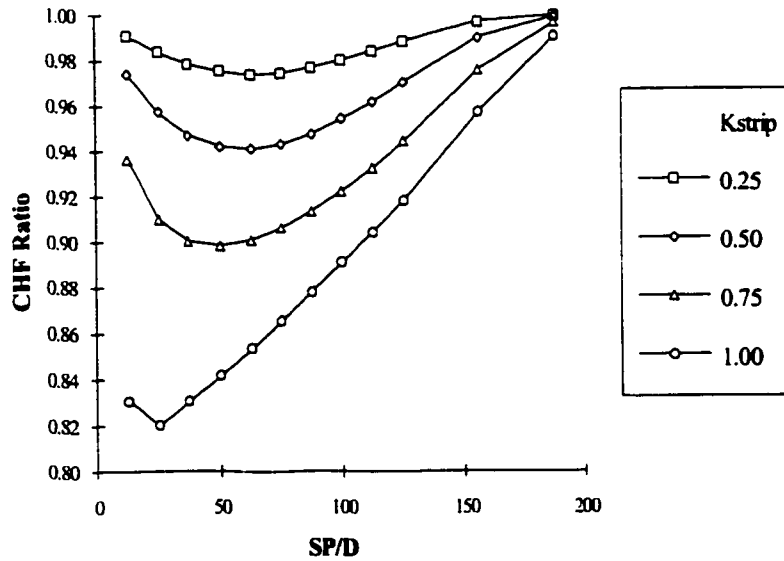


Figure 6.1: Effect of film-stripping (K_{strip}) on CHF ratio — single obstacle in water with $P=7$ MPa, $G=4$ Mg/m²·s, $d=8$ mm, $L=2$ m, $T_{in}=T_{sur}$.

possibility for enhancement. Previous simulations in the reference tube have shown that a majority of liquid flows as entrained liquid (see Figure 5.15), and that any reduction in the initial entrainment fraction (G_{IE}/G_I) causes the CHF to increase (Figure 5.13). Conversely, these results show that any stripping away of the liquid film will cause the CHF to further decrease.

Similarly, the effects of liquid droplet impingement on the obstacle, and associated run-off to the liquid-film, can be modelled as the discrete removal of a portion of the entrained liquid flow ($0 < K_{depos} < 1$) at the obstacle location (z_{obs}):

$$\begin{aligned} G_{IF}(z_{obs}^+) &= G_{IF}(z_{obs}^-) + K_{depos} G_{IE}(z_{obs}^-) \\ G_{IE}(z_{obs}^+) &= (1 - K_{depos}) G_{IE}(z_{obs}^-) \end{aligned} \tag{6.2}$$

and associated transfer to the liquid film. The resultant increase in liquid-film thickness should increase the CHF to achieve dryout at the same location. The results for the single flow obstacle in water are shown in Figure 6.2, where increasing amounts of impingement ($K_{depos} = 0.1, 0.2$, and 0.3) cause an increase in CHF. The line labelled “Upstream” in Figure 6.2 indicates the ratio of nominal CHF at the upstream location (SP/D) to that at the exit ($SP/D=0$). The increase in CHF ratio with decreased obstacle spacing is similar to that observed in the CHF experiments (e.g., see Figure 3.32). The limiting CHF is clearly shown on the graph at the point where the nominal CHF ratio at the upstream location meets the predicted value of CHF at the exit. These results clearly show an increase in CHF enhancement with larger fractions of entrained liquid impinging on the obstacle and depositing on the liquid film.

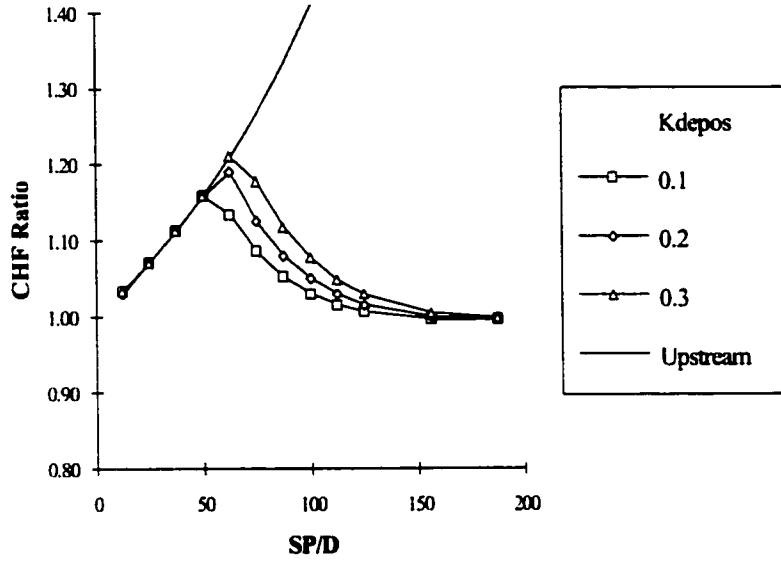


Figure 6.2: Effect of droplet impingement (K_{depos}) on CHF ratio – single obstacle in water with $P=7$ MPa, $G=4$ Mg/m²·s, $d=8$ mm, $L=2$ m, $T_{\text{in}}=T_{\text{sat}}$.

Similar to single-phase heat transfer, turbulent enhancement downstream of the flow obstruction will also increase the mass-transfer deposition coefficient (k). Using the analogy between heat and mass transfer, and the normalized Nusselt number of Yao et al. (1982), the following mass transfer enhancement relation is introduced:

$$\text{Nu}^* = \frac{\text{Nu}_{\text{obs}}}{\text{Nu}_{\text{ref}}} = \frac{\text{Sh}_{\text{obs}}}{\text{Sh}_{\text{ref}}} = \frac{k_{\text{obs}}}{k_{\text{ref}}} = F(z) = 1 + A_0 e^{-b(z/D)} \quad (6.3)$$

In this case, the downstream effect of flow obstructions is modelled by modifying the reference-tube values of k using the above relation. The associated rise in droplet deposition and film thickness will cause an increase in CHF, as shown in Figure 6.3. In this preliminary analysis, the amplitude of mass transfer enhancement ($A_0 = 1, 5, 10,$ and 20) was varied while maintaining a constant decay rate ($b=0.13$). Again, CHF ratios similar to those measured are obtained. It is worth noting that for both droplet impingement and mass transfer enhancement

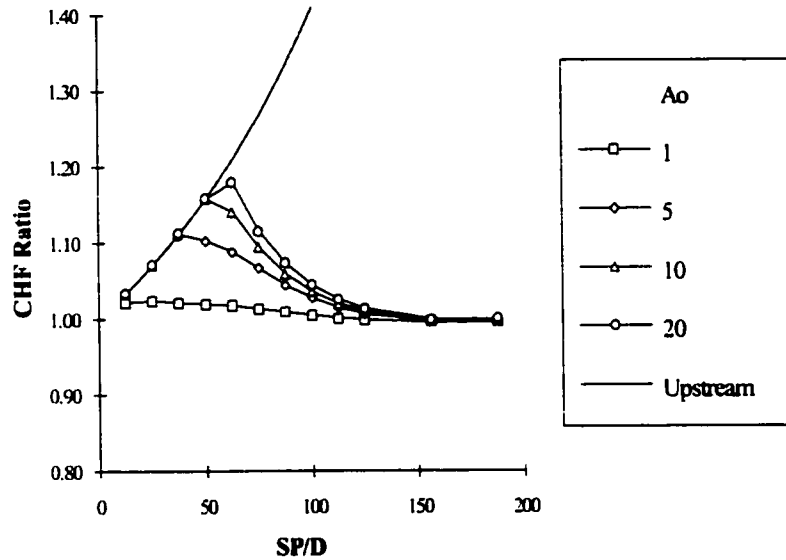


Figure 6.3: Effect of mass transfer enhancement (A_o , $b=0.13$) on CHF ratio — single obstacle in water with $P=7$ MPa, $G=4$ Mg/m²·s, $d=8$ mm, $L=2$ m, $T_{in}=T_{sat}$.

(at the same decay rate), the same decay rate in CHF enhancement with obstacle spacing was obtained. Based on these results, the droplet impingement and mass transfer enhancement mechanisms were both tested using the 30% ring data in Freon-134a.

6.2 Detailed Assessments in Freon-134a

The following section describes the preliminary analysis performed on the 30% ring data in Freon-134a, to determine the optimum flow enhancement parameters for the model. The droplet impingement factor (K_{depos}) and mass transfer enhancement parameters (A_o , b) were assumed constant for each inlet and flow condition (P , G , T_{in}).

6.2.1 Parameter Estimation

A combination of trial-and-error, visual inspection, and statistical analysis were used to estimate an optimal set of flow obstruction parameters (K_{depos} , A_o , b) for each of the seven data sets for the 30% ring in Freon-134a, as shown in Table 3.4. As in the experiment, model results were inspected to ensure that CHF was predicted at the exit. In some cases, reasonably good agreement in absolute CHF was obtained, but the CHF location was predicted incorrectly. In all the experimental data used, the CHF was always located at the exit.

The statistical analysis results for each optimal set of flow enhancement parameters are shown in Table 6.1 for the Whalley et al. (1974) model, and in Table 6.2 for the Hewitt and Govan (1990) model. The RMS error in CHF ratio is well within the estimated error of the experimentally derived ratio (4–12%). Optimum values for (K_{depos} , A_o , b) are shown to vary with inlet and flow conditions. Larger droplet impingement factors are required with the Whalley et al. model as the dryout quality is increased. Impingement factors for the Hewitt and Govan model appear more consistent with all values in the range of 0.02–0.03, but the values

Table 6.1: Optimal enhancement parameters obtained using Whalley et al. (1974).

Data Set	P (MPa)	G (Mg/m ² ·s)	avg T_{in} (°C)	N	Optimal Parameters				
					K_{depos}	A_o	b	Error (CHF ratio)	
								RMS	Avg.
1	1.13	2	40	11	0.02	0	0	4.9%	-0.1%
2	1.13	4	27	7	0.04	0	0	4.8%	-2.1%
3	1.66	3	55	55	0.07	0	0	1.5%	-0.5%
4	1.67	4	11	65	0.02	2	0.26	2.1%	-1.0%
5	1.66	4	34	52	0.04	0	0	2.8%	0.9%
6	1.67	4	45	63	0.09	0	0	2.7%	0.5%
7	1.67	4	53	58	0.07	0	0	2.1%	0.1%

Table 6.2: Optimal enhancement parameters obtained using Hewitt and Govan (1990).

Data Set	P (MPa)	G (Mg/m ² ·s)	avg T_{in} (°C)	N	Optimal Parameters				
					K_{depos}	A_o	b	Error (CHF ratio)	
								rms	avg
1	1.13	2	40	11	0.02	0	0	5.5%	-2.1%
2†	1.13	4	27	7	0	2	0.13	4.9%	1.7%
					0.02	0	0	5.7%	0.3%
3	1.66	3	55	55	0.03	4	1.04	3.9%	-0.1%
4	1.67	4	11	65	0.02	0	0	5.5%	-4.4%
5	1.66	4	34	52	0.01	2	0.26	3.3%	1.2%
6	1.67	4	45	63	0.02	2	0.39	5.1%	0.2%
7	1.67	4	53	58	0.02	2	0.52	2.8%	0.3%

†Equivalent results obtained with both K_{depos} and (A_o, b) .

of (A_o, b) vary considerably. The difference in parameter estimates between these two models can be traced back to differences in their mass transfer coefficient (k). The Hewitt and Govan model uses a k -value correlation which increases with dryout quality, whereas the Whalley et al. model uses the same value of k for all data at the same pressure (see Figure 5.16).

6.2.2 Overall Error in CHF

An overall assessment of the CHF enhancement model was made by comparing the predicted and measured values of CHF, as opposed to non-dimensional CHF ratios. The CHF ratio includes an additional error in the prediction of reference values for CHF, used by both the experiment and model at the same inlet flow condition. The results based on the Whalley et al. model, and Hewitt and Govan model are shown in Figures 6.4 and 6.5, respectively. While the Hewitt and Govan model has a slightly larger RMS error in CHF ratio (2.8–5.5%) versus that

of the Whalley et al. (1.5–4.9%), the overall prediction accuracy of the Hewitt and Govan model (10% RMS) is higher than that of the Whalley et al. model (13% RMS). The superiority of the Hewitt and Govan model to predict the reference value of CHF (see Table 5.3) is somewhat reduced by its inability to predict the CHF enhancement effects produced by these two flow enhancement mechanisms.

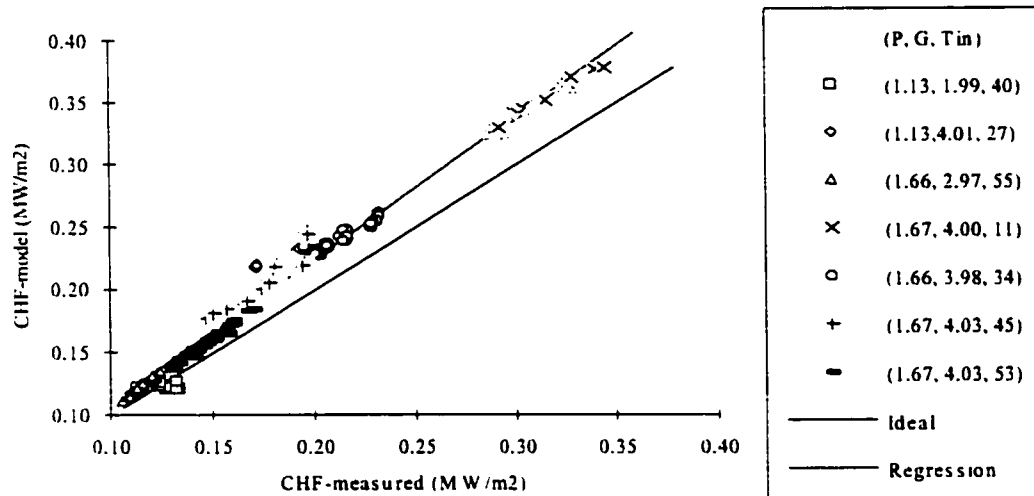


Figure 6.4: Direct comparison between the experimental and predicted CHF enhancement using the Whalley et al. (1974) model.

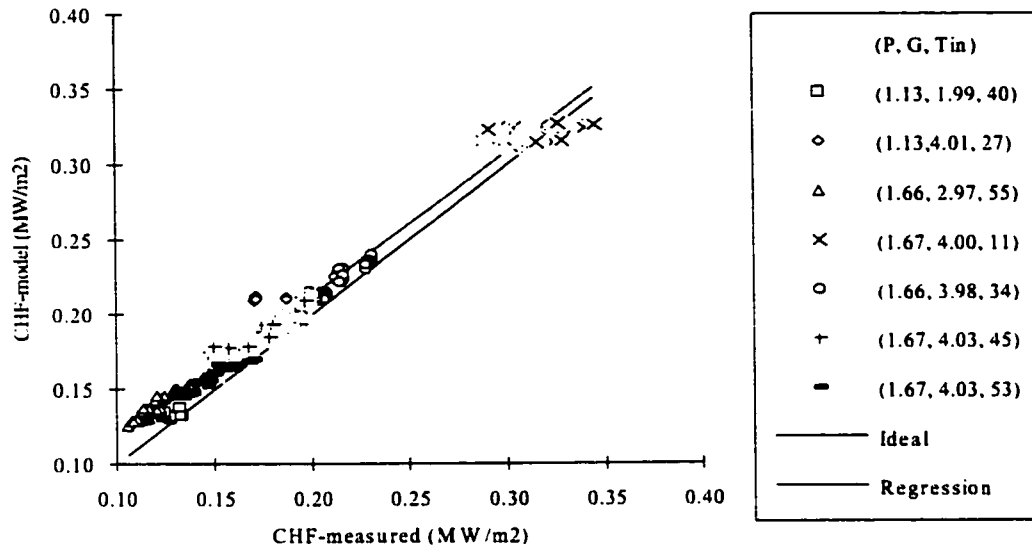


Figure 6.5: Direct comparison between the experimental and predicted CHF enhancement using the Hewitt and Govan (1990) model.

6.2.3 Detailed Profile Analysis

This section presents various CHF enhancement model profiles which will be used to assess the ability of the previous flow enhancement parameters to predict the overall trends in CHF enhancement. Instead of using a purely statistical comparison, the observed parametric trends with obstacle spacing and flow obstacle number will be studied. Sample results for the Whalley et al. model at high flow and high quality are shown in Figure 6.6. As the obstacle spacing is reduced for a given number of flow obstacles (N_{obs}), the CHF ratio increases exponentially until the limiting CHF is reached – this limiting value of CHF occurs when the dryout location moves from the exit to some other location upstream. As described in Chapter 3 (see Figure 3.38), the CHF enhancement ratio versus spacing curve is a direct result of local increases in CHF caused by the obstacle. Clear distinctions are made between CHF at the exit and that occurring upstream, since the latter typically denotes a situation in which the nominal

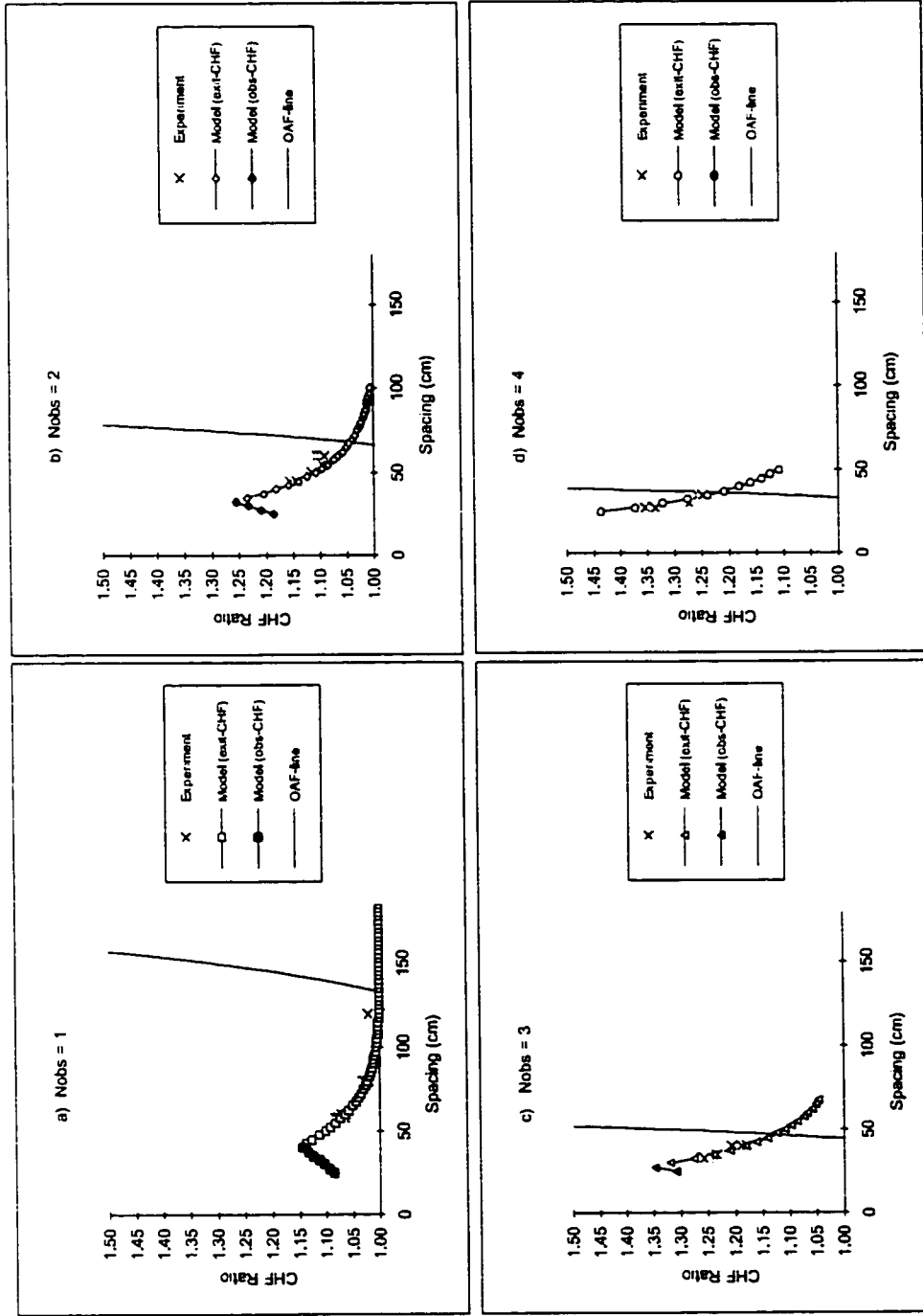


Figure 6.6: CHF ratio versus spacing for each number of the 30% rings tested in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53^{\circ}\text{C}$) using Whalley et al. (1974) with values ($K_{depos}=0.07$, $A_o=0$, $b=0$).

tube CHF has been exceeded before the obstacle. The curve labelled “OAF line” is used to monitor the influence of the OAF boundary condition on CHF at the exit, as each flow obstacle is positioned near the OAF location. In this case, the OAF point is located between 133 and 157 cm from the exit, corresponding to values of heat flux ranging from 1.0 to 1.5 times the reference tube CHF. To identify when the first obstacle ($N_{obs}=1$) is positioned at the OAF, we simply take the intersection of the enhancement ratio curve with the OAF line. In this case there is no apparent effect on enhancement from the OAF. As more obstacles are introduced, the spacer location at which the N_{obs} obstacle is at the OAF is mapped to the CHF ratio curve by simply dividing the original OAF line ($N_{obs}=1$) by the number of flow obstacles (N_{obs}). For example, the second obstacle is positioned at the OAF at a spacing of approximately 66.5 cm (i.e., 133 cm $\div$ 2), the third obstacle at a spacing of approximately 44 cm, and the fourth at a spacing of 33 cm.

To reduce the number of plots, the data for all the obstacle number configurations ($N_{obs}=1-4$) are plotted on the same graph, as shown in Figure 6.7. The experimental data are denoted by hollow symbols with no lines. The model predictions with CHF at the exit are denoted by hollow symbols with lines, and the prediction of CHF somewhere upstream is denoted by solid symbols with lines. The line with no symbols indicates the spacing and heat flux at which the N_{obs} obstacle is at the OAF.

The optimal results for the Hewitt and Govan model at the same inlet conditions are shown in Figure 6.8, with a significant rise in CHF ratio as the obstacle is located at the OAF. This phenomena does not occur in the experiment or in the Whalley et al. model, even when values of ($A_0=6.0$, $b=0.10$) are introduced, as shown in Figure 6.9. This discrepancy in the Hewitt and Govan model is attributed to the mass transfer enhancement relation:

$$\frac{k_{obs}}{k_{ref}} = \frac{k_{obs}(z)}{k_{ref}(z)} = 1 + A_0 e^{-b(z-z_{obs})/D} \quad (6.4)$$

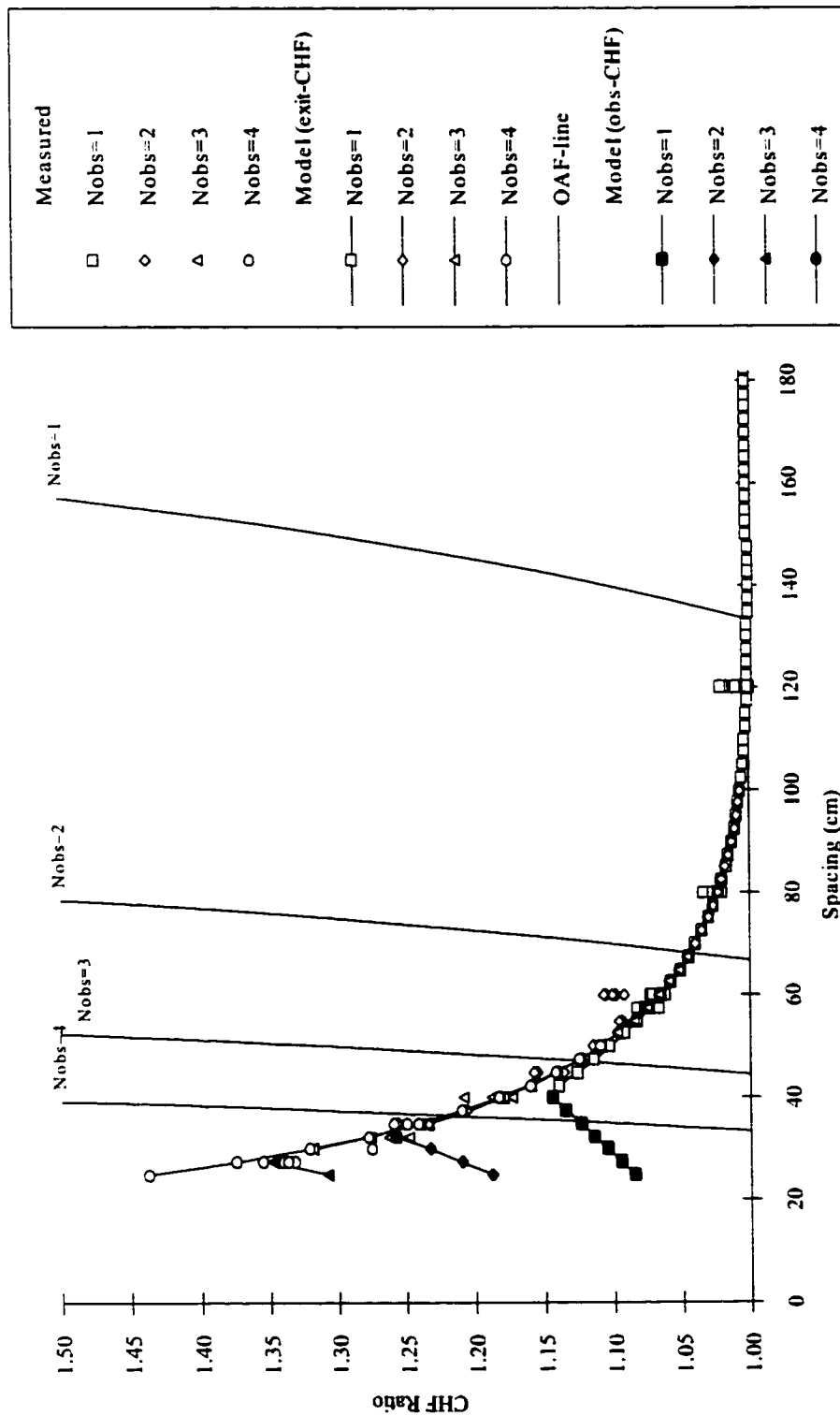


Figure 6.7: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53$ °C) using Whalley et al. (1974) with values ($K_{depos}=0.07$, $A_n=0$, $b=0$).

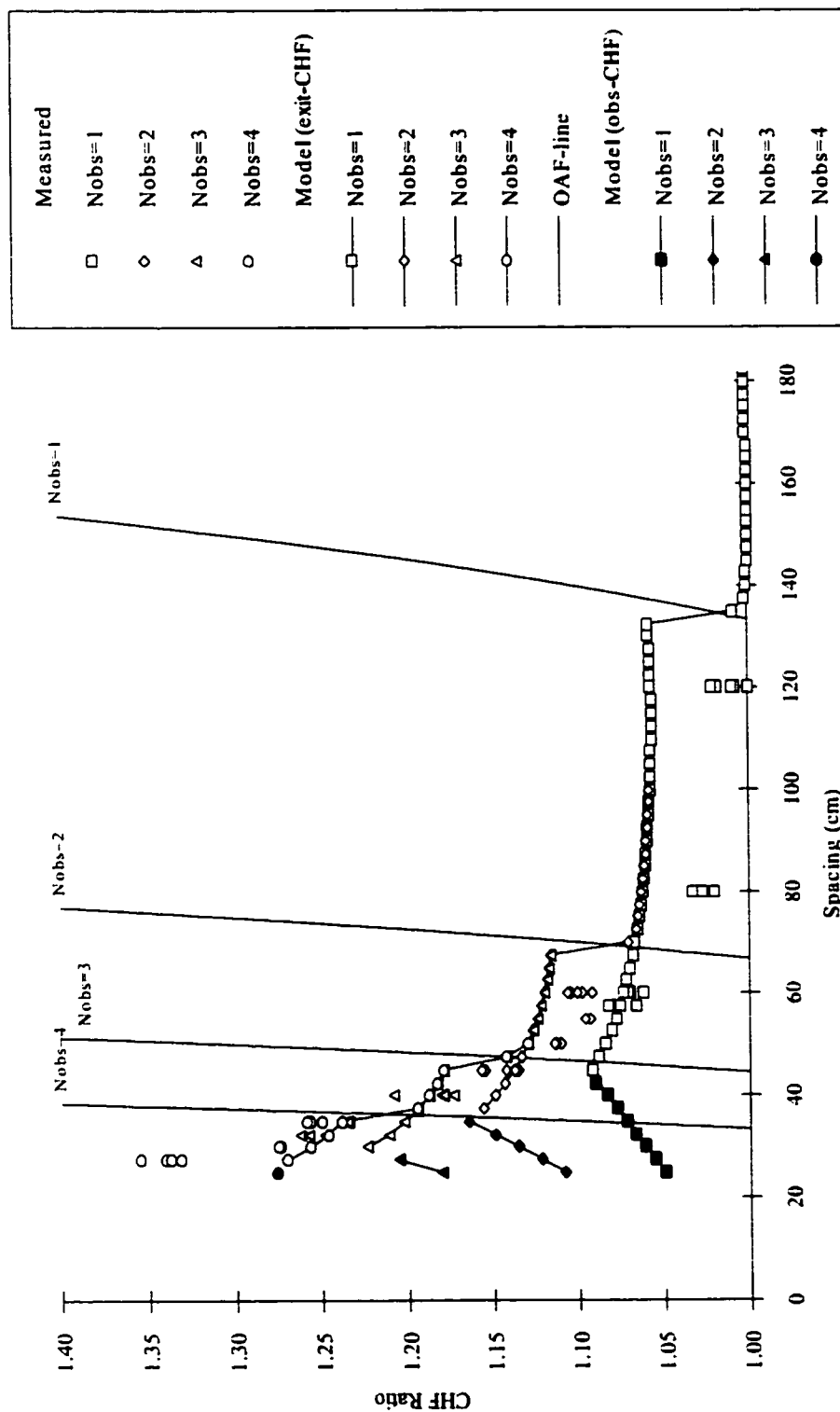


Figure 6.8: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53^{\circ}\text{C}$) using Hewitt and Govan (1990) with values ($K_{depux}=0.02$, $A_0=2.0$, $b=0.52$).

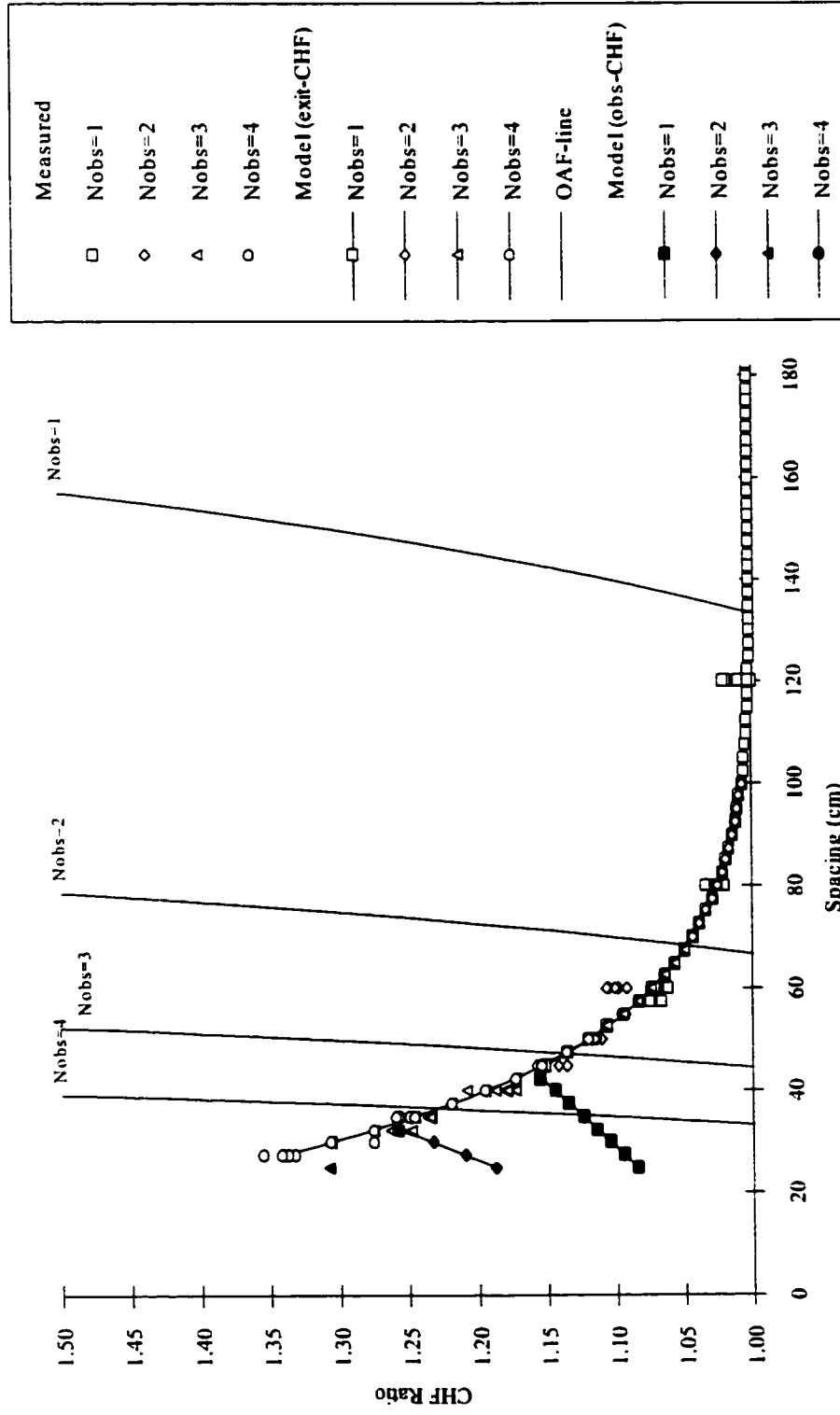


Figure 6.9: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53$ °C) using Whalley et al. (1974) with values ($K_{depas}=0$, $A_0=6.0$, $b=0.10$).

and the fact that when applying this method to the Hewitt and Govan model, the local value of $k_{\text{ref}}(z)$ increases with downstream distance, whereas the Whalley et al. model assumes a constant k -value over the entire tube length. A constant value of k_{ref} shows little or no influence from the obstacle being located at the OAF (see Figure 6.9).

Attempts were made to use a single nominal value of k at the obstruction location:

$$\frac{k_{\text{obs}}}{k_{\text{ref}}} = \frac{k_{\text{obs}}(z)}{k_{\text{ref}}(z_{\text{obs}})} = 1 + A_o e^{-b(z - z_{\text{obs}})/D} \quad (6.5)$$

where if the flow obstruction was located in the subcooled region ($z_{\text{obs}} < z_{\text{OAF}}$), but still exerted a downstream influence:

$$(z - z_{\text{obs}})/D > (z - z_{\text{OAF}})/D \quad \text{and} \quad A_o e^{-b(z - z_{\text{obs}})/D} > 0.01 \quad (6.6)$$

the nominal k -value at the OAF (k_{OAF}) was used. The results for this modified form of the Hewitt and Govan enhancement model are shown in Figure 6.10, but still indicate a persistent influence of the OAF on CHF. This is attributed to the fact that the nominal k -value at the obstacle location also varies with obstacle location.

Results from the single-phase heat transfer experiment have shown that the local Nusselt number enhancement (R_{Nu}) decreases with increased Reynolds number (i.e., larger values of Nu_{ref}), but not enough data were available to empirically correlate the flow effect. In addition, the absolute value was shown to vary with flow obstruction geometry. One could explore the possibility of a relation between the mass transfer coefficient and the core flow Reynolds number, as described in the reference tube profiles of Chapter 5, and incorporate this variation with Reynolds number into the CHF enhancement model.

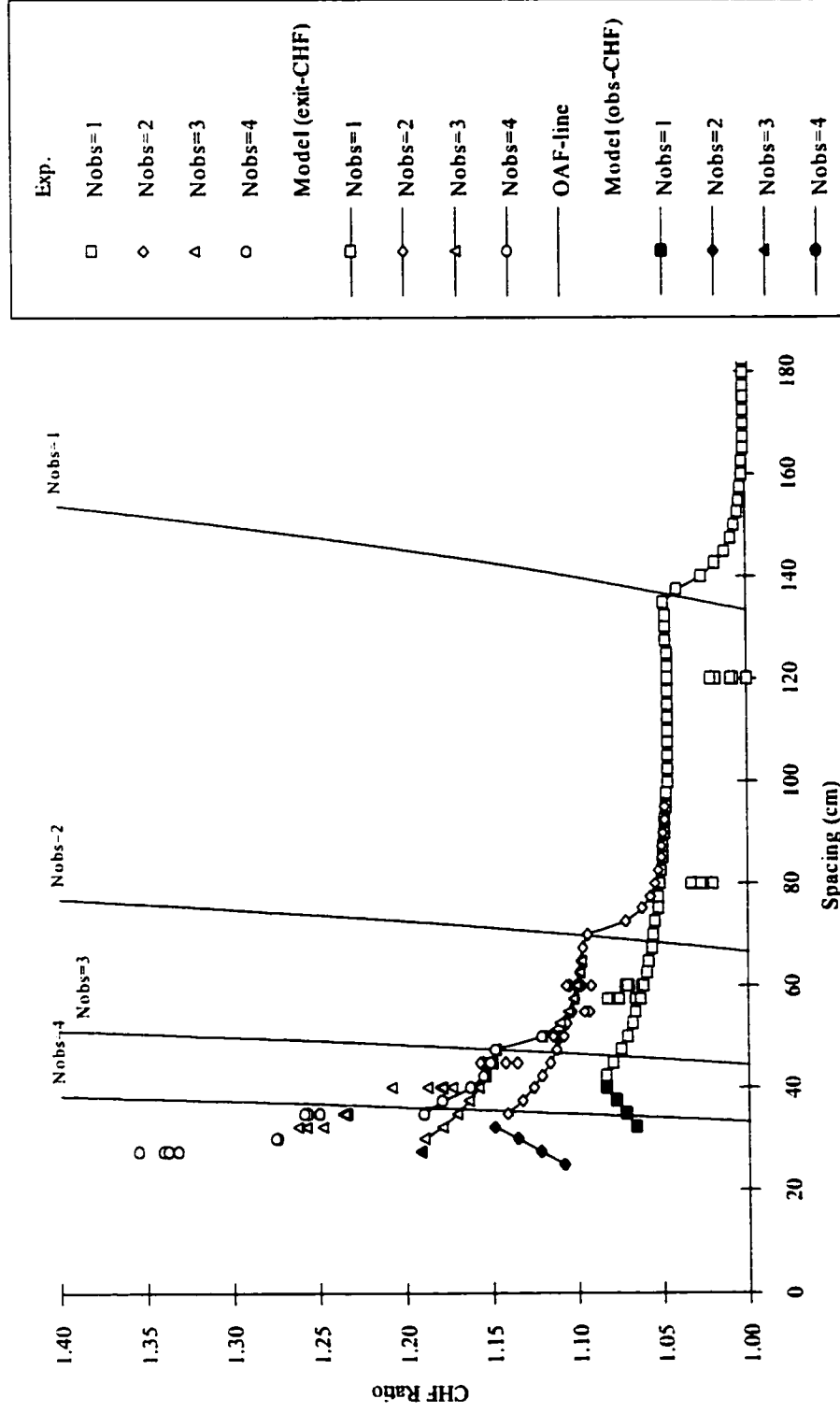


Figure 6.10: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53$ °C) using Hewitt and Govan (1990) with values ($K_{depos}=0$, $A_o=1.8$, $b=0.10$) and a constant nominal k -value at the obstacle location.

Application of the model to conditions at 1.1 MPa (7 MPa water-equivalent) were less successful, with RMS errors in CHF ratio ranging from 4.8% to 5.5% for the two E/D models. The detailed profiles at 2 Mg/m²·s, shown in Figures 6.11 and 6.12, demonstrate the inability of the enhancement mechanism to predict a steep enough decay rate in CHF enhancement with obstacle spacing. Similar results were obtained at higher mass flux (4 Mg/m²·s), even though only two obstacle locations were measured (35 and 40 cm).

6.3 Revised Analysis

The following section will derive analytical expressions for the net deposition of liquid from both droplet impingement on the flow obstacle and turbulence-induced mass transfer enhancement. An equivalency in these two flow mechanisms will also show the indeterminacy of trying to fit both models to measured data. The results of a revised profile assessment will be used to define a set of optimal flow obstruction parameters for each mechanism separately, followed by an attempt to use the analogy between heat and mass transfer to derive an optimal set of parameters for the combined model.

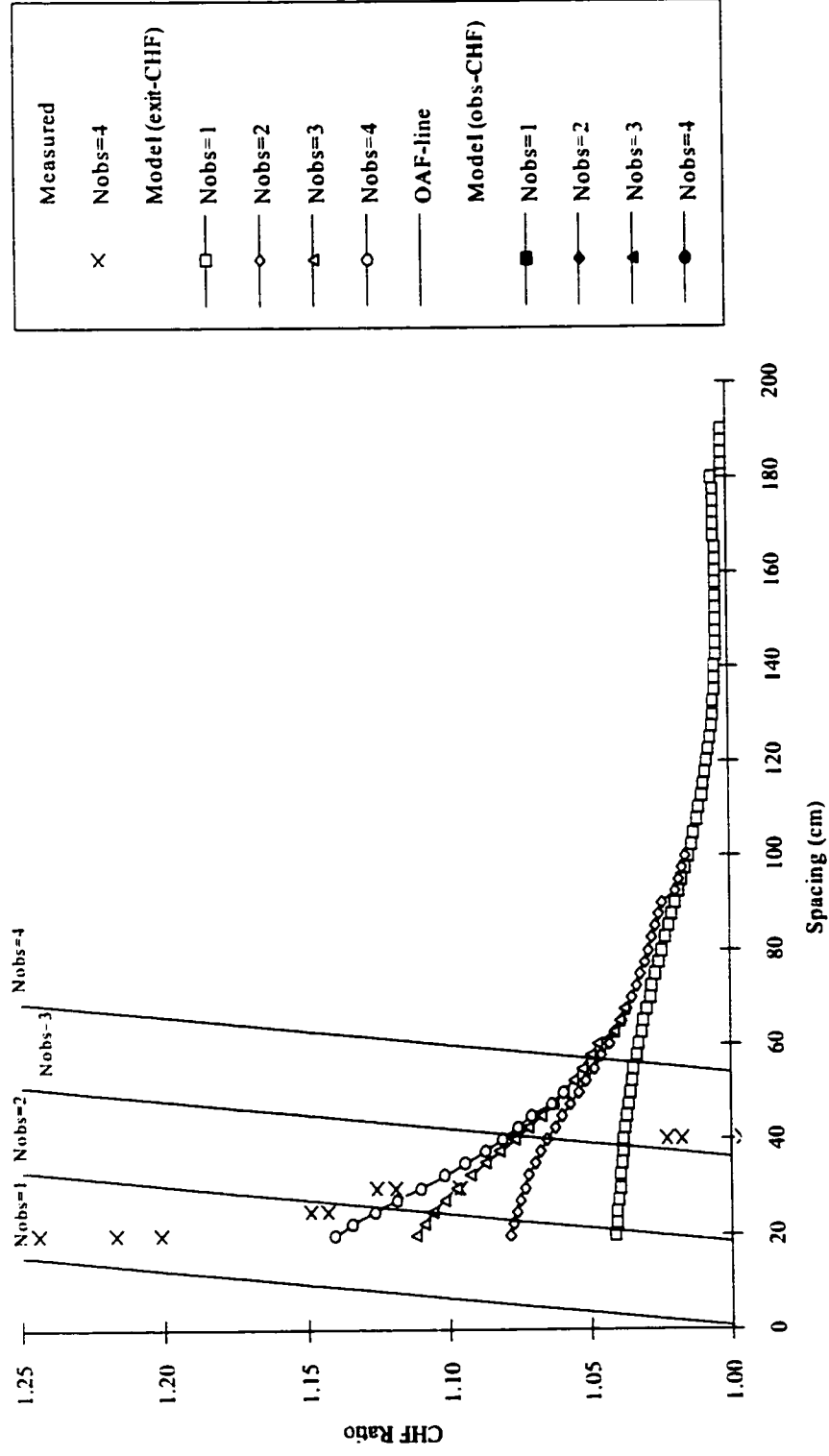


Figure 6.11: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.1$ MPa, $G=2$ Mg/m²·s, $T_m=40^\circ\text{C}$) using Whalley et al. (1974) with values ($K_{\text{depos}}=0.02$, $A_o=0$, $b=0$).

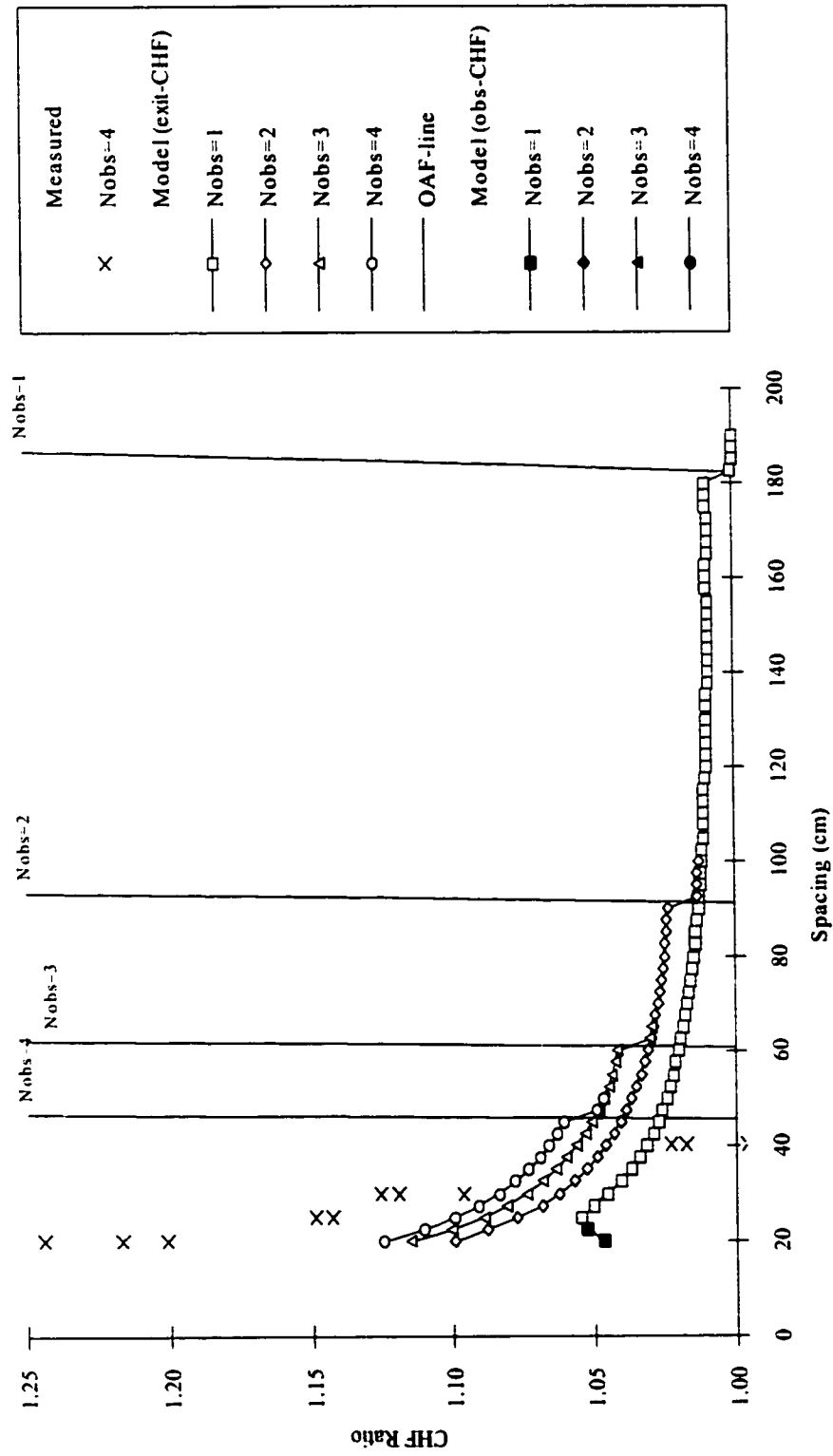


Figure 6.12: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.1$ MPa, $G=2$ Mg/m²·s, $T_{in}=40^{\circ}\text{C}$) using Hewitt and Govan (1990) with values ($K_{depos}=0.02$, $A_o=0$, $b=0$).

6.3.1 Analytical Impingement Model

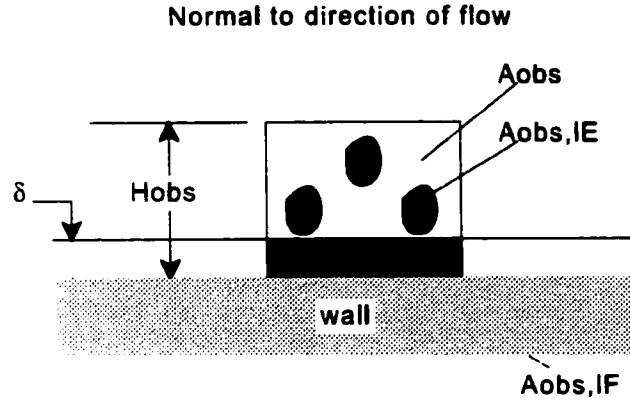


Figure 6.13: Physical representation of annular flow around a flow obstacle.

Figure 6.13 shows a simplified view of the annular flow cross-section as the liquid film and droplets strike the flow obstruction. A conservation of mass over the front face of the obstacle results in the following impingement factor (K_{depos}) relation:

$$\begin{aligned}
 \Delta G_{IF} &= -\Delta G_{IE,obs} = -\frac{1}{A} \int_A \rho \vec{v} \cdot d\vec{A}_{obs,IE} \\
 &= -\frac{1}{A} \left(-\langle \rho u A \rangle_{obs,IE} \right) \\
 &= \rho_l \langle u_{IE} \rangle_{IE} \frac{A_{obs,IE}}{A} = \rho_l \langle u_{IE} \rangle_{IE} \frac{\alpha_{IE,c} A_{obs,c}}{A} \\
 &= \rho_l \langle u_{IE} \rangle_{IE} \frac{\alpha_{IE}}{\alpha_c} \frac{A_{obs,c}}{A} = G_{IE} \cdot \frac{A_{obs,c}}{\alpha_c A} \quad (6.7) \\
 &\quad \left(\text{i.e. } \alpha_{IE} = \alpha_c \cdot \alpha_{IE,c} \right) \\
 &= G_{IE} \cdot \frac{(1 - \delta/H_{obs}) A_{obs}}{A} = K_{depos} \cdot G_{IE}
 \end{aligned}$$

where all the entrained liquid impinging the surface ends up in the liquid film, there are no appreciable gaps between the wall and the obstacle, and the film thickness (upstream) is unaffected by the presence of the flow obstacle. To compensate for these highly idealized assumptions, the following modified form of the equation is used:

$$K_{\text{depos}} = \begin{cases} \frac{(1 - \delta/H') K_{\text{obs}} \alpha_{\text{obs}}}{\alpha_c} & , \delta < H' \\ 0 & , \delta \geq H' \end{cases} \quad (6.8)$$

where α_{obs} is the flow blockage ratio (A_{obs}/A), H' is a correlated obstacle height, and K_{obs} is a correlated form factor. H' denotes the film thickness upstream of the obstacle (δ) at which little or no impingement occurs, and K_{obs} denotes the portion of the total liquid impinging on the obstacle surface that ends up in the liquid film through run-off. Some of the factors affecting these two empirical constants are:

- the accuracy in predicting the liquid film thickness,
- the magnitude of the wall clearance in comparison to liquid film thickness (i.e., the flow obstructions remained moveable throughout the experiment, requiring some minimal gap between the tube wall and the flow obstructions),
- the specific type of flow obstruction geometry (i.e., 30% ring versus 18% blocks) where flow diversion around the obstacle can have an impact on the liquid impingement and run-off.

Since both E/D models predict very small films (0–150 μm in Freon-134a), the effect of δ/H_{obs} on K_{depos} will be minimal since the H_{obs} for the 30% ring and 18% blocks are 650 μm and 1450 μm , respectively. When comparing the detailed CHF enhancement profiles for different values of (H' , K_{obs}), the optimal values shown in Table 6.3 were obtained, and indicate the following:

- $H' \ll H_{\text{obs}}$: either the film thickness is under-predicted or the droplet impingement on the ring is significantly reduced by the presence of a

Table 6.3: Optimal values of (H' , K_{obs}) obtained using the refined impingement model.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	H' (mm)	K_{obs}
Whalley et al. (1974)				
1.13	1.99	40	0.06	0.2
1.13	4.01	27	0.09	0.33
1.66	2.97	55	0.18	0.27
1.67	4	11	0.08	0.17
1.66	3.98	34	0.07	0.2
1.67	4.03	45	0.32	0.33
1.67	4.03	53	0.16	0.27
Hewitt and Govan (1990)				
1.13	1.99	40	0.08	0.13
1.13	4.01	27	0.05	0.13
1.66	2.97	55	0.1	0.27
1.67	4	11	0.05	0.13
1.66	3.98	34	0.1	0.1
1.67	4.03	45	0.1	0.14
1.67	4.03	53	0.075	0.13

liquid film (i.e., liquid film flows over the ring with little or no impingement deposition). The former is more likely the case, since there would be significant droplet deposition on the film as it flowed over the ring, and exposed itself to more of the core flow region.

- The portion of entrained liquid impinging on the obstacle and reaching the liquid film ranges from 17% to 33% for the Whalley et al. model, and from 10% to 27% for the Hewitt and Govan model (assuming no mass transfer enhancement). The Hewitt and Govan model shows a higher

degree of consistency with K_{obs} ranging in most cases from 10% to 14%, except for the one case of 27%.

The results obtained for the optimal values at 1.1 MPa and 2 Mg/m²·s are shown in Figures 6.14 and 6.15, to indicate a significant improvement in the ability of the model to fit this data set. The resulting values of (H' , K_{obs}) are still questionable since neither the film thickness nor the amount of run-off (K_{obs}) could be measured during the experiment. The results do indicate that a small obstructed area (30%) with a moderate amount of run-off (10-30%) can produce the measured CHF enhancement. It should be noted that there was no evidence in the present experiment to indicate the liquid-film was either removed or severely disrupted following the abrupt change in geometry at the flow obstacles (i.e., inferred by the fact that no detrimental decrease in CHF occurred). This may be explained by the fact the small gap between the obstacle and the tube (i.e., necessary to move the obstacle during the experiment) was sufficient to allow a small amount of liquid to pass through, or that any stripping of the liquid-film was immediately replenished by high deposition and run-off from the presence of the obstacle.

6.3.2 Equivalency in Mass Transfer Enhancement

Similar to the droplet impingement, the net increase in liquid film mass flux associated with increased mass transfer can be derived using Equations (2.72) and (6.3):

$$\Delta G_{\text{IF}} = \int_{z_{\text{obs}}}^{z_{\text{obs}} + L_{\text{eff}}} (k_{\text{obs}} - k_{\text{ref}}) C \frac{4}{d} dz = \frac{4 A_o}{d} \int_0^{L_{\text{eff}}} k_{\text{ref}} C e^{-b(z/d)} dz \quad (6.9)$$

Assuming the droplet concentration is constant over the length affected by the obstacle (L_{eff}), the following relation is obtained for ΔG_{IF} :

$$\Delta G_{\text{IF}} = \frac{4 A_o}{d} \int_0^{L_{\text{eff}}} k_{\text{ref}} C e^{-b(z/d)} dz = \frac{4 A_o}{d} k_{\text{ref}} C \int_0^{L_{\text{eff}}} e^{-b(z/d)} dz = \frac{4 A_o}{b} k_{\text{ref}} C \quad (6.10)$$

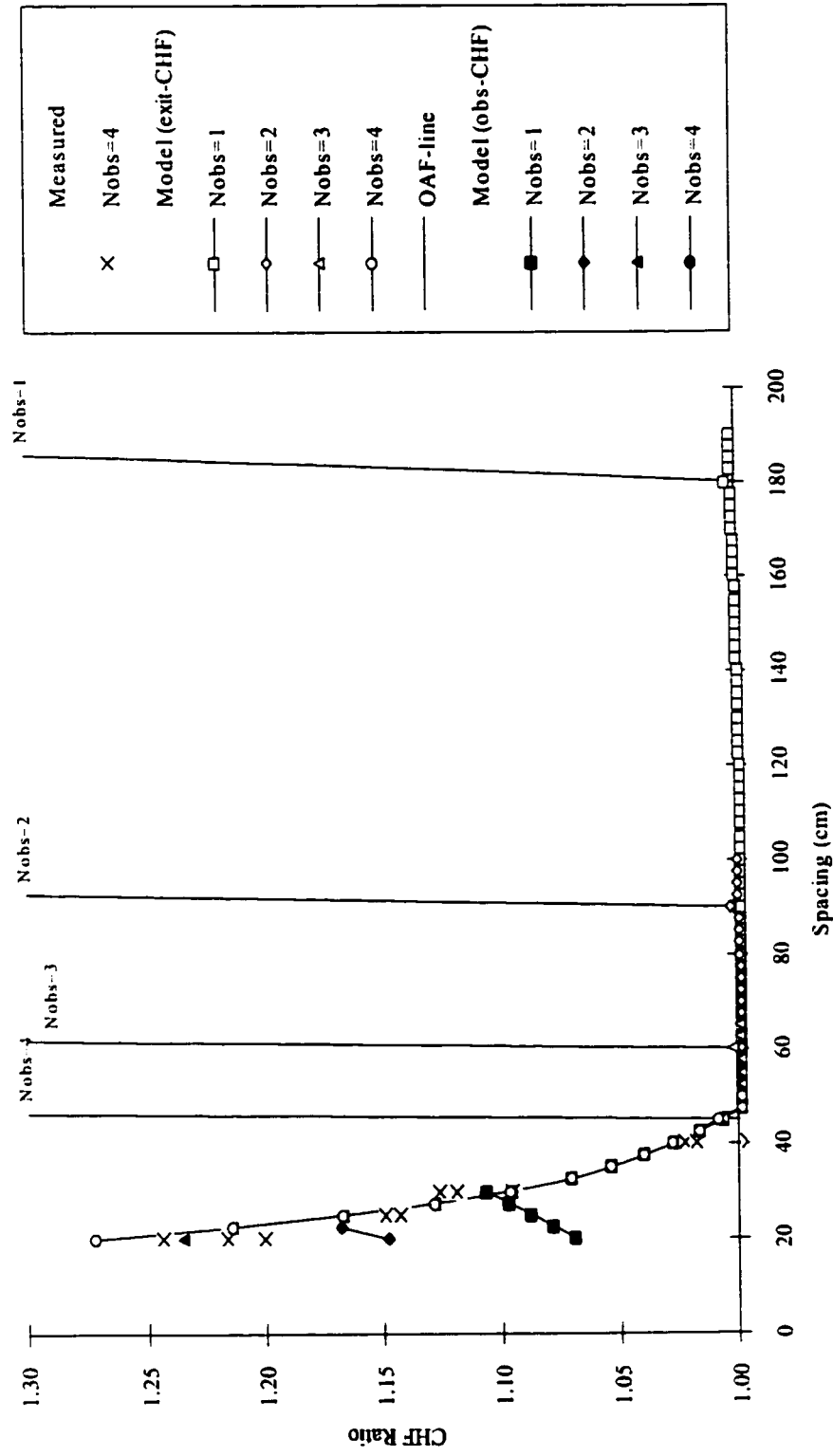


Figure 6.14: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.1$ MPa, $G=2$ Mg/m²s, $T_{in}=40^{\circ}\text{C}$) using Whalley et al. (1974) with values ($H'=0.060$, $K_{obs}=0.20$) and ($A_o=0$, $b=0$).

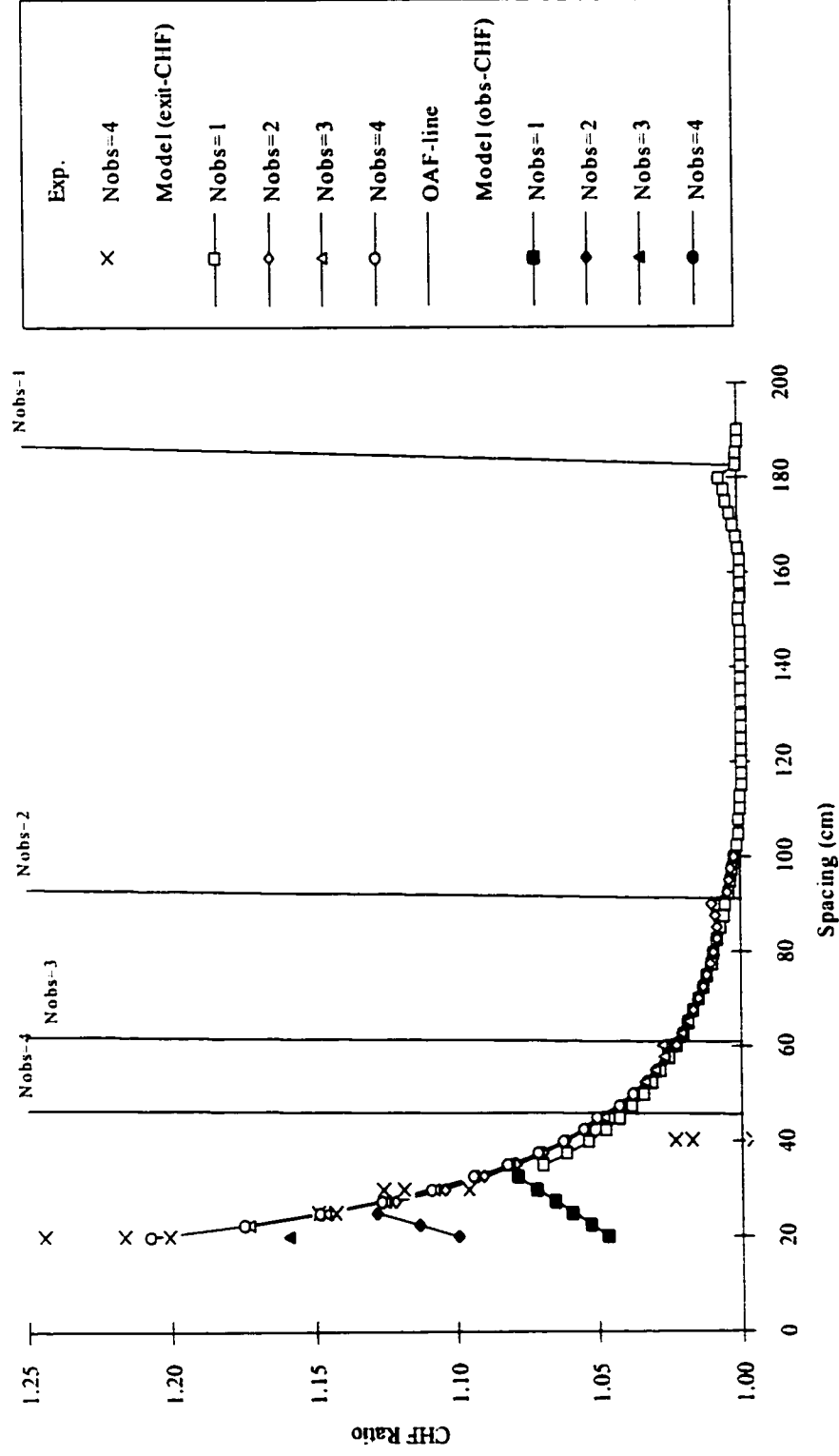


Figure 6.15: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.1$ MPa, $G=2$ Mg/m²·s, $T_{in}=40^{\circ}\text{C}$) using Hewitt and Govan (1990) with values ($H'=0.080$, $K_{obs}=0.13$) and ($A_o=0$, $b=0$).

A different set of (A_o, b) will produce the same net enhancement as long as:

$$\left(\frac{A_o}{b} \right) = \text{const} \quad (6.11)$$

Table 6.4 shows a list of equivalent values for (A_o, b) , obtained using the Whalley et al. model at 1.7 MPa, 4 Mg/m²·s, and 53°C in Freon-134a. The increase in (A_o/b) which occurs at low values of b (large effective length) reflects the predicted decrease in droplet concentration with tube length. Figures 6.16 and 6.17 show the detailed CHF enhancement profiles for two extreme values of (A_o, b) . A large effective length (e.g., $b=0.025$) can cause the enhancement ratio to decrease at small spacings due to a truncation of the mass transfer enhancement effect when the obstacle is moved to within its effective length from the exit (i.e., not all the droplet deposition enhancement has occurred). Since this characteristic decrease in CHF ratio was never observed in the experimental data, we can conclude that either the mass transfer enhancement length is very short (i.e., smallest obstacle spacing tested = 10 cm) or the effects are small in comparison to droplet impingement.

Table 6.4: Equivalent values for (A_o, b) obtained using Whalley et al. (1974) in Freon-134a at $P=1.7$ MPa, $G=4$ Mg/m²·s, and $T_{in}=53^\circ\text{C}$.

A_o	b	A_o/b
22	0.2	110
6	0.1	60
2.5	0.05	50
1.25	0.025	50

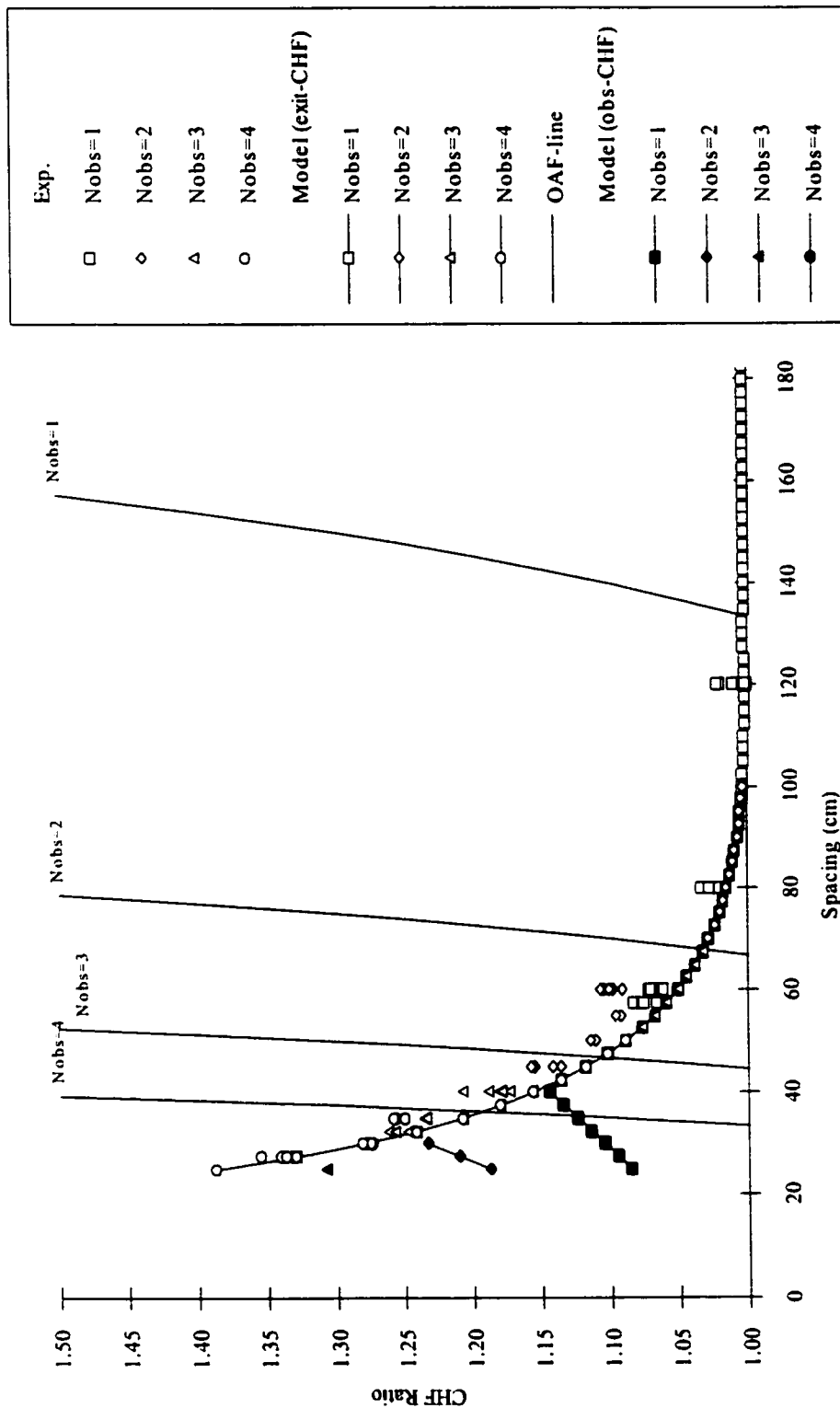


Figure 6.16: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53^{\circ}\text{C}$) using Whalley et al. (1974) with values ($K_{obs}=0$, $A_o=22.0$, $b=0.20$).

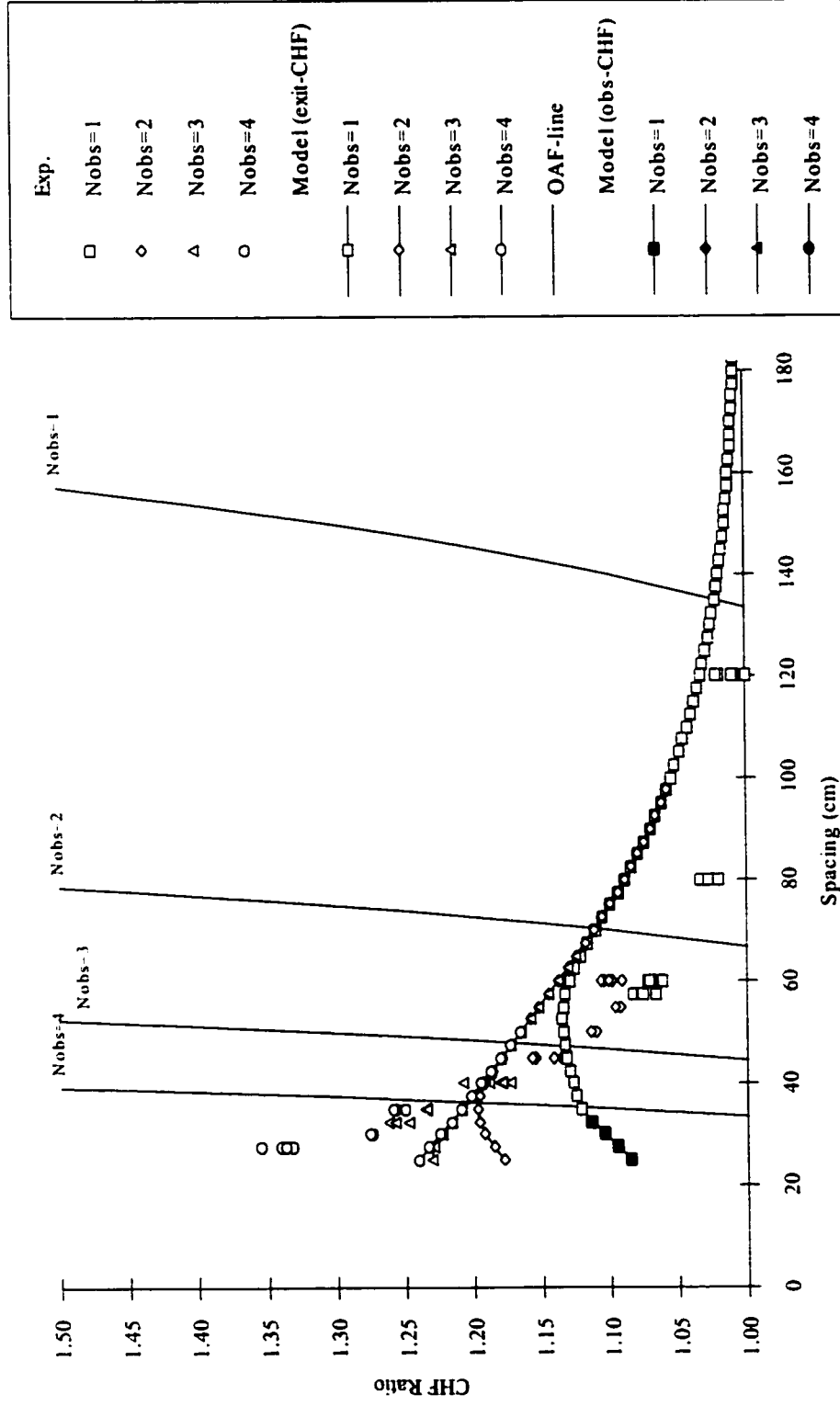


Figure 6.17: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_m=53$ °C) using Whalley et al. (1974) with values ($K_{obs}=0$, $A_o=1.25$, $b=0.025$).

Similar results were obtained for the Hewitt and Govan model, as shown in Table 6.5 and the associated enhancement profiles of Figures 6.18 and 6.19. As described earlier, the sudden increase in CHF as the obstacles approach the OAF stems from the fact that the Hewitt and Govan nominal mass transfer coefficient (k) increases with tube length (z).

Table 6.5: Equivalent values for (A_o, b) obtained using Hewitt and Govan (1990) in Freon-134a at $P=1.7$ MPa, $G=4$ Mg/m²·s, and $T_{in}=53^\circ\text{C}$.

A_o	b	A_o/b
6	0.24	25
3	0.12	25
1.5	0.06	25
0.75	0.03	25

For the 30% ring data in Freon-134a at $P=1.7$ MPa, $G=4$ Mg/m²·s, and $T_{in}=11^\circ\text{C}$, a large number of the CHF enhancement data points were obtained with the first flow obstruction ($N_{obs}=1$) located before the OAF (see Figure 6.20). Since entrained liquid does not exist before the OAF, droplet impingement cannot be used to predict the measured CHF enhancement. Only sustained mass transfer enhancement behind the obstacle, well into the annular flow regime, can predict CHF enhancement in this region. This particular data set can be used to estimate the mass transfer enhancement parameters, which could then be applied to other flow conditions (i.e., isolate instance where only mass transfer enhancement occurs). The enhancement profiles for the optimal values using the Whalley et al. model ($A_o=1.5$, $b=0.10$), and Hewitt and Govan model ($A_o=1.8$, $b=0.06$) are shown in Figures 6.20 and 6.21, respectively. These values are consistent with those measured by Berger and Hau (1979) in Figure 2.6, but significantly larger than those measured for single phase heat transfer enhancement using the same ring ($A_o=0.3-0.6$, $b=0.44$). This would indicate that heat transfer enhancement from increased turbulence in single-phase flow is on a much smaller scale than that associated with mass transfer of droplets in a vapour.

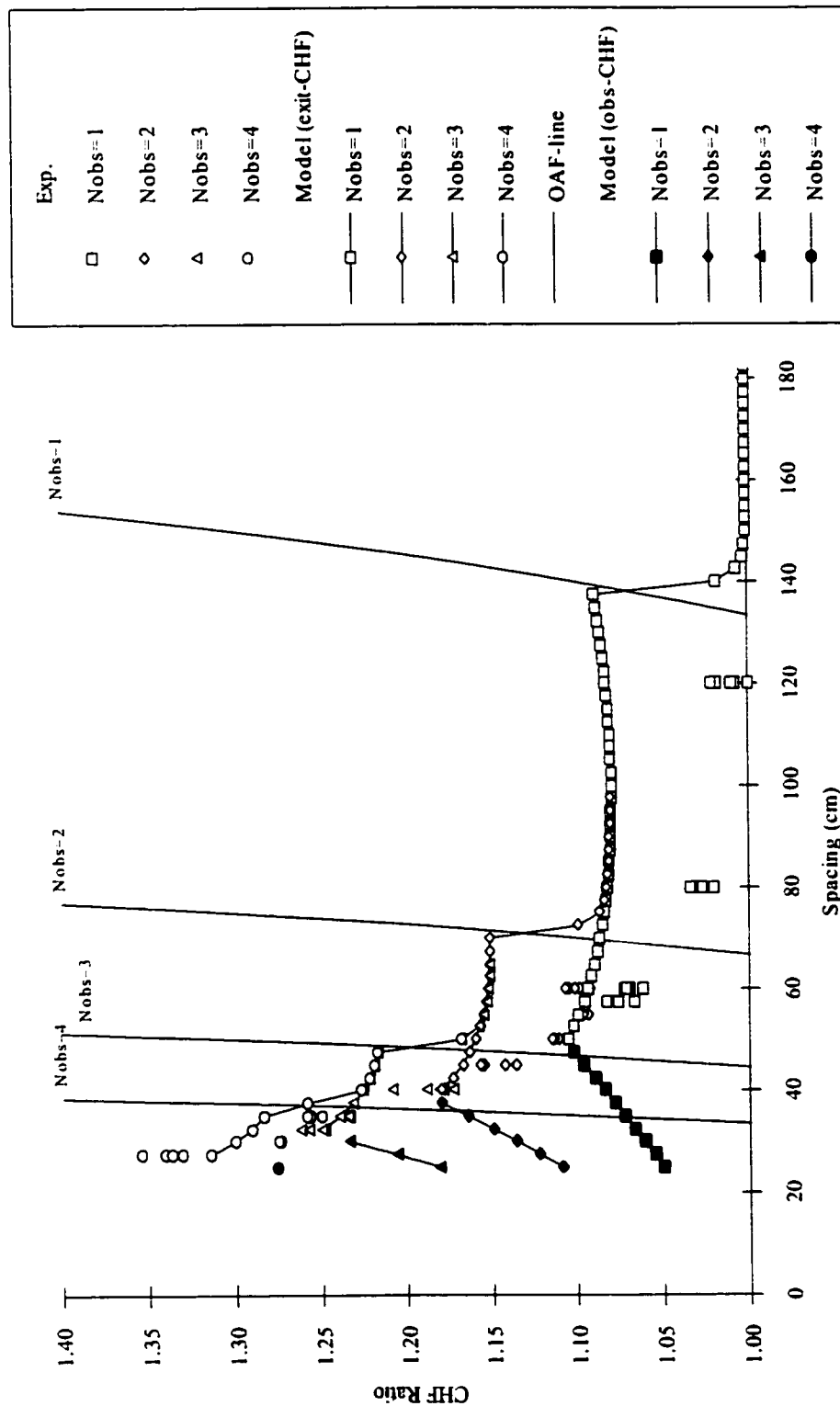


Figure 6.18: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=53$ °C) using Hewitt and Govan (1990) with values ($K_{obs}=0$, $A_o=6.0$, $b=0.24$).

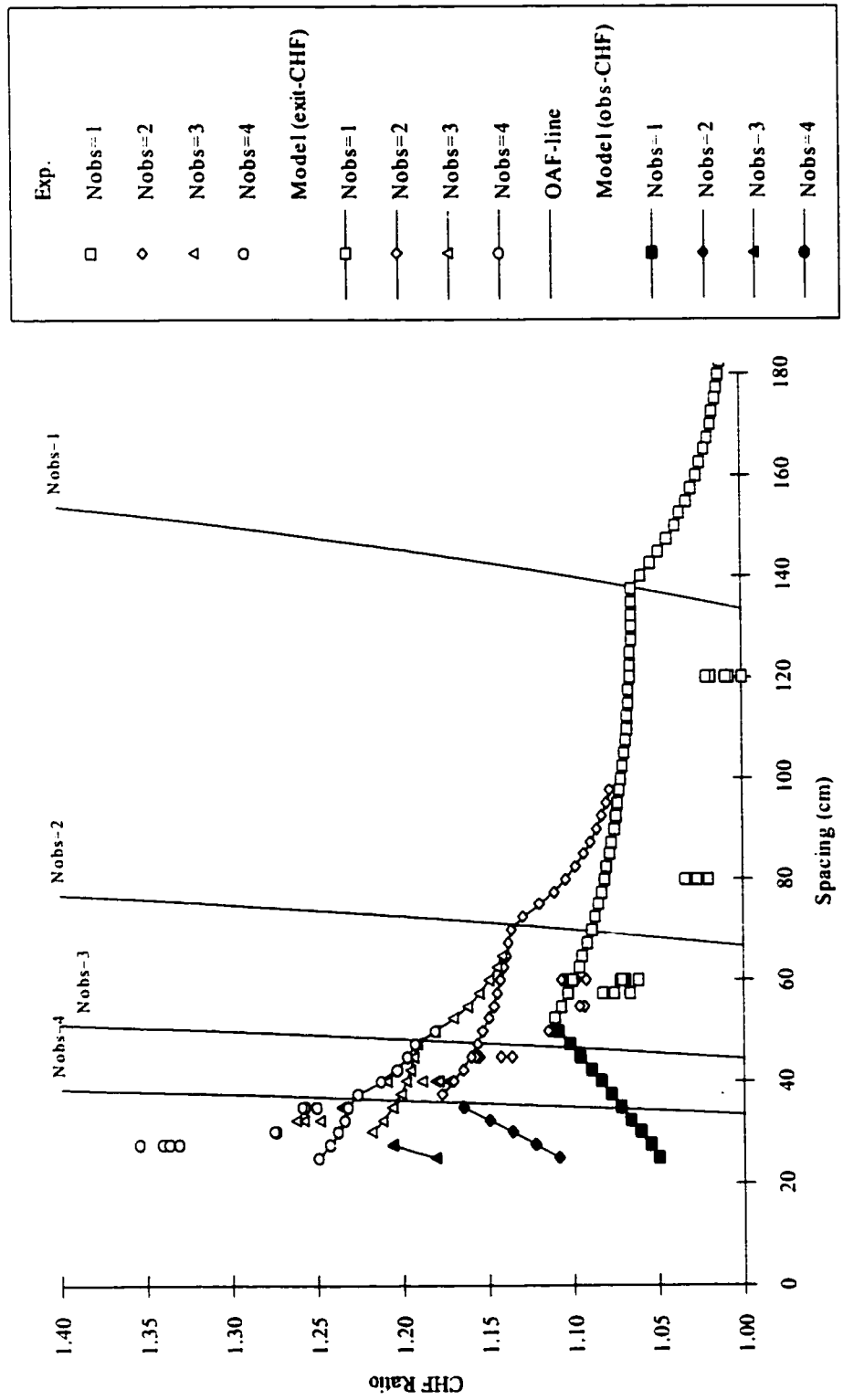


Figure 6.19: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²s, $T_{in}=53$ °C) using Hewitt and Govan (1990) with values ($K_{obs}=0$, $A_o=0.75$, $b=0.03$).

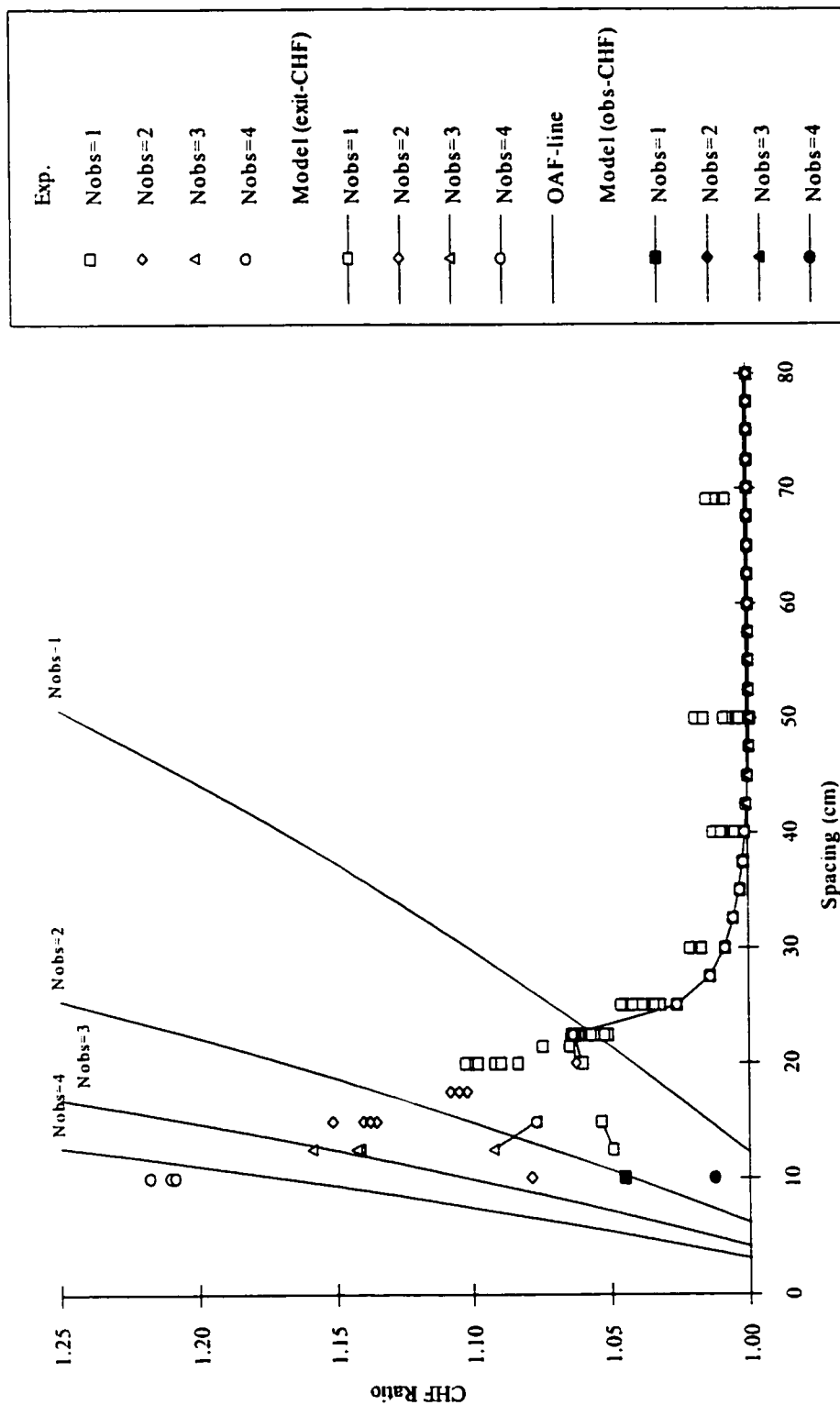


Figure 6.20: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=11$ °C) using Whalley et al. (1970) with values ($K_{obs}=0$, $A_o=1.5$, $b=0.1$).

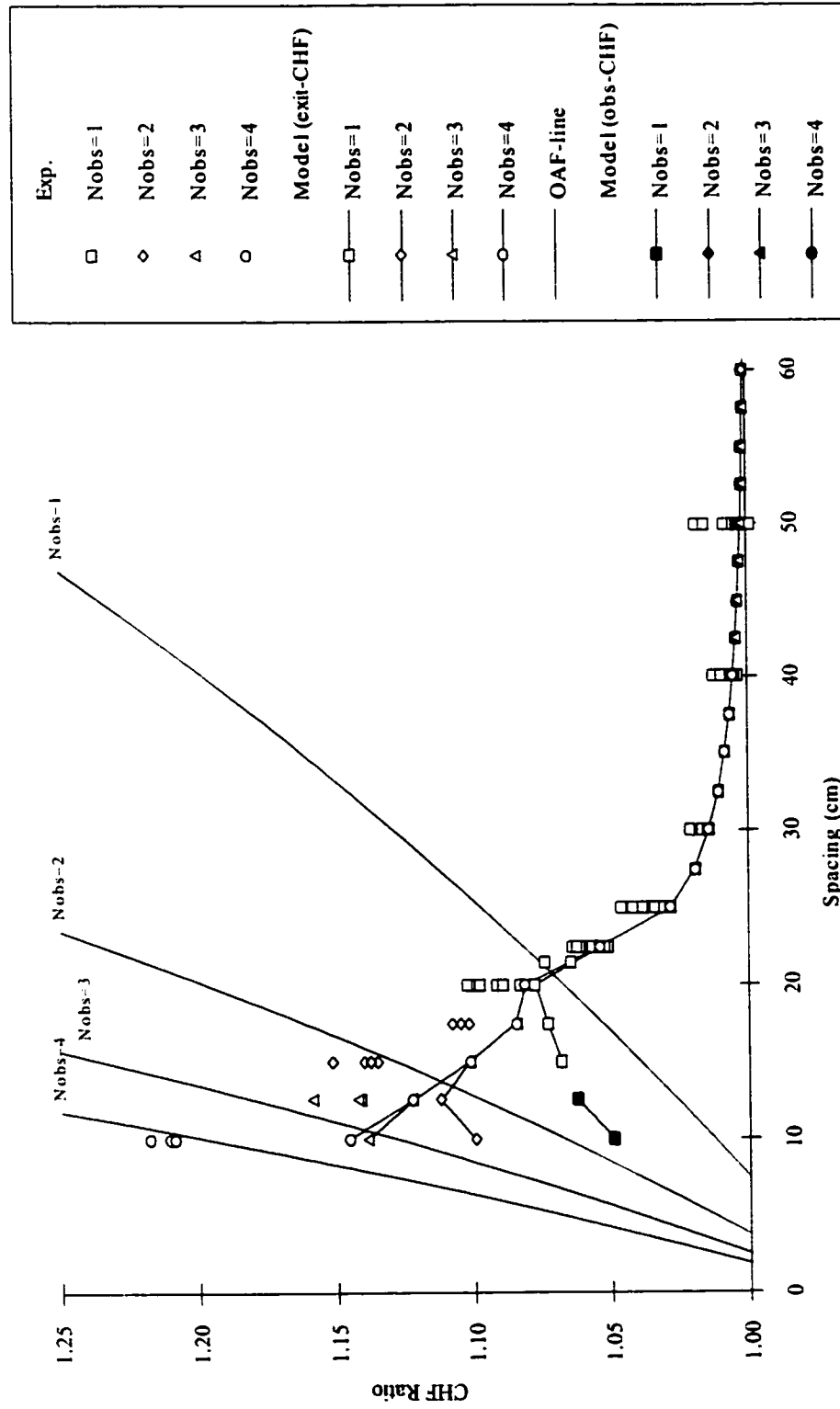


Figure 6.21: CHF ratio versus spacing for 30% rings in Freon-134a ($P=1.7$ MPa, $G=4$ Mg/m²·s, $T_{in}=11$ °C) using Hewitt and Govan (1990) with values ($K_{obs}=0$, $A_o=1.8$, $b=0.06$).

6.3.3 Combined Model

Based on the previous discussion of equivalency between droplet impingement and mass transfer enhancement, the following attempt is made to formulate a combined model of CHF enhancement where:

1. values of (A_o, b) obtained below the OAF location in highly subcooled flow are assumed constant over all the test data, and
2. values of (H', K_{obs}) are optimized to fit the data.

The optimal results obtained for the Whalley et al. model with $(A_o=1.5, b=0.10)$ are shown in Table 6.6, and indicate a high degree of variability in (H', K_{obs}) when compared with optimal results for impingement alone ($A_o=0$ in Table 6.3). The Hewitt and Govan model was far too sensitive to the OAF condition to permit the application of a single value of $(A_o=1.8, b=0.06)$. Only optimal values of $(H'=0.050, K_{obs}=0.02)$ and $(H'=0.050, K_{obs}=0.01)$ could be obtained at $(P=1.7 \text{ MPa}, G=3 \text{ Mg/m}^2\cdot\text{s}, T_{in}=55^\circ\text{C})$ and $(P=1.7 \text{ MPa}, G=4 \text{ Mg/m}^2\cdot\text{s}, T_{in}=11^\circ\text{C})$, respectively. All other data were over-predicted with values of $(A_o=1.8, b=0.06)$ alone.

Table 6.6: Optimal values for (H', K_{obs}) using the Whalley et al. model with $(A_o=1.5, b=0.10)$.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	H' (mm)	K_{obs}
1.13	1.99	40	0.075	0.13
1.13	4.01	27	0.1	0.4
1.66	2.97	55	0.18	0.27
1.67	4	11	0.08	0.07
1.66	3.98	34	0.08	0.13
1.67	4.03	45	0.32	0.4
1.67	4.03	53	0.16	0.27

6.4 Discussion

As the flow obstacles had no negative effect on CHF in this study, only liquid droplet impingement (K_{depos}) and mass transfer enhancement (A_o, b) were used to predict the measured CHF enhancement of the 30% rings in Freon-134a. Although CHF could be enhanced through a combination of liquid film stripping (K_{strip}) and mass transfer enhancement, preliminary tests in water have shown that mass transfer enhancement would first have to overcome the negative effects of liquid film depletion (see Figure 6.1). Recent studies using a similar tube and flow obstruction geometry have shown that flow obstacles can have a negative influence on CHF at low flow and low quality (Pioro et al., 1999). These have been attributed to a shift in the limiting critical quality line towards lower dryout qualities. From the discussion in the previous chapter on the effect of the initial entrainment fraction ($G_{\text{IE}}/G_{\text{I}}$)_o at OAF, one could conclude that under these flow conditions, the flow obstacles are increasing the initial entrainment fraction through the removal of liquid film.

The complexity of flow around the obstacle (i.e., flow area exposed to droplet impingement and amount of liquid impinging on the obstacle and reaching the liquid film), and present uncertainties in the various parameters of the annular flow model, make it necessary to determine a different set of flow enhancement parameters ($H', K_{\text{obs}}, A_o, b$) for each inlet condition. However once established, these parameters predict not only the absolute CHF to within 10–13% RMS, but they also reproduce the limiting obstacle number and spacing at which CHF moves upstream. Although equivalent values of mass transfer enhancement (A_o/b) have been shown to predict the same overall CHF, detailed profile analysis at the smaller values of b in the high quality region (Figure 6.17) and the special case of high inlet subcooling (Figure 6.20) indicates the mass transfer enhancement to be occurring over a short length ($z/d < 20$). Similar effects were observed in the heat transfer experiment for the same ring in liquid Freon-134a.

Although better predictions are obtained for reference CHF using Hewitt and Govan (1990), this model is shown to produce inaccurate CHF enhancement results when the obstacles are located near the OAF, and mass transfer enhancement is used (see Figures 6.18 and 6.19). The sharp rise in CHF as the obstacle passes through the OAF location is a consequence of the exponential decrease in mass transfer enhancement (behind the obstacle) combined with a nominal mass transfer coefficient (k) which increases linearly with quality, as predicted by Hewitt and Govan. Subsequently, the Whalley et al. model, which assumes a constant value of k versus quality, outperforms the Hewitt and Govan model in its ability to predict the non-dimensional CHF ratio, as a function of obstacle number and spacing.

Chapter 7 CONCLUSION

7.1 Experimental Results

A series of single-phase and two-phase flow experiments were conducted to study the effect of flow obstructions on heat transfer, pressure drop, and critical heat flux. Step increases of between 10% and 60% in single-phase heat transfer, with exponential decays over a distance of 5 to 10 tube diameters, were obtained using both 18% and 30% blockage-area rings in Freon-134a. The enhancement from the 30% ring was 1.6 times larger in amplitude and 1.4 times longer in decay length than the 18% ring. The relative enhancement from both rings decreased with increased Reynolds number. The decay rate of heat transfer enhancement in Freon-134a (downstream of the flow obstruction) was much higher than that reported by Yao et al. (1982) for gas flow spacer grids, which can be attributed to the higher Prandtl number of the liquid Freon in comparison to gas flow.

The single-phase pressure drop results produced head loss coefficients of 0.115 and 0.260 for the 18% ring and 30% ring, respectively. Only the results for the small-spaced DP cell ($L=0.504$ m) at mass fluxes of 4 and 6 $\text{Mg/m}^2\cdot\text{s}$ could be used, since all other pressure drops for the obstacle were within one RMS error of the reference tube pressure drop predictions. Uncertainties of 35% and 15% were estimated for these two head loss coefficients, respectively.

No attempts were made to obtain head loss coefficients in two-phase flow, since only a large-spaced DP cell ($L=2.58$ m) was available during the CHF experiments. Uncertainties in predicting the two-phase pressure drop of the reference tube with no obstacles for that length would dominate over any measured pressure drop for the obstacles.

A total of 755 flow obstruction CHF data points were obtained using 1 to 5 flow obstructions at different spacings in both Freon-134a and Freon-22. A 30% ring and 18% block-type spacer were tested. Relative CHF enhancement ratios were obtained using reference tube results at the same quality or inlet temperature, and showed an exponential rise in CHF with decreased obstacle spacing. When plotted for the same inlet temperature and any number of flow obstacles (1–5), all the data follow one curve with spacing, to show there is no cumulative effect from using more than one obstacle at the spacings tested. Adding more than one obstacle only enhances the CHF upstream of the next downstream obstacle, permitting a higher nominal value of CHF to be achieved before the limiting CHF is reached somewhere upstream. Due to large uncertainties in the predicted value of reference CHF, the errors in relative CHF enhancement ranged from 4% to 12% based on inlet temperature. All the ratios did collapse to within $\pm 5\%$ of their nominal value at the largest spacing. The peak values of relative enhancement ranged from 1.6 to 2.0 for the same quality, and from 1.2 to 1.45 for the same inlet temperature, depending on pressure, mass flux, inlet temperature, obstacle type, and fluid.

7.2 Model Results

Of the four reference tube dryout models tested, only Whalley et al. (1974), and Hewitt and Govan (1990) showed the correct parametric trend in CHF with pressure, in addition to other parameters. Both these models had the smallest difference (30–40% RMS) when compared with an extensive range of data for water (Groeneveld et al., 1995). When tested over a limited range of CHF data from the current experiment in Freon-134a (Doerffer et al., 1995), RMS errors ranged from 3% to 15% based on inlet temperature. A sensitivity analysis showed

that most of these differences were within the range of uncertainty for the correlations used to model the mass transfer coefficient (k) and liquid entrainment rate (E). Similar analysis conducted on the constant value of k used for the Whalley et al. model showed a larger value of k is required at high quality for the same initial entrainment fraction (G_{IE}/G_I). Consequently, values of (G_{IE}/G_I) at the onset of annular flow (OAF) lower than 0.6–0.7 were shown to cause a reversal in the trends for CHF with quality (i.e., increase CHF with quality).

Reference tube length profiles have shown a linear increase in k with quality for the Hewitt and Govan model, when used under uniform heat flux conditions, where the slope and intercept are mainly functions of pressure. Profiles for the entrained liquid Reynolds number (Re_{IE}) showed a similar linear increase with tube length (quality), which could be used to improve the model for the effect of mass flux. The linear increase in k with quality is mainly responsible for the improved performance by the Hewitt and Govan model. Both models show little influence from mass flux. The reference tube profiles for both models are very similar, except for the ratio of entrainment to deposition (E/D), which is strongly affected by the mass transfer coefficient.

Preliminary assessments of the proposed flow enhancement mechanisms (liquid film stripping, droplet impingement, and mass transfer enhancement) in water showed that liquid film stripping (K_{strip}) is not a viable mechanism for CHF enhancement. The high degree of entrained liquid (G_{IE}/G_I), and the fact that any increase in initial entrainment fraction causes the CHF to decrease, results in a decrease in CHF from any liquid film stripping. On the other hand, both droplet impingement (K_{depos}) and mass transfer enhancement (A_o, b) were shown to be viable mechanisms of CHF enhancement.

Preliminary assessments of the enhancement model using the 30% ring data in Freon-134a used a constant set of flow enhancement parameters (K_{depos}, A_o, b) for each inlet flow condition to produce RMS errors in CHF of 10% for the Hewitt and Govan model, and 13% for the Whalley et al. model. The RMS error in relative CHF enhancement ratio used to estimate

the optimal set of parameters for each inlet flow condition was much lower with values ranging from 1.5% to 4.9% for the Whalley et al. model, and from 2.8% to 5.5% for the Hewitt and Govan model. Best results were obtained using the Whalley et al. model with K_{depos} ranging from 0.02 to 0.09, and $A_o=0$. In the case of high inlet subcooling, where a significant amount of CHF enhancement was measured with all the flow obstructions in subcooled flow (i.e., before the OAF point), only prolonged enhancement of the mass transfer coefficient (A_o, b) beyond the OAF point could promote CHF using the annular flow model. Optimal results for the Hewitt and Govan model required the use of both impingement and mass transfer enhancement mechanisms (K_{depos}, A_o, b), and slightly larger errors in enhancement ratio were obtained in comparison to the Whalley et al. model.

Detailed profiles of relative CHF enhancement, as a function of obstacle number and spacing, showed the Hewitt and Govan model with flow enhancement to be very sensitive to the OAF location. As obstacles passed through the OAF point, the model predicted a rapid increase in CHF, followed by a more or less flat CHF profile until the effects of the next flow obstruction were felt. Since the Whalley et al., and Hewitt and Govan models are identical except in mass transfer (k), the sensitivity to OAF can be attributed to the linear increase in k with quality. Attempts to use a nominal k -value at the obstacle location for flow enhancement downstream failed since the nominal value also varies with obstruction location. These results and the high degree of coupling between the current k -relations and the arbitrary OAF boundary condition question the real significance of improvements made by Hewitt and Govan (1990) — is the linear increase in k real or empirical. It is however acknowledged that the Hewitt and Govan model does represent a significant improvement over the Whalley et al. model for smooth tube CHF.

The ability of the model to reproduce the limiting CHF was highlighted. When appropriate flow enhancement parameters were found to produce the correct magnitude in CHF enhancement (at the exit), the resulting upstream CHF and obstacle location tended to agree with those measured when comparing the minimum obstacle spacing for each obstacle number. A

more quantitative assessment of upstream CHF might help parameterize the flow obstruction model in the future. Analytical treatment of both droplet impingement and mass transfer enhancement have shown the equivalence between these two mechanisms, and the fact that constant values of (A_o/b) produce the same overall CHF enhancement. A revised analysis of the droplet impingement model introduced an empirical run-off factor (K_{off}) and obstacle height (H') to highlight the complexity in trying to parameterize the annular flow around a flow obstacle.

The results of this study have provided a reasonable estimate of the flow enhancement parameters necessary to augment CHF inside a tube. A 10–30% run-off of the entrained liquid impinging on the flow obstruction is enough to produce the 15-50% rise in peak CHF at the exit for 30% rings in Freon-134a, based on constant inlet temperature. In comparison, a much larger mass transfer enhancement ($A_o=1.5\text{--}1.8$) over a much longer length ($b=0.06\text{--}0.10$) is required to obtain the same value of CHF enhancement. Although values of A_o are much higher than those obtained from single phase heat transfer (i.e., same fluid and flow obstacle), they are of the same order of magnitude as those measured by Berger and Hau (1979) for mass transfer in an aqueous electrolytic solution. Measurement of droplet mass transfer enhancement in two-phase flow is nearly impossible since k is normally measured under equilibrium flow conditions ($E=D$), where adiabatic lengths to achieve equilibrium are much longer than the mass transfer enhancement length. Therefore, the estimation of flow enhancement parameters will always involve the fitting of complex models to such macro variables as magnitude and location of CHF. It would appear from both the experimental and model analysis results of this study that any disruption of the liquid film by the flow obstruction is more than compensated for by the increased deposition, derived from either the direct impingement and run-off entrained liquid or the mass transfer enhancement effect.

7.3 Technical Accomplishments

The technique used to vary the position of the flow obstacle during the experiment (using an external magnet) allowed a wide range of obstacle number, spacing, and type to be tested during both single phase heat transfer and two phase CHF experiments.

The development of an object oriented simulation and modelling framework permitted the rapid development and testing of a stand-alone analytical dryout model for annular flow, capable of predicting the maximum heat flux (CHF) in a single test section with any number of flow obstacles installed. The software is written in C++ and structured in such a way that other physical processes and control situations can be easily incorporated. The model results presented for this study were obtained in a timely manner using the standard procedures and simulation object classes provided by this framework.

7.4 Future Research

Analytical models of two-phase flow in reference and flow-obstructed tubes have increased our understanding of critical heat flux, and the role various flow enhancement mechanisms play in the enhancement of CHF. The sensitivity of the current dryout models to the proximity of the OAF and the initial entrainment fraction (G_{IE}/G_I) indicates a need to better understand and study the transition from subcooled flow to annular flow regimes. It is important that any subcooled flow model includes the effects of high heat flux (i.e., strong diabatic boundary conditions), where CHF can occur. The model developed by Weisman and Pei (1983) for DNB-type CHF could be compared with the annular flow dryout model to establish the boundary between these two mechanisms. It would also be beneficial to develop more detailed models of the flow transition from bubbly or churn flows to annular flow, and better define the OAF condition and initial entrained liquid fraction. Further refinement of the reference tube model is also necessary to take into account the effects of mass flux on dryout. The Reynolds

number of the entrained liquid is one parameter which might prove useful in deriving a relation between droplet mass transfer (k) and mass flow. Given the current difficulty of the Hewitt and Govan model to reproduce the effects of flow enhancement, a more detailed measurement of annular flow (e.g., liquid film thickness and entrained liquid fraction) might be warranted, especially in the vicinity of flow obstructions. These measurements could be carried out in air-water at moderate to low pressures.

The obstacle model will require integration with other subchannel effects, such as flow and enthalpy re-distribution, before the net effect on critical channel power (CCP) of a complex fuel-rod bundle can be predicted analytically. Previous measurements (Groeneveld, 1981) have shown that a reduced grid spacer pitch can increase CHF in a rod bundle, but to a lesser degree than that measured here for a single tube. One cannot say with certitude whether or not the parametric results from this study inside a tube will produce the true effect on bundle CHF when applied to a complex subchannel model. However, this author remains optimistic that the larger resultant CHF increases in the tube will be reduced by other factors affecting the prediction of CHF in rod bundles (e.g., wall curvature, inter-mixing between adjacent channels, etc.).

The object oriented modelling framework could be expanded to include the simulation of closed flow networks. The present study involved only a single one-dimensional flow channel, where flow and pressure were specified at the inlet and used to compute the resultant flow and pressure downstream. Because fluid properties were assumed constant over the test section length, it was not necessary to specify whether the pressure was at the inlet or outlet. In cases where the mass flow is the result of balancing pressure drops between multi-channels of a flow network (e.g., natural circulation boilers, nuclear fuel subchannels), or where the pressure is controlled at the exit and the fluid properties vary with length, a more sophisticated simulation execution object will be required to control the overall mass flow process. The flow must be distributed through the various flow channels in such a way that pressure drops are in balance. Although such methods have been developed for very specific applications (e.g., Westacott et al. 1991), their implementation within an object-oriented framework is still a formidable task,

and will result in a more general purpose simulation and modelling tool. One could easily envisage the development of a steady-state and transient model for the conventional boiler using the two-phase flow objects developed during this study.

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Appendix A: Single-Phase Experiments

A.1 Single-Phase Test Matrix

The following table describes the single-phase test data. Both date (time) and run ID are used to identify a particular data subset and inlet condition (mass flux, inlet fluid temperature, and test section power setting) since the runs are repeated.

Date	Run ID	G [Mg/m ² ·s]	T _{in} [°C]	Q [kW]	Description
Reference Tests					
94-01-28	0	4	2–25	0	zero-power heat balance runs
94-01-31	0	1–4	2–20	0	
94-02-01	0	1–4	10–60	0–6	heat balance runs with both zero-power + non-zero power
94-02-02	0	1–4	2–50	0	zero-power heat balance runs
	1010–1040	1–6	6	2	single-phase heat transfer and pressure drop runs (original test matrix)
	1050–1080	1–6	20	2	
94-02-03	1040	2–4	10,20	0	zero-power heat balance runs
18% Ring Tests					
94-02-04	0–10	1–6	6,20	0	zero-power heat balance runs
	101x–104x	1–6	6	2	single-phase heat transfer and pressure drop runs, following original test matrix
94-02-07	105x, 108x	1, 6	20	2	
30% Ring Tests					
94-02-21	11–18	1–6	2	0	zero-power heat balance runs
94-02-23	403x	4	7	13	single-phase heat transfer and pressure drop runs, using optimum power
	401x	1	4	4	
	402x	2	4	7	
	403x	4	7	12	
	404x	6	10	16	
	1–18	1–6	11–65	0	zero-power heat balance runs

It should be mentioned that some of the data recorded were later rejected because:

1. The fluid was found to be saturated at the test section outlet (i.e., in two-phase flow), making it unuseable for energy balance.
2. The heat balance results indicated a very strong negative imbalance (i.e., heat gain) up to 20%, even though the indicated fluid temperature at the test section outlet was 10–20°C below the saturated fluid temperature. It was determined that these were due to either installation or calibration errors in the two fluid thermocouples. A re-calibration and re-installation of the fluid thermocouples eliminated the problem.
3. The 5 kW reference tube and 18% ring data were removed since their heat loss (actual heat gain) were more than twice the calculated RMS error in heat loss, and since the 2 kW power data covered the same range.
4. Some of the 30% ring data (i.e., those at highest power setting for a given flow condition) were removed since data taken at slightly lower power settings showed better agreement with the reference tube data and correlations (i.e., when the obstacle was located far from the thermocouples: $z/d=30$).

A.2 Raw Data

A.2.1 Legend for Data

The following labels are defined for each of the DAS-measured variables:

Date:	month/day/year
Time:	24hr:min:sec
RUNID:	run identification number (user-defined)
TCW3A:	1 of 2 wall thermocouples mounted 1269 mm from the inlet to the heated test section (°C)
TCW3B:	2 of 2 wall thermocouples mounted 1269 mm from the inlet to the heated test section (°C)
TCPT2:	wall thermocouple mounted at the downstream pressure transducer (PT2), located 1050 mm from the inlet to the heated test section (°C)
TCW1A:	1 of 3 wall thermocouples mounted 927 mm from the inlet to the heated test section (°C)
TCW1B:	2 of 3 wall thermocouples mounted 927 mm from the inlet to the heated test section (°C)
TCW1C:	3 of 3 wall thermocouples mounted 927 mm from the inlet to the heated test section (°C)
TCW2A:	1 of 3 wall thermocouples mounted 672 mm from the inlet to the heated

	test section (°C)
TCW2B:	2 of 3 wall thermocouples mounted 672 mm from the inlet to the heated test section (°C)
TCW2C:	3 of 3 wall thermocouples mounted 672 mm from the inlet to the heated test section (°C)
TCPT3:	wall thermocouple mounted at the upstream pressure transducer (PT3), located 550 mm from the inlet to the heated test section (°C)
TE-AIR:	thermocouple measuring the ambient air temperature in the vicinity of the DAS (°C)
TE-WAT:	thermocouple measuring the water temperature at the inlet to the condenser (°C)
DP2_AVG:	differential pressure transducer measuring the static pressure drop across pressure taps PT2 and PT3, located before and after the flow obstruction, a length of 504 mm (kPa)
MF-AVG:	calculated mass flux through the flow meter ($\text{Mg/m}^2\cdot\text{s}$)
POUT-AVG:	pressure at the outlet to the test section (MPa)
5A-IN_AV:	test section inlet fluid temperature (°C)
Pwr_Avg:	calculated power to the test section (kW)
1A-OUTAV:	test section outlet fluid temperature (°C)
HB_AVG:	calculated heat balance over the test section (kW)
DP1_AVG:	differential pressure transducer measuring the static pressure drop across pressure taps before and after the test section, a length of 2580 mm (kPa)
A1-AVG:	wall thermocouple mounted at the outlet to the heated test section – 30% ring only (°C)

A.2.2 Tabulated DAS Output

The DAS-measured data are presented in two separate spreadsheet tables which follow:

Table A.2-1: Reference tube and 18% ring data sets (384 points)

Table A.2-2: 30% ring data sets (277 points)

The 30% ring data set includes the extra wall thermocouple reading, A1-AVG.

Table A.2-1: Reference tube and 18% ring data

DATE	TIME	RUN	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR
Reference Tube Tests													
28/01/94	11:12:54	0	11.749	11.752	12.526	11.447	11.477	11.611	11.269	11.1	10.91	11.434	22.143
28/01/94	12:13:43	0	15.136	15.162	15.504	14.966	15.029	15.232	14.791	14.732	14.587	14.51	22.419
28/01/94	14:26:45	0	3.575	3.691	4.234	3.512	3.78	3.598	3.332	3.046	2.601	3.221	22.339
28/01/94	14:28:31	0	3.478	3.6	4.118	3.396	3.643	3.568	3.283	3.01	2.57	3.116	22.358
28/01/94	14:31:12	0	8.635	8.681	8.512	8.645	8.822	8.984	8.544	8.281	8.183	7.805	22.403
28/01/94	14:32:01	0	9.099	9.158	8.938	9.106	9.289	9.466	9.018	8.813	8.65	8.203	22.495
28/01/94	14:36:57	0	21.353	21.402	20.056	21.487	21.471	21.942	21.25	21.225	21.35	19.791	22.707
28/01/94	14:37:53	0	21.632	21.691	20.409	21.712	21.723	22.18	21.54	21.521	21.61	20.125	22.805
28/01/94	14:39:36	0	22.063	22.093	21.028	22.104	22.075	22.475	21.858	21.879	21.893	20.677	22.771
28/01/94	14:49:49	0	23.41	23.405	23.038	23.405	23.329	23.728	23.112	23.132	23.134	22.64	22.854
28/01/94	14:52:32	0	23.053	23.043	22.831	23.034	22.965	23.317	22.704	22.704	22.703	22.227	22.811
28/01/94	14:54:31	0	23.001	22.998	22.818	22.992	22.931	23.262	22.638	22.67	22.678	22.209	22.93
28/01/94	15:00:35	0	22.965	22.937	22.846	22.971	22.901	23.185	22.573	22.6	22.596	22.185	22.906
28/01/94	15:01:38	0	22.925	22.9	22.824	22.91	22.858	23.146	22.567	22.596	22.581	22.173	22.731
28/01/94	15:13:52	0	22.944	22.928	22.886	22.946	22.879	23.192	22.576	22.593	22.611	22.207	23.004
28/01/94	15:32:42	0	23.313	23.293	23.786	23.274	23.259	23.509	22.893	22.898	22.872	23.235	23.086
28/01/94	15:32:42	0	23.313	23.293	23.786	23.274	23.259	23.509	22.893	22.898	22.872	23.235	23.086
31/01/94	14:40:18	0	4.397	4.372	4.825	4.259	4.326	4.442	3.989	4.023	3.353	3.835	19.525
31/01/94	14:41:03	0	4.246	4.26	4.719	4.135	4.201	4.321	3.897	3.913	3.238	3.707	19.607
31/01/94	14:41:49	0	4.179	4.175	4.67	4.055	4.126	4.256	3.837	3.853	3.174	3.637	19.583
31/01/94	14:42:47	0	4.215	4.23	4.478	4.101	4.172	4.308	3.894	3.898	3.238	3.522	19.623
31/01/94	14:44:55	0	3.793	3.822	4.003	3.685	3.78	3.866	3.451	3.487	2.789	3.094	19.592
31/01/94	14:45:33	0	3.729	3.752	3.923	3.603	3.704	3.738	3.348	3.384	2.682	3.018	19.564
31/01/94	14:46:03	0	3.681	3.707	3.838	3.561	3.667	3.722	3.311	3.348	2.652	2.998	19.583
31/01/94	14:46:49	0	3.563	3.567	3.711	3.445	3.534	3.62	3.226	3.269	2.546	2.875	19.552
31/01/94	14:51:37	0	7.381	7.377	7.012	7.314	7.395	7.591	7.109	7.174	6.666	6.407	19.503
31/01/94	14:52:35	0	7.599	7.618	7.291	7.578	7.617	7.804	7.334	7.372	6.872	6.659	19.491
31/01/94	14:53:37	0	7.666	7.687	7.371	7.633	7.668	7.865	7.397	7.438	6.948	6.761	19.656
31/01/94	14:54:56	0	7.767	7.779	7.498	7.709	7.744	7.942	7.507	7.533	7.033	6.893	19.696
31/01/94	14:55:31	0	7.806	7.815	7.556	7.743	7.78	7.966	7.519	7.557	7.054	6.922	19.763
31/01/94	14:59:39	0	13.592	13.597	12.7	13.646	13.672	14.026	13.463	13.497	13.258	12.39	19.699
31/01/94	15:00:17	0	13.813	13.798	12.913	13.838	13.888	14.197	13.666	13.725	13.489	12.674	19.604
31/01/94	15:00:59	0	13.964	13.986	13.147	14.008	14.049	14.373	13.846	13.88	13.637	12.866	19.564
31/01/94	15:01:51	0	14.211	14.196	13.381	14.2	14.241	14.553	14.016	14.042	13.807	13.133	19.693
31/01/94	15:03:01	0	14.405	14.396	13.674	14.361	14.404	14.675	14.122	14.188	13.95	13.357	19.767
31/01/94	15:08:58	0	14.535	14.544	14.207	14.543	14.532	14.751	14.247	14.3	14.05	13.797	19.892
31/01/94	15:10:12	0	14.52	14.547	14.243	14.528	14.492	14.764	14.256	14.312	14.068	13.828	19.751
31/01/94	15:16:46	0	20.582	20.576	19.895	20.627	20.585	21.003	20.402	20.486	20.442	19.862	19.858
31/01/94	15:17:36	0	20.597	20.601	19.999	20.636	20.603	21.012	20.441	20.498	20.442	19.943	19.901
31/01/94	15:20:11	0	20.724	20.727	20.276	20.725	20.688	21.067	20.521	20.538	20.482	20.131	19.904
31/01/94	15:22:27	0	20.345	20.339	20.041	20.317	20.288	20.613	20.095	20.085	20.005	19.797	19.92
31/01/94	15:23:58	0	20.214	20.148	19.926	20.135	20.111	20.491	19.961	19.985	19.893	19.758	19.907
31/01/94	15:27:13	0	20.187	20.181	20.014	20.174	20.145	20.552	19.992	20.03	19.927	19.822	19.978
31/01/94	15:28:01	0	20.163	20.151	19.986	20.135	20.099	20.497	19.939	19.997	19.89	19.77	19.972
31/01/94	15:29:46	0	20.208	20.178	20.053	20.177	20.138	20.552	20.007	20.036	19.93	19.801	19.938
31/01/94	15:30:23	0	20.184	20.157	20.029	20.151	20.117	20.552	19.995	20.027	19.939	19.813	19.95
31/01/94	15:34:13	0	15.455	15.441	15.83	15.352	15.327	15.604	15.159	15.151	14.869	15.295	20.048
31/01/94	15:35:57	0	15.258	15.238	15.544	15.191	15.154	15.474	14.974	14.99	14.715	15.029	20.048
31/01/94	15:38:40	0	15.148	15.122	15.343	15.118	15.069	15.394	14.909	14.948	14.697	14.874	20.042
31/01/94	15:42:08	0	20.154	20.196	19.694	20.296	20.245	20.692	20.067	20.128	20.124	19.513	20.021
31/01/94	15:44:12	0	20.573	20.576	20.108	20.649	20.615	21.061	20.447	20.532	20.515	19.976	20.042
31/01/94	15:47:09	0	20.539	20.537	20.218	20.521	20.476	20.903	20.314	20.374	20.266	19.976	20.082

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TE-WA	DP2_AVG	MF-AVG	POUT_A1	SA-IN_A	Pwr_Avg	IA-OUT	HB_AVG	DPI_AVG
Reference Tube Tests											
28/01/94	11:12:54	0	1.066	0.57387	0.76332	1.41196	8.568	0	11.115	0.13522	1.02679
28/01/94	12:13:43	0	1.084	0	1.47557	0.81633	12.805	0	14.778	0.20501	0
28/01/94	14:26:45	0	1.118	7.26591	4.12999	1.1459	1.868	0	1.884	0.00447	39.42594
28/01/94	14:28:31	0	1.103	7.26464	4.1337	1.14665	1.789	0	1.811	0.0061	39.52248
28/01/94	14:31:12	0	1.109	6.97567	4.07044	1.18016	8.234	0	8.126	-0.03039	38.15342
28/01/94	14:32:01	0	1.145	6.93523	4.06993	1.17966	8.577	0	8.46	-0.03283	38.09199
28/01/94	14:36:57	0	1.069	6.67678	4.06116	1.2429	22.118	0	21.892	-0.06691	37.19685
28/01/94	14:37:53	0	1.087	6.67169	4.05981	1.24315	22.197	0	22.016	-0.05362	37.00816
28/01/94	14:39:36	0	1.078	6.68085	4.06251	1.24592	22.513	0	22.265	-0.07351	37.03011
28/01/94	14:49:49	0	1.081	6.7246	4.07246	1.24895	23.482	0	23.347	-0.04028	37.1047
28/01/94	14:52:32	0	1.081	6.72791	4.0642	1.24416	23.005	0	22.885	-0.0357	37.11348
28/01/94	14:54:31	0	1.1	6.73376	4.06639	1.24542	22.975	0	22.845	-0.03857	37.20124
28/01/94	15:00:35	0	1.084	6.76912	4.07061	1.24341	22.966	0	22.815	-0.04477	37.33287
28/01/94	15:01:38	0	1.075	6.75869	4.07213	1.2429	22.933	0	22.77	-0.04851	37.25828
28/01/94	15:13:52	0	1.054	6.78591	4.07972	1.24164	22.948	0	22.818	-0.03861	37.63126
28/01/94	15:32:42	0	1.084	6.86222	4.07364	1.5649	23.129	0	22.997	-0.03914	37.64881
28/01/94	15:32:42	0	1.084	6.86222	4.07364	1.5649	23.129	0	22.997	-0.03914	37.64881
31/01/94	14:40:18	0	0.861	1.98178	0.77243	0.53062	2.604	0	2.974	0.01924	10.54869
31/01/94	14:41:03	0	0.87	2.17536	1.08551	0.5296	2.492	0	2.677	0.0135	12.27755
31/01/94	14:41:49	0	0.87	2.18451	1.08534	0.53212	2.438	0	2.701	0.01919	12.28194
31/01/94	14:42:47	0	0.867	0.44586	1.08197	1.34796	2.68	0	2.738	0.00421	4.13786
31/01/94	14:44:55	0	0.864	1.85332	2.0332	1.56541	2.08	0	2.145	0.00894	11.61058
31/01/94	14:45:33	0	0.879	1.86349	2.03691	1.5707	1.998	0	2.106	0.01479	11.57547
31/01/94	14:46:03	0	0.894	1.87672	2.03742	1.57195	1.934	0	2.042	0.01475	11.6764
31/01/94	14:46:49	0	0.888	1.88537	2.03556	1.57372	1.85	0	2.027	0.02424	11.68079
31/01/94	14:51:37	0	0.9	1.88664	2.04146	1.59287	6.412	0	6.41	-0.00028	11.36485
31/01/94	14:52:35	0	0.9	1.88868	2.04349	1.59463	6.607	0	6.641	0.00473	11.36046
31/01/94	14:53:37	0	0.885	1.89987	2.04231	1.59539	6.653	0	6.632	-0.00288	11.38679
31/01/94	14:54:56	0	0.888	1.91716	2.04264	1.59539	6.72	0	6.716	-0.00047	11.37801
31/01/94	14:55:31	0	0.876	1.90343	2.04214	1.59413	6.762	0	6.735	-0.00375	11.38679
31/01/94	14:59:39	0	0.864	1.86222	2.04804	1.62739	13.737	0	13.475	-0.03781	10.85146
31/01/94	15:00:17	0	0.907	1.86604	2.04383	1.62739	13.857	0	13.721	-0.01962	10.83829
31/01/94	15:00:59	0	0.873	1.86146	2.04821	1.62941	13.887	0	13.809	-0.01126	10.81635
31/01/94	15:01:51	0	0.867	1.87036	2.0472	1.62941	14.041	0	13.925	-0.01679	10.84707
31/01/94	15:03:01	0	0.848	1.8724	2.04821	1.62915	14.154	0	14.049	-0.01512	10.82513
31/01/94	15:08:58	0	0.888	1.88562	2.04551	1.6289	14.093	0	14.012	-0.01171	10.8339
31/01/94	15:10:12	0	0.891	1.89529	2.04956	1.62714	14.084	0	14.009	-0.01086	10.83829
31/01/94	15:16:46	0	0.873	1.86171	2.04973	1.66014	20.906	0	20.755	-0.02243	10.29857
31/01/94	15:17:36	0	0.861	1.85459	2.04703	1.65938	20.887	0	20.677	-0.03141	10.28541
31/01/94	15:20:11	0	0.888	1.87163	2.04686	1.66014	20.857	0	20.67	-0.02795	10.34684
31/01/94	15:22:27	0	0.91	1.87316	2.05159	1.65687	20.257	0	20.148	-0.01633	10.37317
31/01/94	15:23:58	0	0.885	1.87316	2.05074	1.65585	20.121	0	20.027	-0.01418	10.38194
31/01/94	15:27:13	0	0.897	1.89478	2.04855	1.65636	20.197	0	20.096	-0.01502	10.39511
31/01/94	15:28:01	0	0.891	1.88639	2.04922	1.65511	20.182	0	20.032	-0.02228	10.33368
31/01/94	15:29:46	0	0.903	1.89147	2.0499	1.6556	20.245	0	20.112	-0.01986	10.38194
31/01/94	15:30:23	0	0.913	1.90623	2.05158	1.65511	20.188	0	20.072	-0.01726	10.3995
31/01/94	15:34:13	0	0.928	6.59462	4.03063	1.58455	14.675	0	14.686	0.00331	36.83264
31/01/94	15:35:57	0	0.928	6.65465	4.03164	1.58203	14.693	0	14.605	-0.02495	37.02133
31/01/94	15:38:40	0	0.925	6.6371	4.03198	1.58304	14.657	0	14.623	-0.00961	37.07837
31/01/94	15:42:08	0	0.903	6.34915	4.02962	1.61781	20.875	0	20.628	-0.0726	36.41579
31/01/94	15:44:12	0	0.9	6.36848	4.03383	1.61907	20.948	0	20.862	-0.02529	36.38069
31/01/94	15:47:09	0	0.879	6.36848	4.03147	1.61504	20.63	0	20.479	-0.0444	36.49916

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR
31/01/94	15:48:10	0	20.533	20.519	20.227	20.503	20.485	20.841	20.28	20.292	20.239	19.989	20.122
31/01/94	15:49:48	0	20.5	20.504	20.276	20.484	20.433	20.841	20.271	20.295	20.239	20.034	20.097
31/01/94	15:50:28	0	20.506	20.482	20.285	20.46	20.412	20.863	20.29	20.318	20.248	20.062	20.091
31/01/94	15:52:33	0	20.488	20.497	20.33	20.478	20.451	20.857	20.296	20.312	20.221	20.094	20.183
31/01/94	15:55:23	0	20.561	20.543	20.412	20.576	20.552	20.952	20.368	20.386	20.318	20.177	20.11
31/01/94	15:56:12	0	20.615	20.576	20.44	20.618	20.591	20.97	20.39	20.444	20.366	20.189	20.042
31/01/94	16:00:28	0	20.364	20.355	20.282	20.344	20.308	20.713	20.143	20.176	20.1	20.047	19.99
31/01/94	16:01:17	0	20.361	20.361	20.3	20.329	20.302	20.701	20.126	20.157	20.063	20.001	19.895
31/01/94	16:01:29	0	20.385	20.388	20.333	20.363	20.335	20.707	20.123	20.155	20.075	20.019	19.874
31/01/94	16:01:48	0	20.385	20.391	20.333	20.378	20.354	20.698	20.126	20.152	20.066	20.001	19.923
31/01/94	17:50:04	0	14.499	14.487	14.663	14.31	14.265	14.592	14.006	14.039	13.749	13.854	20.306
31/01/94	17:50:04	0	14.499	14.487	14.663	14.31	14.265	14.592	14.006	14.039	13.749	13.854	20.306
01/02/94	8:15:16	0	14.026	13.995	14.189	13.872	13.827	14.154	13.623	13.655	13.367	13.473	18.964
01/02/94	8:32:44	0	19.787	19.798	19.222	19.801	19.795	20.22	19.606	19.656	19.568	19.1	19.283
01/02/94	8:33:58	0	19.96	19.935	19.469	19.971	19.948	20.308	19.727	19.781	19.693	19.294	19.197
01/02/94	8:35:07	0	19.89	19.886	19.445	19.895	19.838	20.341	19.739	19.781	19.705	19.355	19.203
01/02/94	8:37:44	0	19.86	19.865	19.545	19.853	19.808	20.238	19.657	19.696	19.586	19.366	19.157
01/02/94	8:50:22	0	19.972	19.944	19.819	19.935	19.905	20.326	19.718	19.777	19.66	19.561	19.215
01/02/94	8:51:11	0	19.899	19.883	19.77	19.907	19.862	20.269	19.663	19.725	19.614	19.531	18.952
01/02/94	9:01:52	0	33.133	33.037	32.079	33.042	33.082	33.44	32.779	32.85	33.208	32.275	19.074
01/02/94	9:02:04	0	33.145	33.043	32.097	33.057	33.098	33.452	32.788	32.859	33.232	32.297	19.12
01/02/94	9:13:41	0	33.442	33.289	32.852	33.282	33.352	33.772	33.023	33.075	33.433	32.9	19.2
01/02/94	9:14:06	0	33.43	33.289	32.855	33.273	33.349	33.732	33.011	33.066	33.411	32.9	18.989
01/02/94	9:15:23	0	33.354	33.222	32.825	33.181	33.276	33.613	32.874	32.965	33.293	32.824	19.163
01/02/94	9:23:13	0	43.453	43.312	42.13	43.304	43.522	43.956	43.081	43.261	43.875	42.568	19.209
01/02/94	9:24:45	0	43.619	43.455	42.398	43.447	43.682	44.12	43.22	43.43	44.039	42.787	19.329
01/02/94	9:25:52	0	43.748	43.549	42.56	43.547	43.795	44.245	43.314	43.516	44.154	42.969	19.301
01/02/94	9:27:14	0	43.656	43.489	42.579	43.471	43.704	44.196	43.251	43.458	44.09	42.99	19.237
01/02/94	9:34:56	0	54.756	54.825	53.023	55.111	55.403	56.176	54.931	55.189	56.35	54.039	19.267
01/02/94	9:37:28	0	56.896	56.907	55.133	57.056	57.437	58.124	56.85	57.206	58.314	56.022	19.258
01/02/94	9:43:28	0	50.252	49.973	49.634	49.923	50.336	50.717	49.679	49.994	50.753	49.952	19.301
01/02/94	9:51:11	0	49.126	48.888	48.611	48.935	49.275	49.789	48.74	49.04	49.858	48.991	19.307
01/02/94	9:54:19	0	49.138	48.876	48.589	48.972	49.284	49.78	48.737	49.021	49.834	48.954	19.356
01/02/94	9:57:31	0	49.008	48.806	48.477	48.847	49.174	49.665	48.631	48.885	49.697	48.845	19.356
01/02/94	10:01:31	0	49.338	49.161	48.802	49.191	49.563	50.055	48.998	49.246	50.083	49.148	19.298
01/02/94	10:07:05	0	49.32	49.14	48.738	49.163	49.508	50.013	48.956	49.212	50.043	49.167	19.371
01/02/94	10:20:37	0	49.757	49.541	48.62	49.638	49.939	50.564	49.461	49.693	50.592	48.972	19.466
01/02/94	10:22:38	0	50.379	50.134	49.262	50.209	50.55	51.137	50.071	50.335	51.22	49.655	19.414
01/02/94	10:23:34	0	50.699	50.474	49.582	50.522	50.899	51.487	50.364	50.651	51.578	50.025	19.525
01/02/94	10:25:25	0	50.959	50.653	49.871	50.734	51.087	51.622	50.525	50.831	51.693	50.222	19.509
01/02/94	10:51:36	0	11.078	11.121	12.203	11.039	11.011	11.258	10.734	10.729	10.379	11.018	20.1
01/02/94	11:58:21	0	19.996	19.92	20.312	19.74	19.686	19.94	19.468	19.4	19.238	19.576	19.782
01/02/94	13:05:18	0	20.67	20.662	20.581	20.658	20.618	21.039	20.484	20.492	20.409	20.402	20.25
01/02/94	13:50:51	0	20.715	20.718	20.727	20.682	20.639	20.985	20.536	20.477	20.346	20.226	20.211
01/02/94	14:40:17	0	40.961	40.994	38.123	41.514	41.548	42.228	41.158	41.174	42.109	38.846	20.544
01/02/94	15:07:47	0	44.434	44.206	43.699	44.206	44.426	44.803	43.91	43.982	44.643	43.642	20.936
01/02/94	15:07:47	0	44.434	44.206	43.699	44.206	44.426	44.803	43.91	43.982	44.643	43.642	20.936
02/02/94	10:20:09	0	5.083	5.043	6.551	4.792	4.776	4.497	4.828	4.787	4.083	5.391	20.912
02/02/94	10:31:49	0	3.554	3.576	4.206	3.375	3.446	3.315	3.478	3.481	2.767	3.267	20.863
02/02/94	10:45:44	0	7.554	7.569	7.535	7.447	7.52	7.39	7.493	7.499	6.984	6.89	20.805
02/02/94	10:46:28	0	7.56	7.584	7.562	7.45	7.513	7.409	7.493	7.496	6.981	6.893	20.796
02/02/94	10:46:37	0	7.614	7.639	7.626	7.514	7.562	7.406	7.498	7.506	6.984	6.893	20.851
02/02/94	10:51:39	0	20.278	20.345	18.677	20.457	20.494	20.689	20.53	20.578	20.551	18.927	20.985

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TE-WA	DP2_AVG	MF-AVG	POUT_A1	5A-IN_A	Pwr_Avg	1A-OUT	HB_AVG	DPI_AVG
31/01/94	15:48:10	0	0.919	6.41732	4.03114	1.61504	20.585	0	20.467	-0.03461	36.72295
31/01/94	15:49:48	0	0.9	6.37204	4.03333	1.61504	20.558	0	20.413	-0.04272	36.48161
31/01/94	15:50:28	0	0.956	6.42037	4.03434	1.61353	20.555	0	20.4	-0.04565	36.72734
31/01/94	15:52:33	0	0.891	6.4163	4.03788	1.61579	20.501	0	20.379	-0.03586	36.7756
31/01/94	15:55:23	0	0.897	13.72476	6.04274	1.54474	20.715	0	20.54	-0.07702	76.77198
31/01/94	15:56:12	0	0.934	13.77029	6.04527	1.54273	20.724	0	20.625	-0.04339	76.74564
31/01/94	16:00:28	0	0.913	13.75783	6.05016	1.53995	20.338	0	20.245	-0.04112	76.65789
31/01/94	16:01:17	0	0.943	13.69372	6.05067	1.53946	20.329	0	20.245	-0.03713	76.5789
31/01/94	16:01:29	0	0.937	13.72705	6.04999	1.5392	20.377	0	20.282	-0.04218	76.73249
31/01/94	16:01:48	0	0.943	13.68787	6.0505	1.53819	20.395	0	20.279	-0.05147	76.75882
31/01/94	17:50:04	0	0.845	0	0	0.62736	12.424	0	14.012	0	0
31/01/94	17:50:04	0	0.845	0	0	0.62736	12.424	0	14.012	0	0
01/02/94	8:15:16	0	0.845	0	0	0.62736	12.171	0	13.758	0	0
01/02/94	8:32:44	0	0.867	1.77039	2.07976	1.43212	19.973	0	19.835	-0.02058	10.57063
01/02/94	8:33:58	0	0.842	1.76963	2.07537	1.43237	20.154	0	19.987	-0.02534	10.49603
01/02/94	8:35:07	0	0.854	1.76937	2.0779	1.43187	20.042	0	19.896	-0.02181	10.48725
01/02/94	8:37:44	0	0.836	1.79074	2.07756	1.43162	19.952	0	19.771	-0.02689	10.63206
01/02/94	8:50:22	0	0.873	1.8088	2.0811	1.43338	20.018	0	19.869	-0.02234	10.70666
01/02/94	8:51:11	0	0.913	1.80422	2.0833	1.43212	19.943	0	19.796	-0.0219	10.68033
01/02/94	9:01:52	0	0.87	1.57325	2.07233	1.5009	34.409	0	34.06	-0.05412	9.39465
01/02/94	9:02:04	0	0.867	1.5936	2.07503	1.50141	34.394	0	34.08	-0.04863	9.40343
01/02/94	9:13:41	0	0.833	1.58113	2.07554	1.50191	34.644	0	34.336	-0.04784	9.3771
01/02/94	9:14:06	0	0.864	1.5585	2.07284	1.50141	34.644	0	34.318	-0.05054	9.27179
01/02/94	9:15:23	0	0.854	1.57096	2.0671	1.49965	34.476	0	34.151	-0.05011	9.28056
01/02/94	9:23:13	0	0.888	1.31073	2.05766	1.49863	45.823	0	45.376	-0.07053	8.25816
01/02/94	9:24:45	0	0.848	1.31557	2.05951	1.49889	46.01	0	45.547	-0.07312	8.26694
01/02/94	9:25:52	0	0.83	1.30616	2.05901	1.50015	46.091	0	45.638	-0.07167	8.18357
01/02/94	9:27:14	0	0.861	1.34075	2.06053	1.49788	45.961	0	45.544	-0.066	8.33276
01/02/94	9:34:56	0	0.821	0.97699	2.03151	1.78184	59.96	0	59.07	-0.14348	6.59512
01/02/94	9:37:28	0	0.842	1.00269	2.11855	1.76722	61.466	0	60.776	-0.11891	6.16949
01/02/94	9:43:28	0	0.867	1.22908	2.04281	1.61227	52.792	0	52.363	-0.06813	7.36741
01/02/94	9:51:11	0	0.888	1.31201	2.04231	1.73195	52.001	0	51.552	-0.07148	7.56925
01/02/94	9:54:19	0	0.836	1.2998	2.04416	1.73321	52.016	0	51.534	-0.07678	7.42006
01/02/94	9:57:31	0	0.851	1.30997	2.04737	1.73346	51.905	0	51.425	-0.07655	7.46394
01/02/94	10:01:31	0	0.861	1.31938	2.05007	1.73876	52.336	0	51.792	-0.08675	7.50782
01/02/94	10:07:05	0	0.839	1.30259	2.04956	1.73724	52.254	0	51.773	-0.07677	7.43762
01/02/94	10:20:37	0	1.145	5.90831	4.00364	1.80199	52.924	0	52.512	-0.12841	34.52896
01/02/94	10:22:38	0	1.155	5.92561	4.00263	1.80049	53.47	0	53.038	-0.13489	34.62111
01/02/94	10:23:34	0	1.145	5.92383	4.00533	1.80199	53.881	0	53.56	-0.10016	34.56407
01/02/94	10:25:25	0	1.106	5.93782	4.00651	1.79796	53.923	0	53.578	-0.10777	34.59917
01/02/94	10:51:36	0	0.735	2.45313	2.21488	1.02092	10.138	0.00318	10.177	0.00602	12.88309
01/02/94	11:58:21	0	0.894	2.53504	2.39621	1.45101	19.116	0	19	-0.02004	13.9011
01/02/94	13:05:18	0	0.885	2.416	2.37125	1.54777	20.721	0	20.561	-0.02766	13.6466
01/02/94	13:50:51	0	0.894	2.41218	2.3699	1.55054	20.645	0	20.54	-0.01823	13.66854
01/02/94	14:40:17	0	0.735	2.13669	2.36028	1.39079	45.261	0	44.502	-0.13665	11.21566
01/02/94	15:07:47	0	0.845	2.00594	2.35505	1.38122	46.556	0	46.13	-0.07697	11.37363
01/02/94	15:07:47	0	0.845	2.00594	2.35505	1.38122	46.556	0	46.13	-0.07697	11.37363
02/02/94	10:20:09	0	1.103	2.23285	2.12749	0.6833	2.668	0	2.914	0.03513	12.58471
02/02/94	10:31:49	0	1.179	2.24862	2.13424	0.68179	1.835	0	1.918	0.01191	12.70757
02/02/94	10:45:44	0	1.194	2.15399	2.12328	1.2953	6.354	0	6.325	-0.00426	12.16785
02/02/94	10:46:28	0	1.161	2.15526	2.12142	1.2953	6.342	0	6.294	-0.007	12.25122
02/02/94	10:46:37	0	1.176	2.15933	2.12446	1.29581	6.399	0	6.364	-0.00521	12.20734
02/02/94	10:51:39	0	1.158	1.85662	2.11704	1.53568	21.21	0	20.907	-0.04668	10.9436

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR
02/02/94	10:52:26	0	20.573	20.619	19.085	20.712	20.709	20.863	20.779	20.784	20.746	19.303	21.022
02/02/94	10:54:04	0	20.98	20.989	19.661	21.041	21.006	21.18	21.108	21.161	21.082	19.895	21.065
02/02/94	10:54:40	0	21.053	21.074	19.84	21.108	21.076	21.244	21.208	21.225	21.134	20.041	21.099
02/02/94	11:02:19	0	22.676	22.63	22.097	22.536	22.53	22.53	22.567	22.558	22.49	22.479	21.093
02/02/94	11:03:22	0	22.418	22.39	21.957	22.323	22.281	22.359	22.406	22.384	22.327	22.303	21.142
02/02/94	11:04:40	0	22.261	22.223	21.85	22.165	22.139	22.198	22.258	22.226	22.165	22.188	21.114
02/02/94	11:05:13	0	22.184	22.156	21.79	22.101	22.054	22.152	22.193	22.183	22.132	22.143	21.111
02/02/94	11:12:15	0	9.163	9.131	9.63	9.024	9.013	8.905	9.04	8.993	8.54	9.098	20.927
02/02/94	11:14:02	0	9.269	9.243	9.569	9.137	9.101	9.103	9.202	9.194	8.747	9.076	21.08
02/02/94	11:15:05	0	9.342	9.31	9.542	9.213	9.202	9.145	9.214	9.22	8.762	9.047	21.096
02/02/94	11:22:20	0	21.748	21.776	20.882	21.782	21.76	21.982	21.898	21.903	21.856	21.041	21.059
02/02/94	11:23:31	0	21.59	21.615	20.888	21.597	21.568	21.676	21.637	21.645	21.592	20.954	21.139
02/02/94	11:24:58	0	21.34	21.372	20.83	21.323	21.292	21.417	21.421	21.401	21.328	20.887	21.034
02/02/94	11:25:27	0	21.274	21.32	20.833	21.28	21.255	21.368	21.381	21.356	21.286	20.874	21.169
02/02/94	11:35:02	0	32.368	31.878	31.26	32.276	32.272	32.318	32.269	32.244	32.52	31.659	21.332
02/02/94	11:36:54	0	32.502	31.958	31.567	32.407	32.408	32.425	32.415	32.226	32.607	31.829	21.402
02/02/94	11:39:53	0	32.699	32.444	31.947	32.585	32.627	32.65	32.591	32.582	32.923	32.269	21.313
02/02/94	11:40:41	0	32.726	32.474	32.008	32.606	32.654	32.705	32.634	32.622	32.981	32.345	21.374
02/02/94	11:46:54	0	31.737	31.627	31.223	31.456	31.549	31.485	31.436	31.475	31.218	31.331	21.09
02/02/94	11:47:59	0	31.536	31.36	31.095	31.264	31.388	31.3	31.22	31.256	30.773	31.192	21.273
02/02/94	11:49:10	0	31.094	30.888	30.745	30.735	30.933	30.605	30.742	30.779	30.678	30.791	21.286
02/02/94	12:01:09	0	48.685	48.478	46.811	48.577	48.925	49.071	48.612	48.793	49.554	47.574	21.457
02/02/94	12:38:23	0	49.545	49.313	48.565	49.382	49.711	49.899	49.418	49.611	50.398	49.118	21.714
02/02/94	12:38:57	0	49.578	49.346	48.602	49.422	49.754	49.924	49.418	49.636	50.416	49.124	21.451
02/02/94	12:39:33	0	49.545	49.31	48.571	49.376	49.714	49.896	49.406	49.605	50.404	49.124	21.479
02/02/94	12:52:57	0	48.225	47.988	47.051	48.118	48.445	48.665	48.198	48.364	49.16	47.646	21.717
02/02/94	12:54:27	0	48.67	48.383	47.52	48.507	48.813	49.037	48.597	48.784	49.582	48.123	21.966
02/02/94	12:56:15	0	49.159	48.864	48.035	48.981	49.278	49.524	49.108	49.267	50.08	48.639	22.214
02/02/94	12:58:45	0	49.32	49.028	48.288	49.093	49.389	49.57	49.132	49.341	50.118	48.861	22.33
02/02/94	13:01:06	0	49.394	49.094	48.468	49.136	49.478	49.686	49.223	49.484	50.259	49.027	22.027
02/02/94	13:06:20	0	49.518	49.219	48.723	49.288	49.636	49.789	49.33	49.559	50.361	49.237	22.067
02/02/94	13:27:08	1010	42.214	42.018	37.441	38.393	38.309	38.377	35.444	35.657	35.615	32.639	22.027
02/02/94	13:28:06	1010	42.661	42.465	37.938	38.776	38.707	38.777	35.866	36.009	35.954	33	22.116
02/02/94	13:28:55	1010	42.952	42.744	38.236	39.013	38.977	38.975	36.055	36.232	36.242	33.267	22.143
02/02/94	13:29:35	1010	43.003	42.844	38.4	39.092	39.005	39.085	36.149	36.298	36.254	33.392	22.036
02/02/94	13:30:25	1010	43.077	42.88	38.534	39.141	39.038	39.069	36.161	36.292	36.294	33.386	22.128
02/02/94	13:35:05	1010	43.183	42.914	38.908	39.111	39.075	39.06	36.174	36.323	36.221	33.667	22.116
02/02/94	13:36:46	1010	43.177	42.905	38.936	39.114	39.023	39.027	36.149	36.272	36.233	33.782	22.162
02/02/94	13:37:13	1010	43.189	42.914	38.945	39.068	39.044	39.039	36.14	36.292	36.221	33.776	22.171
02/02/94	13:37:40	1010	43.165	42.92	38.948	39.035	38.977	39.036	36.113	36.247	36.197	33.695	22.097
02/02/94	13:38:39	1010	43.156	42.902	38.969	39.038	38.959	39.02	36.101	36.223	36.224	33.728	22.152
02/02/94	13:45:00	1020	28.206	28.288	26.707	25.982	25.9	25.966	24.453	24.559	24.167	23.156	22.253
02/02/94	13:46:39	1020	28.122	28.023	26.146	25.748	25.655	25.716	24.216	24.288	23.916	22.622	22.198
02/02/94	13:47:21	1020	28.113	27.975	25.955	25.739	25.621	25.688	24.14	24.258	23.886	22.567	22.174
02/02/94	13:48:12	1020	28.152	27.981	25.991	25.745	25.642	25.733	24.185	24.272	23.889	22.488	22.125
02/02/94	13:50:29	1020	27.636	27.315	25.374	25.103	24.962	25.084	23.598	23.744	23.328	21.827	22.168
02/02/94	13:54:38	1030	19.149	19.048	18.863	17.798	17.665	17.671	16.932	16.994	16.534	16.257	22.128
02/02/94	13:55:51	1030	19.074	18.99	18.72	17.819	17.646	17.65	16.91	16.991	16.537	16.196	22.207
02/02/94	13:56:44	1030	19.003	18.969	18.626	17.765	17.592	17.65	16.913	16.991	16.54	16.166	22.085
02/02/94	13:58:31	1030	18.927	18.924	18.489	17.755	17.567	17.616	16.859	16.952	16.486	16.06	22.186
02/02/94	14:00:06	1030	18.927	18.887	18.355	17.734	17.549	17.656	16.91	16.982	16.517	16.036	22.162
02/02/94	14:03:41	1040	15.855	15.818	15.617	14.981	14.82	14.797	14.389	14.43	13.89	13.742	22.113
02/02/94	14:06:08	1040	15.71	15.718	15.34	14.911	14.738	14.754	14.31	14.349	13.844	13.521	22.094

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TE-WA	DP2_AVG	MF-AVG	POUT_A1	5A-IN_A	Pwr_Avg	1A-OUT	HB_AVG	DPI_AVG
02/02/94	10:52:26	0	1.109	1.89681	2.11569	1.5392	21.303	0	21.05	-0.03899	11.04014
02/02/94	10:54:04	0	1.145	1.90165	2.11855	1.53844	21.427	0	21.251	-0.02713	11.01381
02/02/94	10:54:40	0	1.142	1.84976	2.11973	1.53844	21.454	0	21.217	-0.03656	10.77247
02/02/94	11:02:19	0	1.103	0.19047	1.02056	1.55306	22.48	0	22.368	-0.00832	2.22031
02/02/94	11:03:22	0	1.201	0.18233	1.01348	1.55306	22.314	0	22.184	-0.00966	2.17644
02/02/94	11:04:40	0	1.21	0.21056	1.01618	1.5513	22.215	0	22.098	-0.00865	2.39583
02/02/94	11:05:13	0	1.198	0.20471	1.01669	1.5513	22.191	0	22.101	-0.00665	2.32563
02/02/94	11:12:15	0	1.164	15.19835	6.02941	1.50267	8.114	0	8.065	-0.02012	76.99577
02/02/94	11:14:02	0	1.139	15.19886	6.04088	1.50342	8.261	0	8.238	-0.00968	77.10985
02/02/94	11:15:05	0	1.173	15.18818	6.04307	1.50393	8.318	0	8.317	-0.00043	77.15372
02/02/94	11:22:20	0	1.234	13.69042	6.06247	1.60522	22.063	0	21.922	-0.0623	77.0177
02/02/94	11:23:31	0	1.17	13.67744	6.05859	1.60547	21.732	0	21.63	-0.04486	77.04403
02/02/94	11:24:58	0	1.216	13.74714	6.0591	1.6027	21.369	0	21.284	-0.03784	77.21955
02/02/94	11:25:27	0	1.204	13.79547	6.06517	1.6027	21.288	0	21.102	-0.08228	77.10986
02/02/94	11:35:02	0	1.136	13.77131	6.06247	1.65812	33.365	0	33.179	-0.08439	77.25027
02/02/94	11:36:54	0	1.152	13.78123	6.06365	1.65661	33.468	0	33.279	-0.08536	77.23272
02/02/94	11:39:53	0	1.225	13.78962	6.07074	1.65736	33.646	0	33.425	-0.1003	77.43456
02/02/94	11:40:41	0	1.231	13.85983	6.0731	1.65585	33.664	0	33.434	-0.10448	77.43456
02/02/94	11:46:54	0	1.112	0.31104	1.21844	1.74203	32.37	0	32.034	-0.0306	2.68983
02/02/94	11:47:59	0	1.103	0.31129	1.21928	1.73876	32.065	0	31.876	-0.01721	2.71177
02/02/94	11:49:10	0	1.096	0.33673	1.22181	1.73422	31.607	0	31.359	-0.02258	2.85218
02/02/94	12:01:09	0	1.124	0	1.21978	1.69668	51.842	0	51.133	-0.06732	0.75473
02/02/94	12:38:23	0	1.152	0	1.21051	1.69768	52.542	0	51.838	-0.06632	0.57044
02/02/94	12:38:57	0	1.185	0	1.20933	1.69617	52.566	0	51.862	-0.06628	0.59676
02/02/94	12:39:33	0	1.167	0	1.21118	1.69895	52.484	0	51.801	-0.06442	0.62748
02/02/94	12:52:57	0	1.825	13.18828	5.9869	1.58707	50.882	0	50.522	-0.1677	76.14011
02/02/94	12:54:27	0	1.859	13.13333	5.98572	1.59563	51.301	0	51.032	-0.12538	75.99531
02/02/94	12:56:15	0	1.865	13.17098	5.99146	1.60295	51.769	0	51.5	-0.12559	76.26298
02/02/94	12:58:45	0	1.877	13.20278	5.99179	1.60144	51.73	0	51.446	-0.1328	76.25858
02/02/94	13:01:06	0	1.957	13.12494	5.99787	1.60219	51.815	0	51.531	-0.13244	76.41216
02/02/94	13:06:20	0	1.933	13.21193	6.01743	1.6027	51.947	0	51.652	-0.13821	76.97382
02/02/94	13:27:08	1010	1.158	0.34589	1.01483	1.76244	6.916	2.03005	33.853	1.97381	2.71616
02/02/94	13:28:06	1010	1.176	0.33164	1.0155	1.7647	7.217	2.03841	34.223	1.98212	2.6284
02/02/94	13:28:55	1010	1.213	0.33521	1.01466	1.7647	7.322	2.03662	34.355	1.98303	2.65472
02/02/94	13:29:35	1010	1.133	0.33444	1.01584	1.7647	7.304	2.04978	34.393	1.98954	2.64156
02/02/94	13:30:25	1010	1.198	0.34131	1.01601	1.76244	7.175	2.04627	34.387	1.99849	2.65472
02/02/94	13:35:05	1010	1.176	0.33546	1.01466	1.76068	6.768	2.06799	34.206	2.0105	2.65472
02/02/94	13:36:46	1010	1.201	0.35021	1.01432	1.7589	6.678	2.05833	34.157	2.01245	2.70738
02/02/94	13:37:13	1010	1.194	0.34284	1.01432	1.75866	6.628	2.06102	34.166	2.01657	2.6986
02/02/94	13:37:40	1010	1.185	0.35377	1.01449	1.7589	6.616	2.06737	34.132	2.01519	2.72932
02/02/94	13:38:39	1010	1.182	0.33063	1.01382	1.75689	6.58	2.06684	34.108	2.01458	2.58452
02/02/94	13:45:00	1020	1.219	1.94184	1.97955	1.72263	6.065	2.09282	21.071	2.09875	10.39072
02/02/94	13:46:39	1020	1.201	1.98229	1.99356	1.72087	6.017	2.09083	20.922	2.09857	10.5092
02/02/94	13:47:21	1020	1.216	1.99017	1.99305	1.71909	5.989	2.09001	20.896	2.09799	10.51358
02/02/94	13:48:12	1020	1.194	2.01332	1.99069	1.71809	6.005	2.08977	20.896	2.09331	10.5092
02/02/94	13:50:29	1020	1.216	1.98686	1.99271	1.71582	5.938	2.02526	20.376	2.0292	10.52236
02/02/94	13:54:38	1030	1.182	6.47201	3.9952	1.80174	6.128	2.01216	13.38	2.01677	36.42895
02/02/94	13:55:51	1030	1.161	6.48931	3.99537	1.8035	6.174	2.0145	13.448	2.02342	36.45089
02/02/94	13:56:44	1030	1.213	6.49948	3.9947	1.80174	6.207	2.00257	13.448	2.01397	36.46845
02/02/94	13:58:31	1030	1.161	6.47811	3.99318	1.80149	6.219	2.00905	13.393	1.99452	36.42456
02/02/94	14:00:06	1030	1.185	6.47786	3.99065	1.80149	6.255	2.01605	13.52	2.01905	36.35436
02/02/94	14:03:41	1040	1.173	13.70517	5.99635	1.71834	6.065	2.02209	10.92	2.01419	75.65305
02/02/94	14:06:08	1040	1.158	13.72832	6.00073	1.71885	6.083	2.01652	10.914	2.00567	75.78907

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR
02/02/94	14:08:34	1040	15.676	15.66	15.188	14.896	14.711	14.699	14.235	14.3	13.819	13.399	22.076
02/02/94	14:09:27	1040	15.616	15.609	15.066	14.853	14.668	14.653	14.195	14.251	13.786	13.335	22.082
02/02/94	14:10:56	1040	15.573	15.59	14.978	14.82	14.622	14.672	14.241	14.278	13.758	13.288	22.165
02/02/94	15:16:11	1050	53.685	53.37	49.506	49.761	49.879	50.013	46.97	47.203	47.522	44.54	21.999
02/02/94	15:17:22	1050	53.56	53.269	49.445	49.665	49.741	49.847	46.86	47.102	47.361	44.446	22.073
02/02/94	15:18:49	1050	53.506	53.205	49.399	49.595	49.705	49.805	46.806	47.083	47.367	44.504	22.018
02/02/94	15:19:59	1050	53.557	53.26	49.503	49.677	49.735	49.958	46.922	47.181	47.449	44.604	22.125
02/02/94	15:21:03	1050	53.563	53.303	49.552	49.677	49.799	49.958	46.97	47.154	47.482	44.64	22.14
02/02/94	15:27:03	1060	39.777	39.527	38.263	37.414	37.417	37.402	35.794	35.888	35.921	34.754	22.024
02/02/94	15:28:59	1060	39.613	39.414	37.874	37.333	37.296	37.368	35.769	35.86	35.939	34.645	22.088
02/02/94	15:31:40	1060	39.665	39.451	37.696	37.429	37.365	37.506	35.933	35.997	36.087	34.662	22.183
02/02/94	15:33:20	1060	39.601	39.399	37.563	37.384	37.293	37.494	35.86	35.976	36.054	34.611	22.067
02/02/94	15:36:03	1060	39.534	39.366	37.404	37.297	37.269	37.375	35.788	35.888	35.951	34.402	22.217
02/02/94	15:44:49	1070	31.698	31.46	30.827	30.383	30.384	30.488	29.589	29.681	29.707	28.983	22.07
02/02/94	15:47:23	1070	31.563	31.329	30.592	30.246	30.241	30.392	29.492	29.577	29.587	28.829	22.186
02/02/94	15:49:47	1070	31.487	31.226	30.425	30.179	30.153	30.282	29.423	29.464	29.51	28.662	22.146
02/02/94	15:51:57	1070	31.56	31.287	30.41	30.231	30.189	30.385	29.48	29.571	29.587	28.726	22.177
02/02/94	15:52:52	1070	31.572	31.332	30.401	30.279	30.256	30.389	29.498	29.584	29.61	28.726	22.253
02/02/94	15:58:53	1080	28.249	28.419	27.807	27.663	27.667	27.782	27.212	27.232	27.189	26.426	22.106
02/02/94	16:03:20	1080	28.231	28.379	27.633	27.599	27.606	27.718	27.153	27.202	27.141	26.287	22.309
02/02/94	16:05:37	1080	28.231	28.37	27.594	27.596	27.591	27.694	27.135	27.192	27.123	26.244	22.229
02/02/94	16:07:48	1080	28.285	28.403	27.578	27.642	27.624	27.718	27.181	27.208	27.159	26.275	22.302
02/02/94	16:11:09	1080	28.267	28.443	27.612	27.721	27.718	27.8	27.26	27.269	27.207	26.344	22.309
03/02/94	8:18:53	0	11.804	11.771	12.618	11.628	11.551	11.447	11.652	11.63	11.183	11.871	23.117
03/02/94	8:36:14	0	20.367	20.391	20.023	20.344	20.263	20.378	20.353	20.395	20.205	19.859	22.939
03/02/94	8:36:40	0	20.287	20.303	19.996	20.28	20.184	20.272	20.253	20.286	20.084	19.791	23.047
03/02/94	8:37:46	0	20.257	20.269	19.99	20.232	20.16	20.247	20.235	20.24	20.081	19.825	23.23
03/02/94	10:16:56	0	10.701	10.723	11.312	10.644	10.555	10.411	10.682	10.647	10.231	10.272	24.002
03/02/94	10:17:11	0	10.692	10.723	11.302	10.641	10.555	10.402	10.686	10.65	10.218	10.266	23.938

Table A.2-1: Reference tube and 18% ring data (cont.'d)

DATE	TIME	RUN#	TE-WA	DP2_AVG	MF-AVG	POUT_A\	SA-IN_A	Pwr_Avg	IA-OUT	HB_AVG	DPI_AVG
02/02/94	14:08:34	1040	1.115	13.72984	5.99213	1.71733	6.008	2.0367	10.881	2.01963	75.69692
02/02/94	14:09:27	1040	1.115	13.73188	5.99011	1.71758	5.992	2.03829	10.854	2.01427	75.67937
02/02/94	14:10:56	1040	1.222	13.7334	5.99534	1.71909	5.98	2.02003	10.848	2.01849	75.7057
02/02/94	15:16:11	1050	1.167	0.0793	1.00201	1.63646	20.353	2.00718	46.228	1.93613	1.44364
02/02/94	15:17:22	1050	1.191	0.0877	1.00387	1.63771	20.191	2.00772	46.085	1.94061	1.44364
02/02/94	15:18:49	1050	1.204	0.12102	1.00167	1.63771	20.176	2.00982	46.096	1.93837	1.57089
02/02/94	15:19:59	1050	1.219	0.09584	0.99509	1.63696	20.154	2.01366	46.102	1.92762	1.37782
02/02/94	15:21:03	1050	1.188	0.08286	0.9956	1.6352	20.166	2.01047	46.154	1.93169	1.43048
02/02/94	15:27:03	1060	1.161	1.76581	1.99946	1.7317	20.057	2.00224	33.908	2.0422	9.4868
02/02/94	15:28:59	1060	1.201	1.76759	2.00064	1.73094	20.072	2.01864	33.838	2.03083	9.45169
02/02/94	15:31:40	1060	1.204	1.74114	1.99828	1.73069	20.281	2.01034	33.999	2.022	9.42975
02/02/94	15:33:20	1060	1.204	1.75691	1.99862	1.7269	20.157	2.01512	33.931	2.03026	9.40343
02/02/94	15:36:03	1060	1.167	1.74114	1.99895	1.72641	20.154	2.01204	33.874	2.02244	9.43853
02/02/94	15:44:49	1070	1.216	6.29242	4.00296	1.67374	20.251	2.02521	27.192	2.03424	35.80147
02/02/94	15:47:23	1070	1.17	6.27792	4.00988	1.67147	20.136	2.01569	27.071	2.03534	35.71371
02/02/94	15:49:47	1070	1.222	6.30921	4.00482	1.67047	20.102	2.01883	26.994	2.02013	35.8278
02/02/94	15:51:57	1070	1.182	6.29776	4.00701	1.66846	20.185	2.01224	27.119	2.03391	35.79709
02/02/94	15:52:52	1070	1.201	6.30641	4.01039	1.67147	20.185	2.02379	27.152	2.04563	35.77514
02/02/94	15:58:53	1080	1.188	13.86135	6.03009	1.7133	20.194	2.01203	24.813	2.03128	76.04797
02/02/94	16:03:20	1080	1.188	13.78072	6.00242	1.71557	20.093	2.02628	24.753	2.03939	75.55212
02/02/94	16:05:37	1080	1.176	13.75706	6.01288	1.7133	20.072	2.02743	24.741	2.04697	75.55651
02/02/94	16:07:48	1080	1.17	13.7881	6.0149	1.7123	20.188	2.02042	24.802	2.02358	75.7057
02/02/94	16:11:09	1080	1.173	13.77054	6.02637	1.71179	20.29	2.01526	24.911	2.03043	75.76713
03/02/94	8:18:53	0	1.305	2.51825	2.27931	1.07938	10.487	0	10.532	0.00717	13.55884
03/02/94	8:36:14	0	1.243	1.88181	2.02004	1.51401	20.066	0	20.024	-0.00627	10.19326
03/02/94	8:36:40	0	1.179	1.85205	2.01937	1.51401	20.03	0	19.966	-0.00934	10.33368
03/02/94	8:37:46	0	1.207	1.85586	2.02004	1.51527	19.994	0.0032	19.905	-0.01282	10.30735
03/02/94	10:16:56	0	1.341	7.07106	4.02338	1.89547	9.553	0	9.502	-0.01395	37.31971
03/02/94	10:17:11	0	1.329	7.10413	4.02506	1.89647	9.547	0	9.493	-0.01476	37.42941

Table A.2-2: 30% ring data

DATE	TIME	RUNID	AI-AVG	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR	TE-WAT
30 % Ring Tests															
21:02:94	15:12:23	11	2.793	4.607	4.832	5.699	4.843	5.085	4.644	4.759	4.57	3.999	4.077	25.154	1.06
21:02:94	15:13:13	11	2.824	4.644	4.901	5.714	4.903	5.139	4.702	4.834	4.631	4.066	4.15	25.129	1.054
21:02:94	15:13:27	11	2.876	4.677	4.938	5.717	4.924	5.157	4.741	4.873	4.655	4.102	4.18	25.154	1.047
21:02:94	15:13:57	11	2.888	4.777	5.049	5.824	5.034	5.316	4.783	4.95	4.698	4.132	4.211	25.123	1.06
21:02:94	15:14:39	12	2.616	4.537	4.807	5.629	4.764	5.018	4.485	4.649	4.452	3.857	3.992	25.154	1.081
21:02:94	15:14:52	12	2.521	4.497	4.771	5.584	4.716	4.96	4.436	4.606	4.412	3.817	3.953	25.142	1.069
21:02:94	15:15:03	12	2.444	4.464	4.731	5.547	4.688	4.918	4.405	4.575	4.342	3.781	3.931	25.111	1.072
21:02:94	15:15:24	12	2.41	4.412	4.664	5.479	4.612	4.845	4.354	4.506	4.272	3.707	3.862	25.04	1.05
21:02:94	15:16:19	13	2.061	4.097	4.388	5.196	4.32	4.532	4.053	4.18	3.977	3.42	3.588	24.838	1.044
21:02:94	15:16:37	13	2.034	4.052	4.318	5.148	4.274	4.46	4.007	4.117	3.931	3.365	3.537	24.863	1.054
21:02:94	15:16:48	13	2.012	4.033	4.275	5.129	4.232	4.442	3.967	4.067	3.895	3.322	3.501	24.844	1.047
21:02:94	15:17:14	13	1.908	3.97	4.211	5.087	4.171	4.366	3.93	3.964	3.85	3.283	3.452	24.912	1.038
21:02:94	15:17:57	14	1.816	3.808	4.09	4.947	4.04	4.207	3.777	3.858	3.761	3.156	3.358	25.004	1.087
21:02:94	15:18:27	14	1.847	3.778	4.038	4.886	4.007	4.198	3.711	3.828	3.722	3.073	3.279	25.105	1.09
21:02:94	15:18:36	14	1.792	3.76	4.026	4.865	3.992	4.187	3.69	3.809	3.713	3.059	3.249	25.096	1.078
21:02:94	15:19:42	15	1.678	3.629	3.886	4.573	3.88	4.038	3.592	3.7	3.579	2.98	3.039	25.102	1.109
21:02:94	15:19:51	15	1.672	3.626	3.874	4.542	3.871	4.025	3.58	3.688	3.57	2.977	3.024	25.102	1.115
21:02:94	15:20:00	15	1.62	3.629	3.868	4.521	3.862	4.025	3.568	3.691	3.561	2.977	3.015	25.093	1.112
21:02:94	15:20:46	16	1.617	3.584	3.828	4.414	3.78	4.004	3.537	3.703	3.515	2.916	2.927	25.053	1.103
21:02:94	15:20:57	16	1.623	3.581	3.828	4.405	3.807	4.01	3.534	3.715	3.524	2.91	2.93	25.086	1.121
21:02:94	15:21:16	16	1.611	3.587	3.828	4.417	3.789	4.019	3.528	3.724	3.509	2.907	2.946	25.077	1.106
21:02:94	15:21:38	16	1.599	3.535	3.792	4.384	3.74	3.989	3.525	3.688	3.49	2.919	2.933	25.037	1.103
21:02:94	15:22:11	17	1.586	3.529	3.783	4.387	3.716	3.977	3.497	3.684	3.478	2.922	2.918	25.044	1.106
21:02:94	15:22:48	17	1.605	3.563	3.81	4.402	3.764	4.007	3.519	3.706	3.542	2.961	2.964	24.991	1.093
21:02:94	15:22:58	17	1.663	3.563	3.804	4.411	3.752	4.01	3.522	3.7	3.549	2.971	2.961	24.991	1.103
21:02:94	15:23:34	18	1.614	3.581	3.819	4.426	3.819	4.01	3.537	3.688	3.579	3.022	2.985	24.961	1.124
21:02:94	15:23:51	18	1.657	3.596	3.846	4.454	3.85	4.035	3.558	3.727	3.639	3.059	3.036	25.028	1.121
21:02:94	15:24:22	18	1.727	3.632	3.877	4.515	3.886	4.065	3.589	3.763	3.67	3.082	3.051	24.976	1.237
21:02:94	15:24:58	18	1.758	3.708	3.965	4.582	3.964	4.153	3.623	3.809	3.743	3.122	3.109	24.881	1.176
21:02:94	15:25:34	18	1.789	3.699	3.983	4.612	3.979	4.138	3.647	3.846	3.767	3.134	3.137	24.912	1.127
21:02:94	15:26:21	18	1.733	3.684	3.965	4.6	3.998	4.153	3.639	3.828	3.749	3.137	3.137	24.921	1.161
21:02:94	15:26:43	18	1.749	3.681	3.95	4.588	3.955	4.114	3.671	3.812	3.736	3.168	3.143	24.979	1.152
23:02:94	9:02:07	4031	80.827	73.803	73.307	64.668	69.98	69.085	70.061	65.889	66.835	66.619	69.669	21.77	1.06
23:02:94	9:02:26	4031	80.864	73.854	73.359	64.804	70.074	69.094	70.108	65.901	66.823	66.574	69.688	21.754	1.063
23:02:94	9:03:37	4031	80.781	73.885	73.389	65.057	70.138	69.161	70.105	65.913	66.88	66.616	69.864	21.635	1.05
23:02:94	9:05:11	4031	80.732	73.936	73.432	65.325	70.245	69.294	70.222	66.029	66.981	66.696	60.055	21.58	1.072
23:02:94	9:05:43	4031	80.643	73.936	73.405	65.367	70.242	69.279	70.203	66.047	66.941	66.693	60.121	21.592	1.063
23:02:94	9:06:13	4031	80.604	73.909	73.386	65.376	70.138	69.2	70.176	65.952	66.805	66.571	60.061	21.613	1.06
23:02:94	9:09:13	4035	80.664	74.022	73.487	64.738	66.431	64.474	67.183	66.005	66.762	66.601	60.364	21.665	1.05
23:02:94	9:09:51	4035	80.542	74.037	73.487	64.759	66.379	64.407	67.14	65.962	66.808	66.693	60.397	21.675	1.038
23:02:94	9:11:10	4035	80.484	74.025	73.477	64.731	66.285	64.316	67.063	66.005	66.78	66.665	60.491	21.693	1.066
23:02:94	9:11:24	4035	80.469	74.037	73.468	64.704	66.276	64.303	67.027	65.938	66.835	66.58	60.451	21.668	1.05
23:02:94	9:11:36	4035	80.49	74.037	73.465	64.689	66.233	64.334	67.033	65.977	66.88	66.595	60.457	21.656	1.069
23:02:94	9:11:48	4035	80.49	74.034	73.468	64.725	66.279	64.313	67.091	65.971	66.865	66.662	60.467	21.659	1.093
23:02:94	9:13:24	4036	80.441	74.052	73.502	64.613	63.635	62.212	64.491	65.895	66.808	66.723	60.583	21.623	1.066
23:02:94	9:13:50	4036	80.438	74.031	73.481	64.579	63.598	62.078	64.424	65.822	66.777	66.613	60.573	21.619	1.066
23:02:94	9:15:57	4036	80.432	74.089	73.569	64.698	63.674	62.258	64.568	65.995	66.981	66.853	60.806	21.733	1.106
23:02:94	9:16:18	4036	80.432	74.095	73.581	64.741	63.747	62.264	64.616	65.977	67.057	66.853	60.91	21.766	1.096
23:02:94	9:16:41	4036	80.46	74.089	73.553	64.728	63.726	62.267	64.635	66.041	67.029	66.878	60.928	21.831	1.103
23:02:94	9:17:00	4036	80.401	74.083	73.55	64.741	63.717	62.224	64.647	66.047	67.084	66.902	60.898	21.822	1.106
23:02:94	9:18:48	4037	80.371	74.098	73.572	64.795	59.532	58.517	60.278	66.099	67.133	66.89	60.985	21.672	1.081
23:02:94	9:19:10	4037	80.368	74.086	73.563	64.792	59.499	58.505	60.278	66.011	67.148	66.899	60.971	21.699	1.109
23:02:94	9:19:25	4037	80.352	74.089	73.56	64.801	59.456	58.496	60.275	66.053	67.212	66.911	60.968	21.69	1.106
23:02:94	9:21:39	4037	80.254	74.068	73.553	64.783	59.45	58.496	60.233	66.008	67.215	66.856	60.953	21.751	1.06
23:02:94	9:21:52	4037	80.239	74.071	73.538	64.762	59.477	58.52	60.23	66.041	67.203	66.814	60.976	21.733	1.078
23:02:94	9:22:03	4037	80.212	74.065	73.532	64.741	59.453	58.502	60.2	66.047	67.221	66.826	60.985	21.727	1.078
23:02:94	9:24:50	4034	80.15	74.013	73.514	65.136	66.851	65.803	68.438	66.002	66.929	66.693	60.928	21.763	1.057
23:02:94	9:26:37	4034	80.028	73.968	73.459	65.103	66.887	65.845	68.36	65.88	66.886	66.574	60.861	21.782	1.066
23:02:94	9:26:55	4034	80.031	73.962	73.453	65.112	66.908	65.848	68.329	65.867	66.892	66.553	60.819	21.714	1.038
23:02:94	10:13:48	4011	70.99	65.708	65.286	59.926	61.824	60.946	61.778	56.443	56.865	57.175	53.259	21.849	1.069
23:02:94	10:14:16	4011	70.996	65.708	65.271	59.92	61.821	60.904	61.726	56.413	56.822	57.184	53.204	21.889	1.05
23:02:94	10:14:24	4011	71.002	65.732	65.28	59.875	61.854	60.904	61.76	56.345	56.799	57.16	53.192	21.855	1.063
23:02:94	10:14:33	4011	70.971	65.744	65.265	59.908	61.848	60.919	61.794	56.355	56.774	57.136	53.126	21.84	1.06
23:02:94	10:14:41	4011	70.975	65.735	65.28	59.908	61.833	60.922	61.708	56.339	56.774	57.145	53.132	21.849	1.069
23:02:94	10:16:44	4014	70.855	65.738	65.265	59.159	57.916	56.891	58.538	56.617	57.109	57.342	52.892	21.742	1.029
23:02:94	10:17:07	4014	70.812	65.714	65.252	59.046	57.782	56.757	58.462	56.598	57.075	57.324	52.883	21.794	1.029
23:02:94	10:17:17	4014	70.809	65.698	65.24	59.016	57.715	56.705	58.483	56.641	57.093	57.291	52.904	21.8	1.041
23:02:94	10:17:30	4014	70.8	65.695	65.252	59.004	57.624	56.635	58.45	56.714	57.09	57.336	52.898	21.812	1.05
23:02:94	10:17:40	4014	70.775	65.714	65.234	58.985	57.569	56.66	58.435	56.665	57.197	57.375	52.861	21.834	1.057
23:0															

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	DP2_AVG	1A-OUTAV	5A-IN_AV	POUT_AVG	Pwr_Avg	MF-AVG	HB_AVG	DPI_AVG
30 % Ring Tests										
21:02/94	15:12:23	11	1.05738	2.871	2.574	1.32327	0	0.99999	0.01999	4.50206
21:02/94	15:13:13	11	1.03525	2.899	2.604	1.32403	0	0.99948	0.01982	4.41869
21:02/94	15:13:27	11	1.02634	2.926	2.647	1.32454	0	1.00049	0.01874	4.40114
21:02/94	15:13:57	11	1.01719	2.945	2.737	1.46966	0	0.99729	0.01389	4.48451
21:02/94	15:14:39	12	3.2623	2.629	2.525	1.45882	0	1.99322	0.01383	12.51011
21:02/94	15:14:52	12	3.24882	2.583	2.474	1.45984	0	1.99238	0.01457	12.5891
21:02/94	15:15:03	12	3.23076	2.537	2.435	1.45984	0	1.99423	0.0137	12.53205
21:02/94	15:15:24	12	3.16869	2.501	2.357	1.46109	0	1.99609	0.0193	12.40919
21:02/94	15:16:19	13	5.90475	2.139	2.08	1.43867	0	2.99691	0.01198	24.68235
21:02/94	15:16:37	13	5.87296	2.103	2.028	1.43867	0	2.99016	0.01506	24.6999
21:02/94	15:16:48	13	5.87092	2.096	1.995	1.43917	0	2.99809	0.02038	24.63847
21:02/94	15:17:14	13	5.89483	2.052	1.952	1.43917	0	2.98814	0.02	24.63408
21:02/94	15:17:57	14	11.20822	1.954	1.847	1.41045	0	3.98593	0.02885	40.32109
21:02/94	15:18:27	14	11.13522	1.932	1.81	1.40944	0	3.98357	0.03267	40.09291
21:02/94	15:18:36	14	11.19016	1.93	1.81	1.40944	0	3.98171	0.03185	40.12301
21:02/94	15:19:42	15	16.46056	1.739	1.696	1.37165	0	5.00733	0.01441	59.93533
21:02/94	15:19:51	15	16.49058	1.757	1.672	1.37114	0	5.00868	0.02855	60.12839
21:02/94	15:20:00	15	16.45649	1.723	1.681	1.37089	0	5.00868	0.01414	60.07135
21:02/94	15:20:46	16	19.87046	1.693	1.651	1.3268	0	6.00512	0.01709	82.84931
21:02/94	15:20:57	16	19.96003	1.748	1.717	1.32655	0	6.00563	0.01238	82.77911
21:02/94	15:21:16	16	19.88089	1.748	1.726	1.3263	0	5.99955	0.00873	82.73524
21:02/94	15:21:38	16	19.85087	1.68	1.66	1.32781	0	6.0004	0.00822	82.62553
21:02/94	15:22:11	17	26.22272	1.677	1.705	1.27288	0	7.00662	-0.01308	109.1289
21:02/94	15:22:48	17	26.27741	1.723	1.741	1.27414	0	7.0245	-0.00861	109.34829
21:02/94	15:22:58	17	26.31608	1.723	1.741	1.27363	0	7.02636	-0.00862	109.42727
21:02/94	15:23:34	18	32.78688	1.772	1.777	1.21594	0	7.97978	-0.00307	137.96226
21:02/94	15:23:51	18	32.77237	1.838	1.81	1.2172	0	7.98484	0.01485	137.96666
21:02/94	15:24:22	18	32.81358	1.857	1.835	1.21569	0	7.99091	0.01205	138.22554
21:02/94	15:24:58	18	32.96773	1.897	1.907	1.21519	0	7.99901	-0.00545	138.51515
21:02/94	15:25:34	18	32.998	1.932	1.904	1.21443	0	8.0125	0.01542	138.78282
21:02/94	15:26:21	18	32.62967	1.906	1.886	1.21392	0	8.01318	0.01071	138.95395
21:02/94	15:26:43	18	32.63806	1.9	1.874	1.21392	0	8.0206	0.01401	138.98027
23:02/94	9:02:07	4031	9.32203	48.435	7.108	1.82467	12.6641	3.98913	12.11811	38.3465
23:02/94	9:02:26	4031	9.27548	48.441	7.157	1.82441	12.66781	3.99116	12.11285	38.10077
23:02/94	9:03:37	4031	9.30117	48.4	7.154	1.82316	12.69891	3.99014	12.0978	38.2368
23:02/94	9:05:11	4031	9.24114	48.499	7.16	1.82139	12.7073	3.99217	12.13275	38.22302
23:02/94	9:05:43	4031	9.2096	48.414	7.163	1.82063	12.67554	3.99149	12.10398	38.27629
23:02/94	9:06:13	4031	9.21748	48.311	7.175	1.82089	12.72081	3.99065	12.06646	38.31578
23:02/94	9:09:13	4035	9.20909	48.469	7.214	1.82215	12.74383	3.99605	12.12047	38.38599
23:02/94	9:09:51	4035	9.18823	48.487	7.226	1.82089	12.73555	3.99622	12.12316	38.46497
23:02/94	9:11:10	4035	9.21748	48.487	7.223	1.81963	12.74412	3.99723	12.12705	38.43426
23:02/94	9:11:24	4035	9.20807	48.414	7.229	1.82038	12.75303	3.99689	12.1021	38.35527
23:02/94	9:11:36	4035	9.25284	48.475	7.217	1.82063	12.77592	3.99757	12.12608	38.3816
23:02/94	9:11:48	4035	9.25055	48.487	7.22	1.82038	12.75562	3.99487	12.12072	38.40793
23:02/94	9:13:24	4036	9.27573	48.569	7.25	1.82089	12.77429	3.99925	12.15102	38.42987
23:02/94	9:13:50	4036	9.27166	48.524	7.259	1.82114	12.76823	3.99909	12.13402	38.46497
23:02/94	9:15:57	4036	9.25436	48.73	7.286	1.81963	12.80528	4.00077	12.19511	38.55273
23:02/94	9:16:18	4036	9.24445	48.679	7.283	1.81963	12.79563	4.00178	12.18315	38.63611
23:02/94	9:16:41	4036	9.23656	48.699	7.298	1.81988	12.85046	3.99976	12.17926	38.601
23:02/94	9:17:00	4036	9.24266	48.702	7.268	1.81913	12.81204	3.99925	12.18692	38.54834
23:02/94	9:18:48	4037	9.20502	48.809	7.256	1.82089	12.84548	4.00178	12.23061	38.56589
23:02/94	9:19:10	4037	9.22002	48.736	7.262	1.82014	12.82011	4.00533	12.21749	38.63172
23:02/94	9:19:25	4037	9.26378	48.705	7.259	1.81963	12.81998	4.00195	12.19855	38.57467
23:02/94	9:21:39	4037	9.33195	48.657	7.265	1.82114	12.81685	4.00735	12.19837	38.80285
23:02/94	9:21:52	4037	9.26912	48.696	7.268	1.82038	12.8103	4.00769	12.2108	38.67121
23:02/94	9:22:03	4037	9.34009	48.727	7.268	1.81938	12.80196	4.01005	12.22747	38.70192
23:02/94	9:24:50	4034	9.30066	48.639	7.283	1.81736	12.80052	4.00212	12.17198	38.55712
23:02/94	9:26:37	4034	9.33856	48.575	7.265	1.81711	12.79433	4.00246	12.15846	38.68437
23:02/94	9:26:55	4034	9.30117	48.521	7.268	1.81636	12.76186	4.00128	12.13726	38.54834
23:02/94	10:13:48	4011	0.60637	50.619	3.678	1.80325	3.94577	1.05515	3.62996	2.76003
23:02/94	10:14:16	4011	0.61273	50.452	3.615	1.80325	3.95735	1.05633	3.62479	2.76442
23:02/94	10:14:24	4011	0.61909	50.541	3.621	1.80225	3.94523	1.05717	3.63452	2.82147
23:02/94	10:14:33	4011	0.60586	50.535	3.603	1.80249	3.95792	1.05801	3.6382	2.79514
23:02/94	10:14:41	4011	0.60993	50.486	3.588	1.80199	3.95173	1.05666	3.63063	2.71177
23:02/94	10:16:44	4014	0.60688	50.559	3.392	1.80073	3.94715	1.04924	3.62486	2.78198
23:02/94	10:17:07	4014	0.57305	50.434	3.374	1.80124	3.97079	1.0516	3.62413	2.60646
23:02/94	10:17:17	4014	0.61604	50.37	3.362	1.80174	3.96138	1.05717	3.63887	2.72054
23:02/94	10:17:30	4014	0.61333	50.434	3.356	1.80023	3.95601	1.05245	3.62834	2.79075
23:02/94	10:17:40	4014	0.61578	50.425	3.341	1.79998	3.95887	1.05784	3.64717	2.75126
23:02/94	10:17:49	4014	0.64249	50.392	3.332	1.80073	3.95899	1.05565	3.63757	2.88729
23:02/94	10:18:59	4015	0.60128	50.404	3.277	1.79947	3.95467	1.05194	3.62967	2.72493
23:02/94	10:19:22	4015	0.61985	50.358	3.261	1.79897	3.95673	1.05127	3.62468	2.81269
23:02/94	10:19:38	4015	0.63308	50.519	3.261	1.79922	3.95845	1.05093	3.63667	2.78636
23:02/94	10:19:54	4015	0.6084	50.429	3.255	1.79871	3.95296	1.05093	3.6297	2.73809
23:02/94	10:20:05	4015	0.59823	50.373	3.252	1.79897	3.95351	1.05515	3.63992	2.73371
23:02/94	10:20:57	4016	0.61883	50.252	3.228	1.79746	3.9404	1.057	3.63805	2.78636
23:02/94	10:21:16	4016	0.61654	50.297	3.249	1.79796	3.9494	1.05447	3.63159	2.82585

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	AI-AVG	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR	TE-WAT
23/02/94	10:21:27	4016	70.604	65.668	65.198	58.312	51.944	51.283	52.862	56.601	56.971	57.163	52.652	21.763	1.032
23/02/94	10:21:41	4016	70.524	65.653	65.195	58.282	51.904	51.226	52.828	56.507	56.999	57.118	52.522	21.8	1.023
23/02/94	10:21:49	4016	70.533	65.647	65.185	58.272	51.871	51.193	52.805	56.571	57.02	57.197	52.546	21.825	1.038
23/02/94	10:23:02	4017	70.491	65.62	65.143	58.224	48.172	47.99	48.906	56.555	56.965	57.23	52.525	21.871	1.063
23/02/94	10:23:14	4017	70.524	65.635	65.131	58.193	48.151	47.951	48.872	56.586	56.971	57.233	52.561	21.773	1.044
23/02/94	10:23:32	4017	70.503	65.608	65.134	58.187	48.13	47.905	48.845	56.601	57.02	57.248	52.543	21.751	1.041
23/02/94	10:23:41	4017	70.512	65.617	65.137	58.19	48.151	47.89	48.817	56.583	56.98	57.312	52.583	21.766	1.038
23/02/94	10:23:51	4017	70.445	65.626	65.119	58.187	48.09	47.89	48.826	56.614	57.017	57.276	52.592	21.791	1.032
23/02/94	10:30:48	4021	75.746	69.041	68.683	61.722	64.394	63.782	64.186	59.593	60.266	60.285	55.325	21.641	1.035
23/02/94	10:30:57	4021	75.774	69.083	68.722	61.732	64.422	63.794	64.199	59.575	60.247	60.37	55.312	21.616	1.035
23/02/94	10:31:07	4021	75.792	69.071	68.741	61.765	64.471	63.806	64.244	59.627	60.296	60.364	55.367	21.613	1.023
23/02/94	10:31:16	4021	75.749	69.105	68.762	61.847	64.495	63.812	64.344	59.6	60.281	60.428	55.383	21.589	1.023
23/02/94	10:31:26	4021	75.749	69.117	68.789	61.866	64.528	63.881	64.241	59.609	60.344	60.336	55.376	21.589	1.02
23/02/94	10:31:36	4021	75.682	69.144	68.786	61.862	64.528	63.893	64.235	59.633	60.314	60.409	55.398	21.635	0.986
23/02/94	10:32:52	4024	75.679	69.241	68.868	61.318	61.377	60.433	62.26	59.859	60.573	60.443	55.565	21.675	1.011
23/02/94	10:33:13	4024	75.584	69.232	68.862	61.272	61.285	60.342	62.227	59.819	60.561	60.425	55.592	21.678	1.032
23/02/94	10:33:21	4024	75.513	69.262	68.847	61.254	61.209	60.318	62.184	59.859	60.49	60.388	55.583	21.681	1.041
23/02/94	10:33:30	4024	75.495	69.211	68.829	61.224	61.14	60.218	62.104	59.737	60.512	60.282	55.498	21.702	1.041
23/02/94	10:33:39	4024	75.428	69.18	68.808	61.172	60.958	60.16	62.058	59.67	60.442	60.233	55.501	21.717	1.047
23/02/94	10:33:50	4024	75.4	69.199	68.789	61.163	60.952	60.102	61.994	59.685	60.433	60.218	55.444	21.711	1.063
23/02/94	10:34:58	4025	75.345	69.208	68.75	60.989	58.958	57.938	60.175	59.794	60.344	60.227	55.516	21.742	1.06
23/02/94	10:35:17	4025	75.351	69.22	68.744	60.992	58.858	57.835	60.111	59.788	60.399	60.218	55.549	21.779	1.05
23/02/94	10:35:33	4025	75.336	69.226	68.732	60.934	58.797	57.771	60.007	59.771	60.381	60.206	55.494	21.776	1.05
23/02/94	10:35:46	4025	75.333	69.226	68.768	60.958	58.73	57.713	60.031	59.761	60.299	60.2	55.513	21.776	1.029
23/02/94	10:36:04	4025	75.287	69.223	68.747	60.921	58.651	57.64	59.946	59.712	60.299	60.16	55.519	21.757	1.05
23/02/94	10:36:31	4025	75.262	69.217	68.771	60.952	58.633	57.634	59.97	59.761	60.381	60.221	55.531	21.773	1.066
23/02/94	10:37:32	4025	75.158	69.162	68.662	60.821	58.426	57.398	59.687	59.584	60.238	60.091	55.419	21.773	1.041
23/02/94	10:37:44	4025	75.18	69.15	68.692	60.827	58.392	57.416	59.705	59.593	60.296	60.064	55.367	21.773	1.023
23/02/94	10:39:05	4026	75.106	69.111	68.625	60.602	55.727	54.793	56.81	59.47	60.061	60.067	55.349	21.754	1.008
23/02/94	10:39:27	4026	75.06	69.114	68.613	60.581	55.639	54.729	56.807	59.454	60.095	60.006	55.358	21.825	1.011
23/02/94	10:39:37	4026	75.091	69.09	68.607	60.596	55.648	54.747	56.819	59.46	60.177	60.067	55.361	21.852	1.017
23/02/94	10:39:54	4026	75.091	69.077	68.592	60.565	55.612	54.696	56.77	59.423	60.132	60.024	55.37	21.874	1.023
23/02/94	10:40:11	4026	75.039	69.077	68.583	60.544	55.63	54.657	56.743	59.408	60.123	59.957	55.324	21.901	1.029
23/02/94	10:40:37	4026	75.026	69.074	68.573	60.544	55.554	54.59	56.731	59.38	60.135	59.975	55.355	21.88	1.026
23/02/94	10:41:39	4027	75.023	69.056	68.576	60.535	51.77	51.32	52.484	59.42	59.98	59.897	55.364	21.846	1.02
23/02/94	10:42:08	4027	74.98	69.065	68.57	60.483	51.719	51.217	52.415	59.454	60.025	59.906	55.398	21.852	1.063
23/02/94	10:42:52	4027	74.962	69.065	68.546	60.495	51.661	51.202	52.424	59.408	60.046	59.906	55.395	21.88	1.038
23/02/94	10:43:22	4027	74.922	69.041	68.528	60.416	51.61	51.163	52.32	59.393	59.983	59.939	55.364	21.883	1.02
23/02/94	10:44:11	4027	74.889	69.053	68.543	60.416	51.61	51.181	52.24	59.286	59.949	59.9	55.34	21.935	1.023
23/02/94	10:48:18	4023	75.18	69.311	68.856	61.759	61.471	61.018	62.55	59.998	60.794	60.731	55.993	21.92	1.066
23/02/94	10:48:34	4023	75.149	69.305	68.89	61.759	61.547	61.137	62.55	60.15	60.871	60.755	55.993	21.953	1.069
23/02/94	10:48:49	4023	75.149	69.317	68.905	61.789	61.623	61.149	62.577	60.123	60.852	60.779	56.019	21.969	1.057
23/02/94	10:48:59	4023	75.121	69.305	68.887	61.829	61.629	61.226	62.643	60.138	60.84	60.758	56.028	21.944	1.063
23/02/94	10:49:20	4023	75.112	69.341	68.899	61.85	61.699	61.223	62.634	60.135	60.911	60.816	56.013	21.898	1.044
23/02/94	10:55:39	4013	70.552	65.034	64.566	59.372	59.298	58.854	59.967	57.197	57.765	57.791	53.031	21.962	1.017
23/02/94	10:55:59	4013	70.549	65.046	64.56	59.302	59.268	58.879	59.901	57.1	57.674	57.788	52.953	21.886	0.986
23/02/94	10:56:09	4013	70.53	65.034	64.536	59.268	59.259	58.727	59.858	57.063	57.592	57.655	52.932	21.855	0.983
23/02/94	10:56:25	4013	70.53	64.997	64.493	59.235	59.144	58.654	59.724	57.018	57.556	57.56	52.855	21.822	0.989
23/02/94	10:56:35	4013	70.457	64.985	64.46	59.229	59.101	58.602	59.736	56.936	57.51	57.576	52.822	21.84	0.998
23/02/94	10:57:04	4013	70.439	64.91	64.42	59.107	58.979	58.508	59.666	56.842	57.407	57.473	52.783	21.901	0.983
23/02/94	11:01:47	4031	81.342	70.875	70.491	60.599	65.006	63.939	65.159	60.853	61.634	61.714	55.67	21.969	1.06
23/02/94	11:02:11	4031	81.265	71.138	70.728	60.721	65.19	64.116	65.302	61.075	61.814	61.829	55.805	21.898	1.02
23/02/94	11:02:23	4031	81.17	71.205	70.871	60.836	65.245	64.218	65.396	61.111	61.892	61.947	55.874	21.892	1.047
23/02/94	11:02:51	4031	81.155	71.503	71.062	60.983	65.483	64.367	65.534	61.373	62.09	62.084	55.965	21.907	1.026
23/02/94	11:03:09	4031	81.179	71.654	71.195	61.059	65.595	64.503	65.644	61.495	62.233	62.23	56.08	21.889	1.072
23/02/94	11:03:19	4031	81.195	71.712	71.25	61.09	65.616	64.567	65.659	61.525	62.258	62.272	56.138	21.926	1.05
23/02/94	11:03:28	4031	81.173	71.766	71.28	61.154	65.635	64.607	65.71	61.568	62.284	62.315	56.15	21.923	1.069
23/02/94	11:04:42	4033	81.008	72.174	71.709	60.946	63.589	62.342	64.082	61.616	62.498	62.285	56.351	21.996	1.066
23/02/94	11:04:57	4033	81.038	72.231	71.73	60.949	63.589	62.246	64.049	61.653	62.534	62.224	56.342	22.011	1.026
23/02/94	11:05:08	4033	81.026	72.28	71.8	60.979	63.598	62.24	64.055	61.643	62.531	62.242	56.399	21.984	1.035
23/02/94	11:05:22	4033	80.959	72.274	71.794	60.934	63.568	62.234	63.994	61.625	62.562	62.275	56.426	21.999	1.035
23/02/94	11:05:32	4033	80.895	72.322	71.861	60.924	63.538	62.234	63.973	61.65	62.577	62.23	56.435	22.011	1.041
23/02/94	11:06:06	4033	80.907	72.364	71.852	60.986	63.559	62.206	63.97	61.619	62.598	62.275	56.478	21.999	1.093
23/02/94	11:06:31	4033	80.931	72.449	71.922	61.001	63.531	62.2	64.04	61.674	62.644	62.248	56.535	21.981	1.066
23/02/94	11:07:12	4033	80.879	72.507	71.955	61.029	63.538	62.209	63.982	61.719	62.726	62.245	56.581	21.892	1.038
23/02/94	11:09:12	4034	80.803	72.671	72.104	60.376	62.915	61.75	64.07	61.975	62.58	62.357	56.636	21.892	1.06
23/02/94	11:09:42	4034	80.8	72.671	72.086	60.806	62.906	61.811	64.046	61.957	62.589	62.348	56.626	21.889	1.069
23/02/94	11:10:00	4034	80.744	72.649	72.083	60.791	62.888								

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	DP2_AVG	IA-OUTAV	5A-IN_AV	POUT_AVG	Pwr_Avg	MF-AVG	HB_AVG	DP1_AVG
23/02/94	10:21:27	4016	0.62494	50.337	3.237	1.79922	3.95662	1.05649	3.64267	2.89606
23/02/94	10:21:41	4016	0.60332	50.258	3.225	1.7962	3.9418	1.05447	3.63004	2.63717
23/02/94	10:21:49	4016	0.62825	50.386	3.219	1.7972	3.94529	1.05228	3.63342	2.82585
23/02/94	10:23:02	4017	0.60332	50.228	3.195	1.7962	3.93906	1.0543	3.62915	2.66789
23/02/94	10:23:14	4017	0.59594	50.234	3.192	1.7962	3.93514	1.05076	3.61766	2.61523
23/02/94	10:23:32	4017	0.63003	50.37	3.18	1.79645	3.95538	1.05447	3.64246	2.88729
23/02/94	10:23:41	4017	0.62621	50.309	3.162	1.7967	3.94758	1.05616	3.6446	2.71177
23/02/94	10:23:51	4017	0.64198	50.34	3.141	1.7962	3.95231	1.05228	3.63522	2.76003
23/02/94	10:30:48	4021	2.5007	48.754	3.693	1.80401	6.99751	2.00553	6.60889	10.60373
23/02/94	10:30:57	4021	2.51749	48.751	3.705	1.80426	6.97492	2.00216	6.59571	10.55308
23/02/94	10:31:07	4021	2.49638	48.828	3.72	1.80451	7.00707	2.00115	6.60211	10.53114
23/02/94	10:31:16	4021	2.48595	48.8	3.717	1.80451	6.98203	2.00604	6.61436	10.47848
23/02/94	10:31:26	4021	2.50808	48.779	3.744	1.80451	6.98295	2.00216	6.59472	10.5443
23/02/94	10:31:36	4021	2.50655	48.803	3.757	1.80376	6.96599	2.00418	6.60342	10.60134
23/02/94	10:32:52	4024	2.48468	48.919	3.79	1.80401	6.96066	2.00081	6.60571	10.5794
23/02/94	10:33:13	4024	2.48366	48.87	3.811	1.803	6.96049	2.00182	6.59873	10.51358
23/02/94	10:33:21	4024	2.47552	48.825	3.811	1.80325	6.96789	2.00148	6.59058	10.4346
23/02/94	10:33:30	4024	2.48137	48.708	3.811	1.80325	6.9532	2.00233	6.57551	10.46971
23/02/94	10:33:39	4024	2.48747	48.679	3.805	1.80325	6.96292	2.00233	6.57174	10.52236
23/02/94	10:33:50	4024	2.46407	48.651	3.817	1.80199	6.95175	2.00165	6.56362	10.52236
23/02/94	10:34:58	4025	2.47984	48.673	3.838	1.80274	6.96288	2.00266	6.56745	10.52675
23/02/94	10:35:17	4025	2.45822	48.633	3.832	1.803	6.95369	2.00165	6.55884	10.44338
23/02/94	10:35:33	4025	2.49841	48.63	3.838	1.80174	6.94843	2.00317	6.56255	10.5443
23/02/94	10:35:46	4025	2.46865	48.688	3.862	1.80199	6.95834	2.00064	6.55988	10.51358
23/02/94	10:36:04	4025	2.49205	48.536	3.835	1.80199	6.95504	2.0052	6.55508	10.50481
23/02/94	10:36:31	4025	2.46356	48.688	3.844	1.80325	6.96823	2.00351	6.57172	10.42582
23/02/94	10:37:32	4025	2.48442	48.503	3.835	1.80098	6.93058	2.00351	6.54451	10.5443
23/02/94	10:37:44	4025	2.47348	48.572	3.844	1.80124	6.94342	2.00098	6.54572	10.52236
23/02/94	10:39:05	4026	2.4773	48.472	3.859	1.80199	6.92755	2.00452	6.53983	10.52675
23/02/94	10:39:27	4026	2.47145	48.545	3.856	1.80124	6.91377	2.00266	6.54531	10.42144
23/02/94	10:39:37	4026	2.45949	48.566	3.862	1.80073	6.92207	2.00098	6.54237	10.42144
23/02/94	10:39:54	4026	2.47145	48.46	3.856	1.80098	6.91638	2.00165	6.52904	10.57063
23/02/94	10:40:11	4026	2.46941	48.463	3.862	1.80098	6.90865	2.00199	6.52979	10.50481
23/02/94	10:40:37	4026	2.48646	48.429	3.856	1.80049	6.90556	2.003	6.5247	10.48287
23/02/94	10:41:39	4027	2.4684	48.557	3.853	1.80073	6.9242	2.00385	6.5516	10.58379
23/02/94	10:42:08	4027	2.47043	48.524	3.85	1.80098	6.92053	2.00351	6.54569	10.49164
23/02/94	10:42:52	4027	2.46662	48.493	3.859	1.79847	6.92624	2.00435	6.54248	10.51358
23/02/94	10:43:22	4027	2.48111	48.396	3.838	1.79822	6.95064	2.00469	6.53145	10.53552
23/02/94	10:44:11	4027	2.48239	48.457	3.862	1.79897	6.90391	2.003	6.53217	10.53991
23/02/94	10:48:18	4023	2.49333	49.137	3.823	1.80049	7.03917	2.00081	6.63483	10.52236
23/02/94	10:48:34	4023	2.49638	49.077	3.82	1.79998	7.03453	2.00233	6.63096	10.43899
23/02/94	10:48:49	4023	2.49409	49.08	3.799	1.80023	7.02551	2.00014	6.627	10.52675
23/02/94	10:48:59	4023	2.49689	49.058	3.814	1.79973	7.02776	2.00148	6.62605	10.5092
23/02/94	10:49:20	4023	2.4918	49.116	3.802	1.80049	7.02429	2.00132	6.636	10.51358
23/02/94	10:55:39	4013	0.6486	50.802	3.588	1.78914	3.97354	1.05532	3.65197	2.92678
23/02/94	10:55:59	4013	0.62087	50.75	3.561	1.79015	3.97493	1.06021	3.66656	2.77759
23/02/94	10:56:09	4013	0.62977	50.725	3.522	1.78939	3.98871	1.05784	3.6591	3.05403
23/02/94	10:56:25	4013	0.69744	50.619	3.464	1.78889	3.97676	1.06004	3.66202	3.1725
23/02/94	10:56:35	4013	0.6893	50.571	3.452	1.78839	3.96536	1.05633	3.64606	3.08474
23/02/94	10:57:04	4013	0.59441	50.486	3.368	1.78889	3.98397	1.05835	3.65208	2.63278
23/02/94	11:01:47	4031	9.2653	45.046	6.421	1.85365	11.90216	4.01798	11.35022	38.15342
23/02/94	11:02:11	4031	9.27573	45.085	6.463	1.8539	11.91952	4.01697	11.34795	38.04812
23/02/94	11:02:23	4031	9.2709	45.043	6.475	1.8544	11.92533	4.01427	11.32383	38.11394
23/02/94	11:02:51	4031	9.25487	45.195	6.58	1.85214	11.8792	4.01612	11.34674	38.06567
23/02/94	11:03:09	4031	9.21138	45.258	6.61	1.85238	11.89719	4.01612	11.35801	37.96474
23/02/94	11:03:19	4031	9.26683	45.313	6.622	1.85238	11.90055	4.01562	11.37011	38.01302
23/02/94	11:03:28	4031	9.23478	45.322	6.637	1.8539	11.9169	4.01663	11.37155	38.02617
23/02/94	11:04:42	4033	9.25131	45.304	6.759	1.8539	11.85572	4.01359	11.32384	38.15781
23/02/94	11:04:57	4033	9.2447	45.356	6.771	1.8544	11.88585	4.0141	11.33787	38.09638
23/02/94	11:05:08	4033	9.25564	45.35	6.771	1.85541	11.90489	4.0114	11.32841	38.07006
23/02/94	11:05:22	4033	9.24266	45.341	6.771	1.85516	11.88545	4.01342	11.33136	37.96913
23/02/94	11:05:32	4033	9.26479	45.353	6.777	1.85415	11.9097	4.01713	11.34384	37.89893
23/02/94	11:06:06	4033	9.23223	45.401	6.786	1.85339	11.85823	4.01309	11.34493	37.99546
23/02/94	11:06:31	4033	9.2185	45.407	6.792	1.85415	11.88292	4.01579	11.35274	38.10955
23/02/94	11:07:12	4033	9.27014	45.398	6.819	1.85415	11.87978	4.01528	11.34104	38.01301
23/02/94	11:09:12	4034	9.21952	45.468	6.873	1.85289	11.89227	4.01275	11.34033	38.12271
23/02/94	11:09:42	4034	9.27624	45.416	6.852	1.8544	11.91588	4.01713	11.34261	38.06566
23/02/94	11:10:00	4034	9.30092	45.447	6.873	1.85314	11.8835	4.01477	11.3396	38.07883
23/02/94	11:10:22	4034	9.25869	45.483	6.91	1.85339	11.86764	4.0146	11.34015	38.14465
23/02/94	11:10:39	4034	9.32228	45.453	6.916	1.8539	11.89515	4.01713	11.33644	38.20608
23/02/94	11:11:05	4034	9.22918	45.508	6.907	1.8544	11.88708	4.01545	11.35104	38.17975
23/02/94	11:11:29	4034	9.2274	45.471	6.898	1.8539	11.87333	4.01629	11.34458	38.1271
23/02/94	11:15:18	4035	9.25233	45.787	7.217	1.85868	11.89544	4.01072	11.3379	38.11393
23/02/94	11:15:45	4035	9.2213	45.887	7.316	1.85843	11.89831	4.01056	11.34087	38.12271
23/02/94	11:16:13	4035	9.23198	45.893	7.341	1.86019	11.88268	4.01342	11.34385	37.99985
23/02/94	11:16:29	4035	9.26683	45.887	7.353	1.85919	11.89692	4.0114	11.33298	38.14904
23/02/94	11:16:39	4035	9.26886	45.844	7.372	1.85793	11.87328	4.01342	11.32053	38.15342
23/02/94	11:17:37	4036	9.24368	45.878	7.399	1.85742	11.86631	4.01292	11.32203	38.19292

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	AI-AVG	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR	TE-WAT
23/02/94	11:17:54	4036	80.836	72.987	72.284	60.635	59.943	59.098	61.169	62.118	62.984	62.682	56.975	21.935	0.998
23/02/94	11:18:03	4036	80.824	72.966	72.302	60.632	59.943	59.073	61.166	62.118	62.936	62.697	56.987	21.913	0.998
23/02/94	11:18:12	4036	80.827	72.987	72.302	60.635	59.927	59.101	61.193	62.148	62.926	62.7	57.003	21.877	0.986
23/02/94	11:18:23	4036	80.888	72.981	72.317	60.654	59.918	59.055	61.199	62.194	62.957	62.712	57.015	21.917	0.998
23/02/94	11:19:24	4037	80.855	73.038	72.238	60.635	55.876	55.676	57.188	62.209	62.884	62.682	56.997	21.831	1.029
23/02/94	11:19:44	4037	80.784	73.011	72.247	60.608	55.788	55.652	57.185	62.23	62.878	62.74	57.045	21.874	1.014
23/02/94	11:20:34	4037	80.818	73.072	72.296	60.66	55.764	55.607	57.158	62.17	63.003	62.734	57.024	21.91	1.017
23/02/94	11:20:44	4037	80.8	73.072	72.262	60.641	55.767	55.637	57.136	62.179	62.994	62.76	57.045	21.907	1.029
23/02/94	11:20:57	4037	80.818	73.044	72.281	60.648	55.764	55.61	57.124	62.242	62.997	62.745	57.069	21.907	1.023
23/02/94	11:28:38	4041	83.85	70.701	70.281	61.506	65.224	63.854	65.707	61.434	62.318	62.321	56.808	21.993	1.047
23/02/94	11:28:58	4041	83.792	70.953	70.482	61.753	65.425	64.064	65.878	61.628	62.534	62.524	56.997	22.015	1.038
23/02/94	11:29:10	4041	83.721	71.078	70.625	61.896	65.495	64.137	65.951	61.725	62.601	62.53	57.033	22.027	1.054
23/02/94	11:29:23	4041	83.737	71.147	70.734	61.987	65.607	64.224	66.027	61.823	62.68	62.627	57.105	21.996	1.057
23/02/94	11:29:35	4041	83.7	71.253	70.786	62.078	65.641	64.285	66.067	61.884	62.787	62.697	57.179	21.981	1.054
23/02/94	11:31:19	4043	83.602	72.015	71.369	62.469	63.851	63.013	64.454	62.312	63.075	62.922	57.7	22.036	1.038
23/02/94	11:31:33	4043	83.617	72.06	71.414	62.533	62.977	64.442	62.358	63.06	62.879	57.764	22.033	1.063	
23/02/94	11:32:19	4043	83.602	72.198	71.527	62.74	63.729	63.123	64.494	62.37	63.182	62.919	57.867	22.011	1.057
23/02/94	11:33:01	4043	83.513	72.328	71.63	62.91	63.659	63.159	64.549	62.343	63.23	62.879	57.919	22.039	1.029
23/02/94	11:33:39	4043	83.421	72.395	71.703	62.998	63.608	63.162	64.592	62.355	63.234	62.913	57.946	22.048	1.041
23/02/94	11:35:33	4044	83.274	72.628	71.736	62.944	63.043	62.847	64.375	62.331	63.143	62.954	58.095	21.941	1.023
23/02/94	11:35:55	4044	83.308	72.689	71.803	63.004	63.064	62.844	64.396	62.401	63.167	63.04	58.089	21.944	1.017
23/02/94	11:36:08	4044	83.339	72.68	71.809	63.035	63.067	62.838	64.329	62.361	63.186	63.04	58.149	21.947	1.008
23/02/94	11:36:22	4044	83.265	72.671	71.785	63.029	63.049	62.81	64.363	62.425	63.206	62.991	58.155	22.008	1.05
23/02/94	11:36:37	4044	83.283	72.652	71.8	62.989	63	62.768	64.363	62.412	63.267	63.064	58.176	22.002	1.023
23/02/94	11:36:48	4044	83.256	72.714	71.779	63.01	63.034	62.755	64.412	62.412	63.286	63.085	58.198	22.005	1.011
23/02/94	11:37:44	4045	83.299	72.735	71.706	62.947	62.34	62.44	64.009	62.449	63.255	63.055	58.243	21.95	1.05
23/02/94	11:38:06	4045	83.299	72.793	71.797	63.029	62.361	62.54	64.052	62.534	63.27	63.092	58.337	21.938	1.014
23/02/94	11:38:17	4045	83.262	72.799	71.843	63.017	62.361	62.574	64.076	62.525	63.319	63.11	58.319	21.95	1.029
23/02/94	11:38:28	4045	83.311	72.808	71.849	63.032	62.337	62.571	64.076	62.525	63.352	63.085	58.398	21.975	1.011
23/02/94	11:38:39	4045	83.329	72.811	71.822	63.041	62.349	62.609	64.067	62.556	63.37	63.119	58.401	21.99	1.017
23/02/94	11:39:43	4046	83.201	72.661	71.861	62.877	61.319	61.04	62.162	62.401	63.37	63.146	58.401	22.024	1.035
23/02/94	11:40:07	4046	83.136	72.686	71.901	62.871	61.276	61.07	62.153	62.383	63.361	63.113	58.419	22.067	1.072
23/02/94	11:40:19	4046	83.195	72.692	71.879	62.864	61.297	61.122	62.129	62.343	63.332	63.155	58.462	22.067	1.075
23/02/94	11:40:29	4046	83.158	72.674	71.882	62.874	61.319	61.061	62.132	62.386	63.392	63.185	58.477	22.048	1.075
23/02/94	11:40:44	4046	83.13	72.646	71.901	62.846	61.316	61.095	62.077	62.334	63.338	63.119	58.416	21.999	1.044
23/02/94	11:40:55	4046	83.13	72.658	71.861	62.84	61.322	61.058	62.104	62.361	63.304	63.107	58.413	21.972	1.035
23/02/94	11:42:04	4047	83.051	72.655	71.727	62.837	58.056	57.668	58.303	62.516	63.167	63.088	58.474	21.92	1.038
23/02/94	11:42:26	4047	83.054	72.692	71.718	62.816	57.989	57.701	58.239	62.437	63.121	63.119	58.45	21.907	1.026
23/02/94	11:42:38	4047	83.054	72.671	71.718	62.804	57.979	57.701	58.23	62.477	63.158	63.098	58.422	21.975	1.02
23/02/94	11:42:51	4047	83.072	72.665	71.724	62.831	57.998	57.728	58.222	62.474	63.173	63.088	58.48	21.999	1.032
23/02/94	11:43:03	4047	83.072	72.686	71.712	62.804	57.989	57.701	58.194	62.443	63.179	63.095	58.435	21.962	1.008
23/02/94	11:43:26	4047	83.054	72.708	71.721	62.81	58.034	57.728	58.188	62.431	63.194	63.009	58.432	21.953	0.977
23/02/94	11:43:45	4047	83.048	72.708	71.67	62.813	58.046	57.707	58.188	62.409	63.2	63.049	58.404	21.877	0.98
23/02/94	11:44:09	4047	83.011	72.756	71.694	62.822	58.016	57.71	58.291	62.492	63.289	63.152	58.498	21.956	1.041
23/02/94	13:54:43	1	24.9	24.856	24.866	23.674	24.945	24.898	25.179	25.071	25.063	25.096	24.13	22.244	1.112
23/02/94	13:54:55	1	24.887	24.874	24.888	23.717	24.973	24.92	25.194	25.097	25.085	25.117	24.172	22.241	1.103
23/02/94	13:55:04	1	24.918	24.898	24.912	23.735	24.994	24.932	25.219	25.109	25.094	25.124	24.214	22.244	1.115
23/02/94	13:55:13	1	24.912	24.919	24.924	23.768	25.012	24.956	25.24	25.128	25.121	25.145	24.263	22.22	1.118
23/02/94	13:55:22	1	24.912	24.935	24.948	23.814	25.036	24.981	25.243	25.131	25.115	25.151	24.288	22.189	1.09
23/02/94	14:04:42	2	15.43	16.597	16.498	17.24	16.415	16.365	16.345	16.364	16.35	16.143	16.291	22.073	1.069
23/02/94	14:05:04	2	15.378	16.521	16.425	17.155	16.351	16.292	16.275	16.305	16.289	16.065	16.172	22.128	1.057
23/02/94	14:05:28	2	15.347	16.468	16.383	17.1	16.315	16.253	16.239	16.294	16.277	16.049	16.142	22.198	1.075
23/02/94	14:05:41	2	15.304	16.423	16.325	17.061	16.273	16.213	16.202	16.266	16.234	16.028	16.103	22.253	1.075
23/02/94	14:05:53	2	15.225	16.396	16.292	17.014	16.246	16.192	16.181	16.254	16.216	16.01	16.075	22.309	1.093
23/02/94	14:06:02	2	15.228	16.362	16.307	16.999	16.246	16.192	16.187	16.245	16.216	16.013	16.069	22.309	1.072
23/02/94	14:12:36	3	11.17	12.635	12.57	13.439	12.486	12.437	12.264	12.444	12.42	12.075	12.298	22.388	1.087
23/02/94	14:12:49	3	11.16	12.599	12.537	13.391	12.438	12.383	12.239	12.41	12.381	12.042	12.261	22.348	1.081
23/02/94	14:13:06	3	11.13	12.577	12.509	13.348	12.413	12.377	12.245	12.416	12.378	12.045	12.232	22.391	1.115
23/02/94	14:13:23	3	11.114	12.52	12.473	13.287	12.371	12.331	12.224	12.388	12.332	12.027	12.205	22.293	1.09
23/02/94	14:13:35	3	11.096	12.492	12.464	13.263	12.352	12.319	12.215	12.367	12.32	12.011	12.159	22.269	1.096
23/02/94	14:20:50	4	10.358	11.579	11.579	12.191	11.502	11.484	11.343	11.461	11.456	11.155	11.152	22.241	1.096
23/02/94	14:20:59	4	10.346	11.582	11.576	12.185	11.505	11.484	11.359	11.507	11.492	11.174	11.184	22.247	1.103
23/02/94	14:21:07	4	10.376	11.61	11.594	12.188	11.526	11.499	11.383	11.537	11.526	11.198	11.203	22.25	1.112
23/02/94	14:21:15	4	10.395	11.622	11.616	12.203	11.535	11.514	11.435	11.549	11.538	11.219	11.212	22.247	1.1
23/02/94	14:21:26	4	10.404	11.646	11.637	12.224	11.566	11.535	11.447	11.57	11.559	11.235	11.23	22.269	1.096
23/02/94	14:26:00	5	9.534	11.002	11.012	11.549	10.881	10.91	10.658	10.908	10.884	10.503	10.529	22.345	1.1
23/02/94	14:26:10	5	9.574	11.012	11.002	11.558	10.884	10.913	10.633	10.908	10.881	10.509	10.511	22.336	1.103
23/02/94	14:34:55	5	8.563	10.049	10.014	10.653	9.896	9.902	9.679	9.923	9.908	9.511	9.526	2	

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	DP2_AVG	IA-OUTAV	5A-IN_AV	POUT_AVG	Pwr_Avg	MF-AVG	HB_AVG	DPI_AVG
23/02/94	11:17:54	4036	9.25284	45.878	7.429	1.85868	11.86567	4.01309	11.31418	37.99107
23/02/94	11:18:03	4036	9.25691	45.893	7.435	1.85868	11.85672	4.01123	11.31186	38.13587
23/02/94	11:18:12	4036	9.21723	45.903	7.444	1.85843	11.86824	4.0146	11.32192	38.1622
23/02/94	11:18:23	4036	9.2302	45.927	7.438	1.85793	11.85482	4.01157	11.32239	38.17976
23/02/94	11:19:24	4037	9.24648	45.899	7.48	1.85893	11.85089	4.01123	11.30121	38.16659
23/02/94	11:19:44	4037	9.26556	45.95	7.471	1.85793	11.86378	4.01815	11.33914	38.13588
23/02/94	11:20:34	4037	9.2419	45.969	7.522	1.85742	11.85731	4.01444	11.32033	38.15781
23/02/94	11:20:44	4037	9.23223	45.978	7.507	1.85717	11.83418	4.01376	11.32533	38.07444
23/02/94	11:20:57	4037	9.20298	45.909	7.519	1.85742	11.84923	4.01511	11.30437	38.11393
23/02/94	11:28:38	4041	19.12718	42.88	9.432	1.88816	15.49517	6.05387	14.84848	80.78698
23/02/94	11:28:58	4041	19.16533	42.968	9.507	1.88665	15.52966	6.04948	14.84697	80.82207
23/02/94	11:29:10	4041	19.16432	42.907	9.522	1.88816	15.49839	6.05185	14.81864	80.8133
23/02/94	11:29:23	4041	19.17805	42.944	9.595	1.88716	15.51579	6.04544	14.78972	80.81769
23/02/94	11:29:35	4041	19.0936	42.971	9.625	1.88716	15.50798	6.051	14.80309	80.7738
23/02/94	11:31:19	4043	19.06765	43.244	9.775	1.88639	15.52435	6.04341	14.84727	80.91422
23/02/94	11:31:33	4043	19.07249	43.232	9.784	1.88463	15.47807	6.04712	14.84714	80.97128
23/02/94	11:32:19	4043	19.06562	43.257	9.809	1.88639	15.53903	6.04561	14.8448	80.77819
23/02/94	11:33:01	4043	19.10225	43.226	9.839	1.88438	15.49753	6.04915	14.82679	80.923
23/02/94	11:33:39	4043	19.10047	43.263	9.845	1.88438	15.52117	6.05016	14.84365	81.05025
23/02/94	11:35:33	4044	19.03916	43.157	9.833	1.88463	15.51794	6.04948	14.79814	80.87912
23/02/94	11:35:55	4044	18.9888	43.214	9.881	1.88438	15.55245	6.05455	14.81695	81.0722
23/02/94	11:36:08	4044	19.03128	43.217	9.89	1.88413	15.53126	6.05353	14.81205	81.08536
23/02/94	11:36:22	4044	19.01118	43.244	9.89	1.88338	15.56632	6.05471	14.82728	81.1073
23/02/94	11:36:37	4044	19.05315	43.193	9.86	1.88338	15.5305	6.05488	14.81649	81.09852
23/02/94	11:36:48	4044	19.02746	43.196	9.872	1.88388	15.5474	6.05522	14.81413	81.01076
23/02/94	11:37:44	4045	18.99719	43.321	9.911	1.88438	15.56817	6.05724	14.85988	81.10291
23/02/94	11:38:06	4045	19.09614	43.366	9.914	1.88413	15.56286	6.06298	14.89376	81.23455
23/02/94	11:38:17	4045	19.12362	43.366	9.908	1.88514	15.57996	6.06045	14.89006	81.36179
23/02/94	11:38:28	4045	19.04781	43.412	9.941	1.88413	15.53866	6.06264	14.90265	81.34425
23/02/94	11:38:39	4045	19.01398	43.421	9.938	1.88539	15.57999	6.06349	14.91012	81.28721
23/02/94	11:39:43	4046	19.03	43.333	9.929	1.88388	15.57214	6.06062	14.86612	81.40129
23/02/94	11:40:07	4046	19.0183	43.384	9.935	1.88388	15.56355	6.06129	14.88904	81.37058
23/02/94	11:40:19	4046	18.94403	43.378	9.944	1.88388	15.56231	6.06163	14.88335	81.37496
23/02/94	11:40:29	4046	19.01195	43.375	9.932	1.88413	15.58352	6.06315	14.89074	81.43201
23/02/94	11:40:44	4046	18.97888	43.324	9.929	1.88211	15.53367	6.06433	14.8711	81.44956
23/02/94	11:40:55	4046	19.02593	43.278	9.938	1.88463	15.60502	6.06534	14.84874	81.3969
23/02/94	11:42:04	4047	19.05672	43.26	9.929	1.88111	15.58404	6.06045	14.8323	81.44079
23/02/94	11:42:26	4047	19.03408	43.269	9.92	1.88187	15.56194	6.06298	14.84639	81.56803
23/02/94	11:42:38	4047	19.00304	43.381	9.947	1.8801	15.55427	6.07074	14.90583	81.51537
23/02/94	11:42:51	4047	18.89137	43.375	9.944	1.88187	15.5472	6.07175	14.90683	81.432
23/02/94	11:43:03	4047	18.99643	43.409	9.944	1.88211	15.54104	6.06585	14.90791	81.43201
23/02/94	11:43:26	4047	18.97481	43.354	9.956	1.88085	15.51896	6.06517	14.87602	81.43639
23/02/94	11:43:45	4047	18.96794	43.33	9.941	1.88111	15.57968	6.07411	14.89279	81.3223
23/02/94	11:44:09	4047	19.04629	43.369	9.956	1.87985	15.55158	6.06551	14.88372	81.6514
23/02/94	13:54:43	1	0.00889	25.278	25.693	1.83273	0	0.49864	-0.01529	0.01755
23/02/94	13:54:55	1	0.01167	25.284	25.708	1.83247	0	0.50033	-0.01568	0
23/02/94	13:55:04	1	0.01142	25.284	25.717	1.83223	0	0.50016	-0.01601	0.01316
23/02/94	13:55:13	1	0.01548	25.321	25.736	1.83247	0	0.49696	-0.01522	0.01316
23/02/94	13:55:22	1	0.01117	25.306	25.757	1.83122	0	0.5005	-0.01666	0
23/02/94	14:04:42	2	0.70736	15.665	15.599	1.7836	0	0.99982	0.00474	3.04964
23/02/94	14:05:04	2	0.76917	15.598	15.55	1.78284	0	1.00741	0.00345	3.212
23/02/94	14:05:28	2	0.78749	15.577	15.481	1.78335	0	1.01044	0.00697	3.3217
23/02/94	14:05:41	2	0.73788	15.535	15.46	1.78234	0	1.00538	0.00538	3.1725
23/02/94	14:05:53	2	0.7679	15.526	15.493	1.78259	0	0.99324	0.00231	3.25588
23/02/94	14:06:02	2	0.73788	15.529	15.472	1.78436	0	1.00994	0.0041	3.13301
23/02/94	14:12:36	3	2.04333	11.394	11.341	1.75916	0	1.488	0.00557	6.88912
23/02/94	14:12:49	3	2.04308	11.361	11.323	1.75916	0	1.48935	0.00404	6.91983
23/02/94	14:13:06	3	2.02121	11.357	11.317	1.75992	0	1.4912	0.00426	6.87595
23/02/94	14:13:23	3	2.06623	11.316	11.278	1.75916	0	1.49019	0.00399	7.08219
23/02/94	14:13:35	3	2.04333	11.297	11.245	1.75916	0	1.49002	0.00548	7.00759
23/02/94	14:20:50	4	2.92602	10.617	10.638	1.75487	0	2.00148	-0.00303	11.4921
23/02/94	14:20:59	4	2.93645	10.619	10.65	1.75538	0	1.99811	-0.00431	11.53159
23/02/94	14:21:07	4	2.92856	10.656	10.68	1.75438	0	2.00047	-0.00338	11.58425
23/02/94	14:21:15	4	2.95069	10.671	10.698	1.75512	0	2.00418	-0.00383	11.77293
23/02/94	14:21:26	4	2.95247	10.684	10.723	1.75538	0	2.00216	-0.00555	11.64129
23/02/94	14:26:00	5	4.42352	9.793	9.854	1.74203	0	2.49304	-0.01041	17.02095
23/02/94	14:26:10	5	4.48458	9.803	9.848	1.74279	0	2.49321	-0.00767	17.293
23/02/94	14:34:55	5	5.91645	8.757	8.759	1.72162	0	3.0573	-0.0004	24.67357
23/02/94	14:35:19	5	5.87601	8.745	8.768	1.72011	0	3.04853	-0.0048	24.42785
23/02/94	14:35:45	6	5.88135	8.736	8.747	1.72136	0	3.05089	-0.00225	24.25671
23/02/94	14:35:54	6	5.90399	8.739	8.741	1.72187	0	3.05949	-0.00036	24.52438
23/02/94	14:42:40	7	11.18075	7.485	7.534	1.68559	0	4.01005	-0.01355	39.89106
23/02/94	14:42:50	7	11.17668	7.482	7.528	1.68559	0	4.01292	-0.01271	39.74626
23/02/94	14:43:33	7	11.16574	7.522	7.579	1.68484	0	4.01056	-0.01588	39.6234
23/02/94	14:43:43	7	11.19423	7.509	7.564	1.68584	0	4.0146	-0.0153	39.79892
23/02/94	14:47:29	8	16.78209	6.851	6.882	1.64149	0	5.0107	-0.01103	59.25519
23/02/94	14:48:00	8	16.72079	6.839	6.876	1.64049	0	5.00936	-0.01306	59.2157
23/02/94	14:48:17	8	16.74775	6.845	6.855	1.64099	0	5.00953	-0.00373	59.37366

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUND	AI-AVG	TCW3A	TCW3B	TCPT2	TCW1A	TCW1B	TCW1C	TCW2A	TCW2B	TCW2C	TCPT3	TE-AIR	TE-WAT
23/02/94	14:48:33	8	6.536	8.313	8.285	8.461	8.128	8.197	7.832	8.112	8.071	7.609	7.427	22.315	1.152
23/02/94	14:48:47	8	6.557	8.3	8.285	8.452	8.122	8.2	7.838	8.118	8.065	7.612	7.424	22.327	1.133
23/02/94	14:52:03	9	6.131	7.906	7.858	8.208	7.709	7.793	7.424	7.72	7.645	7.191	7.081	22.348	1.103
23/02/94	14:52:57	9	6.113	7.879	7.858	8.19	7.7	7.768	7.453	7.729	7.664	7.209	7.116	22.425	1.194
23/02/94	14:53:08	9	6.138	7.87	7.852	8.178	7.691	7.762	7.453	7.726	7.661	7.209	7.113	22.419	1.201
23/02/94	14:53:17	9	6.122	7.861	7.846	8.178	7.685	7.765	7.45	7.717	7.664	7.206	7.104	22.422	1.188
23/02/94	15:08:29	10	2.046	4.097	4.084	4.63	1.859	4.019	3.513	3.849	3.807	3.198	3.227	22.4	1.201
23/02/94	15:17:10	11	5.886	7.524	7.557	7.587	7.399	7.501	7.127	7.41	7.366	6.896	6.598	22.358	1.207
23/02/94	15:17:19	11	5.92	7.536	7.566	7.608	7.417	7.526	7.179	7.407	7.378	6.902	6.607	22.364	1.207
23/02/94	15:17:29	11	5.911	7.548	7.572	7.629	7.426	7.55	7.179	7.41	7.383	6.911	6.622	22.348	1.188
23/02/94	15:17:40	11	5.932	7.554	7.572	7.635	7.423	7.556	7.192	7.425	7.395	6.914	6.634	22.351	1.198
23/02/94	15:18:17	11	5.966	7.596	7.581	7.666	7.435	7.562	7.21	7.422	7.389	6.948	6.662	22.345	1.191
23/02/94	15:37:23	12	17.687	18.344	18.322	18.11	18.351	18.284	18.296	18.404	18.409	18.264	17.78	22.284	1.198
23/02/94	15:37:31	12	17.656	18.347	18.325	18.113	18.357	18.29	18.302	18.411	18.412	18.279	17.786	22.29	1.198
23/02/94	15:37:40	12	17.669	18.356	18.337	18.119	18.363	18.29	18.317	18.414	18.418	18.298	17.798	22.293	1.201
23/02/94	15:37:48	12	17.69	18.359	18.358	18.129	18.369	18.299	18.329	18.437	18.436	18.313	17.816	22.305	1.21
23/02/94	15:52:59	13	21.24	21.632	21.624	21.29	21.645	21.592	21.792	21.789	21.8	21.755	21.199	22.358	1.176
23/02/94	15:53:08	13	21.283	21.641	21.634	21.302	21.645	21.598	21.753	21.753	21.764	21.729	21.175	22.336	1.145
23/02/94	15:53:18	13	21.249	21.657	21.652	21.326	21.664	21.604	21.768	21.764	21.773	21.732	21.184	22.345	1.133
23/02/94	15:53:27	13	21.258	21.672	21.661	21.344	21.667	21.613	21.774	21.767	21.785	21.735	21.196	22.364	1.121
23/02/94	15:53:37	13	21.279	21.675	21.661	21.366	21.676	21.617	21.774	21.773	21.773	21.735	21.205	22.345	1.167
23/02/94	16:05:43	14	32.146	31.764	31.6	30.452	31.477	31.719	31.94	31.888	31.91	32.271	31.041	22.569	1.198
23/02/94	16:06:19	14	32.17	31.822	31.642	30.586	31.608	31.759	32.016	31.944	31.965	32.28	31.128	22.557	1.204
23/02/94	16:06:36	14	32.198	31.84	31.67	30.62	31.64	31.78	32.044	31.995	32.008	32.295	31.174	22.581	1.21
23/02/94	16:10:15	14	32.253	32.004	31.827	31.01	31.795	31.887	32.12	32.144	32.126	32.317	31.444	22.603	1.231
23/02/94	16:10:33	14	32.278	31.995	31.827	31.032	31.804	31.893	32.114	32.132	32.123	32.317	31.468	22.6	1.25
23/02/94	16:11:50	14	32.308	32.058	31.885	31.135	31.859	31.929	32.156	32.157	32.138	32.317	31.529	22.566	1.237
23/02/94	16:12:31	14	32.247	32.016	31.83	31.138	31.826	31.893	32.156	32.157	32.135	32.317	31.541	22.569	1.234
23/02/94	16:28:21	15	36.204	35.37	35.26	34.225	35.309	35.259	35.695	35.55	35.52	35.835	34.887	22.437	1.198
23/02/94	16:28:37	15	36.222	35.403	35.285	34.277	35.345	35.292	35.716	35.572	35.544	35.863	34.911	22.449	1.213
23/02/94	16:31:04	15	36.284	35.61	35.4	34.527	35.521	35.426	35.881	35.72	35.702	35.988	35.17	22.333	1.194
23/02/94	16:31:18	15	36.29	35.628	35.418	34.552	35.548	35.45	35.893	35.729	35.711	36.009	35.188	22.33	1.188
23/02/94	16:39:09	16	40.66	39.55	39.39	38.306	39.475	39.409	39.987	39.777	39.802	40.223	39.17	22.514	1.17
23/02/94	16:39:17	16	40.672	39.562	39.393	38.321	39.484	39.415	39.987	39.786	39.83	40.229	39.177	22.517	1.182
23/02/94	16:39:40	16	40.648	39.583	39.402	38.346	39.508	39.43	39.98	39.78	39.836	40.223	39.204	22.52	1.133
23/02/94	16:40:16	16	40.7	39.616	39.408	38.391	39.523	39.427	40.017	39.792	39.845	40.24	39.256	22.544	1.1
23/02/94	16:40:41	16	40.709	39.631	39.43	38.434	39.548	39.436	40.039	39.82	39.866	40.252	39.282	22.511	1.109
23/02/94	16:52:02	17	48.62	46.859	46.642	44.838	46.824	46.679	47.598	47.161	47.257	47.835	46.26	22.48	1.191
23/02/94	16:52:11	17	48.608	46.856	46.642	44.841	46.827	46.682	47.595	47.17	47.257	47.822	46.263	22.452	1.191
23/02/94	16:52:20	17	48.66	46.865	46.648	44.85	46.827	46.682	47.562	47.128	47.238	47.792	46.226	22.407	1.121
23/02/94	17:06:34	18	62.384	59.376	58.954	56.302	59.38	59.261	60.584	59.767	60.068	60.913	58.577	22.422	1.121
23/02/94	17:06:46	18	62.417	59.409	58.996	56.354	59.426	59.319	60.598	59.771	60.074	60.929	58.589	22.394	1.09
23/02/94	17:06:55	18	62.417	59.433	59.018	56.376	59.444	59.337	60.613	59.782	60.086	60.937	58.608	22.367	1.078
23/02/94	17:07:05	18	62.424	59.436	59.018	56.391	59.444	59.334	60.623	59.776	60.068	60.949	58.62	22.324	1.063

Table A.2-2: 30% ring data (cont.'d)

DATE	TIME	RUNID	DP2_AVG	IA-OUTAV	SA-IN_AV	POUT_AVG	Pwr_Avg	MF-AVG	HB_AVG	DPI_AVG
23/02/94	14:48:33	8	16.72282	6.829	6.861	1.64074	0	5.01003	-0.01129	59.27713
23/02/94	14:48:47	8	16.74292	6.823	6.855	1.64074	0	5.01155	-0.01127	59.22886
23/02/94	14:52:03	9	20.79435	6.361	6.402	1.59236	0	6.03531	-0.01729	82.7835
23/02/94	14:52:57	9	20.81216	6.352	6.399	1.59161	0	6.03852	-0.01977	82.98535
23/02/94	14:53:08	9	20.81419	6.346	6.381	1.59262	0	6.03548	-0.01472	82.91514
23/02/94	14:53:17	9	20.85108	6.349	6.396	1.59136	0	6.04274	-0.01977	83.00729
23/02/94	15:08:29	10	21.18049	2.185	2.209	1.56087	0	6.07968	-0.00996	84.13939
23/02/94	15:17:10	11	21.02202	6.13	6.186	1.58203	0	6.08255	-0.02309	83.81467
23/02/94	15:17:19	11	21.03652	6.107	6.168	1.58304	0	6.08103	-0.02549	83.94631
23/02/94	15:17:29	11	21.08892	6.139	6.186	1.58304	0	6.08103	-0.01934	84.05601
23/02/94	15:17:40	11	21.04796	6.158	6.198	1.58254	0	6.08407	-0.01649	84.22276
23/02/94	15:18:17	11	21.04975	6.179	6.189	1.58355	0	6.07833	-0.00396	84.01214
23/02/94	15:37:23	12	20.44688	17.94	18.042	1.65914	0	6.06787	-0.04432	83.23547
23/02/94	15:37:31	12	20.48452	17.943	18.051	1.65914	0	6.06585	-0.04695	83.06872
23/02/94	15:37:40	12	20.49419	17.971	18.054	1.65812	0	6.06821	-0.03616	83.30567
23/02/94	15:37:48	12	20.49139	17.958	18.054	1.65938	0	6.065	-0.04177	83.35394
23/02/94	15:32:59	13	20.31027	21.597	21.684	1.68206	0	6.07057	-0.03856	83.38026
23/02/94	15:53:08	13	20.2823	21.597	21.675	1.68257	0	6.07327	-0.03457	83.43291
23/02/94	15:53:18	13	20.28128	21.616	21.705	1.68155	0	6.07799	-0.03959	83.24863
23/02/94	15:53:27	13	20.28255	21.621	21.711	1.68155	0	6.07091	-0.03957	83.45048
23/02/94	15:53:37	13	20.3057	21.627	21.705	1.68206	0	6.0731	-0.03428	83.26179
23/02/94	16:05:43	14	19.79695	32.571	32.719	1.67954	0	6.0338	-0.06693	82.66064
23/02/94	16:06:19	14	19.82086	32.617	32.759	1.67828	0	6.03936	-0.06405	82.59482
23/02/94	16:06:36	14	19.83154	32.625	32.783	1.67954	0	6.03329	-0.07082	82.58166
23/02/94	16:10:15	14	19.83358	32.665	32.843	1.67652	0	6.04004	-0.08015	82.57288
23/02/94	16:10:33	14	19.82798	32.677	32.852	1.67501	0	6.0365	-0.07881	82.7089
23/02/94	16:11:50	14	19.82493	32.726	32.901	1.67551	0	6.037	-0.07905	82.65625
23/02/94	16:12:31	14	19.81043	32.665	32.855	1.67601	0	6.04071	-0.08559	82.65186
23/02/94	16:28:21	15	14.60744	36.534	36.729	1.74328	0	4.99417	-0.07321	57.99584
23/02/94	16:28:37	15	14.58276	36.55	36.741	1.74354	0	4.99535	-0.07178	57.91685
23/02/94	16:31:04	15	14.41106	36.632	36.844	1.74101	0	4.99164	-0.07962	57.94757
23/02/94	16:31:18	15	14.49017	36.648	36.838	1.74127	0	4.99114	-0.07137	57.7545
23/02/94	16:39:09	16	10.12458	41.003	41.258	1.77226	0	4.08883	-0.07932	39.51808
23/02/94	16:39:17	16	10.14799	41.039	41.285	1.77201	0	4.08798	-0.07631	39.46543
23/02/94	16:39:40	16	10.1139	41.033	41.285	1.771	0	4.08714	-0.07814	39.53564
23/02/94	16:40:16	16	10.13578	41.054	41.294	1.77074	0	4.08798	-0.07449	39.50931
23/02/94	16:40:41	16	10.14951	41.06	41.3	1.77125	0	4.0895	-0.07453	39.55573
23/02/94	16:52:02	17	5.30646	49.031	49.346	1.84407	0	3.05393	-0.07392	21.65026
23/02/94	16:52:11	17	5.27975	49.022	49.358	1.84206	0	3.05325	-0.07883	21.72924
23/02/94	16:52:20	17	5.32935	49.018	49.328	1.84281	0	3.05882	-0.07282	21.93109
23/02/94	17:06:34	18	2.06012	62.942	63.481	1.86196	0	2.25873	-0.09907	7.20066
23/02/94	17:06:46	18	2.05987	63	63.505	1.85516	0	2.24726	-0.09244	7.21383
23/02/94	17:06:55	18	2.00085	63	63.49	1.85062	0	2.22803	-0.08892	7.4069
23/02/94	17:07:05	18	2.01714	62.991	63.442	1.86271	0	2.18316	-0.08015	7.24454

A.3 Heat Transfer Analysis

A.3.1 Analysis Procedures

- Energy balance: based on the mass flow rate ($\dot{m}$), inlet fluid temperature (T_{in}), outlet fluid temperature (T_{out}), and test section power (Q), the following energy balance is defined:

$$\begin{aligned} Q_{loss} &= Q - Q_b \\ &= Q - \dot{m} [H_f(T_{out}) - H_f(T_{in})] \end{aligned} \quad (A.1)$$

where H_f is the saturated liquid enthalpy (J/kg) based on fluid temperature, and Q_{loss} is the balance of energy lost.

- Heat loss: with the outer surface temperature measured at various locations along the tube, assuming a uniform resistance wall heating, the following relations are used to formulate the heat loss:

$$Q_{loss} = \int_0^L U_o P_{wo} (T_{wo} - T_{\infty}) dz \quad (A.2)$$

From a conservation of energy on the wall:

$$T_w(z) = a_1 z + b_1 \quad (A.3)$$

and

$$\begin{aligned} Q_{loss} &= U_o P_o \int_0^{L_h} (a_1 z + b_1 - T_{\infty}) dz \\ &= U_o \pi d_o \left\{ a_1 \frac{L_h^2}{2} + (b_1 - T_{\infty}) L_h \right\} \\ &= U_o(AT) \end{aligned} \quad (A.4)$$

An overall heat transfer coefficient (U_o) is defined over the outer surface area, based on the outer perimeter (P_o) and outer diameter (d_o) of the tube. The mean area-temperature difference (AT) is computed from a linear regression of the average wall temperature at each thermocouple location, to obtain (a_1, b_1). Then, U_o is derived from a linear regression of the heat loss (Q_{loss}) versus AT data.

- Radial wall temperature distribution: assuming no heat losses, the radial wall temperature distribution is derived from a conservation of energy resulting in:

$$\frac{T_w(r) - T_{wo}}{T_{wi} - T_{wo}} = \frac{\frac{1}{2} \frac{S}{K} r_o^2 \ln\left(\frac{r}{r_o}\right) - \frac{1}{4} \frac{S}{K} (r^2 - r_o^2)}{\frac{1}{2} \frac{S}{K} r_o^2 \ln\left(\frac{r_i}{r_o}\right) - \frac{1}{4} \frac{S}{K} (r_i^2 - r_o^2)} \quad (\text{A.5})$$

where K is the thermal conductivity of the tube ($\text{W/m} \cdot ^\circ\text{C}$), and S is the volumetric heat generation (W/m^3):

$$S = \frac{Q}{\pi \left(\frac{d_o^2 - d_i^2}{4} \right) L_h} = \frac{4Q}{\pi (d_o^2 - d_i^2) L_h} \quad (\text{A.6})$$

Since T_{wo} and Q are both measured, the above relation is used to compute the inner tube wall temperature as:

$$T_{wi} = T_{wo} - \frac{Q}{4 \pi K L_h} \left\{ 2 \left(\frac{d_o^2}{d_o^2 - d_i^2} \right) \ln\left(\frac{d_o}{d_i}\right) - 1 \right\} = T_{wo} - C_w Q \quad (\text{A.7})$$

If heat losses were included in the formulation, the following modified equation would be obtained:

$$\begin{aligned} T_{wi} &= T_{wo} - C_w Q + \frac{U_o r_o}{K} (T_{wo} - T_\infty) \ln\left(\frac{r_o}{r_i}\right) \\ &\approx T_{wo} - C_w Q + \frac{Q_{loss} r_o}{K (AT)} (T_{wo} - T_\infty) \ln\left(\frac{d_o}{d_i}\right) \end{aligned} \quad (\text{A.8})$$

- Forced tube convection: the same energy equation can be used to define the heat transfer coefficient on the inner wall of the tube:

$$h_i = \frac{Q}{\pi d_i L_h (T_{wi} - T_f)} \quad (\text{A.9})$$

where the effects of heat loss have been ignored (i.e., to be treated as an error term).

- Local fluid temperature: since the fluid temperature is only measured at the inlet and outlet of the test section, the following energy equation is used to determine the bulk fluid temperature at the wall temperature thermocouple directly downstream of the flow obstacle:

$$\dot{Q}_b = \dot{m} [H_f(T_{out}) - H_f(T_{in})] \approx q_w \pi d_i L_h \quad (\text{A.10})$$

since the tube heat flux (q_w) is uniform, and all conditions at steady-state:

$$\frac{dH_f}{dz} = \frac{H_{f,o} - H_{f,i}}{L_h} \approx \frac{q_w \pi d_i}{\dot{m}} = \text{const} \quad (\text{A.11})$$

The local liquid enthalpy and temperature are defined by:

$$H_f(z) = H_{f,i} + \frac{dH_f}{dz} \cdot z = H_{f,i} + \frac{\dot{Q}}{\dot{m}} \left(\frac{z}{L_h} \right) \quad (\text{A.12})$$

$$T_f(z) = f(H_f(z)) \quad (\text{A.13})$$

- Local Nusselt number: based on forced tube convection, the Nusselt number is defined as:

$$\text{Nu} = \frac{h d_i}{K_f} \quad (\text{A.14})$$

where K_f is the thermal conductivity of the fluid, based on a local bulk fluid temperature and corresponding saturation fluid properties. The values of Nu derived from the reference tube experiment are compared with the following empirical correlations:

- Dittus and Boelter (1930):

$$\text{Nu} = 0.023 \text{Re}^{0.8} \text{Pr}^{0.4} \quad 0.6 < \text{Pr} < 100 \quad (\text{A.15})$$

Note: all fluid properties evaluated at the bulk fluid temperature, T_f .

- Sieder and Tate (1936):

$$\text{Nu} = 0.027 \text{Re}^{0.8} \text{Pr}^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} \quad (\text{A.16})$$

Note: all fluid properties except μ_w evaluated at the bulk fluid temperature, T_f .

- Petukhov (1970):

$$Nu = \frac{(f/8) Re Pr}{1.07 + 12.7 (f/8)^{1/2} (Pr^{2/3} - 1)} \left(\frac{\mu_b}{\mu_w} \right)^n \quad (A.17)$$

$$f = (1.82 \log_{10} Re - 1.64)^{-2} \quad n = 0 \quad (\text{constant heat flux}) \quad (A.18)$$

where

$$\begin{aligned} 0.5 < Pr_f < 200 & \quad \text{for 6\% accuracy} \\ 200 < Pr_f < 2000 & \quad \text{for 10\% accuracy} \\ 10^4 < Re_f < 5 \times 10^6 \\ 0 < \frac{\mu_b}{\mu_w} < 40 \end{aligned}$$

Note: all fluid properties except μ_b and μ_w evaluated at $T_{\text{film}} = (T_w + T_f)/2$.

- Reynolds number:

$$Re = \frac{\rho_f u d_i}{\mu_f} = \frac{G d_i}{\mu_f} = \frac{\dot{m} d_i}{\mu_f A_x} \quad (A.19)$$

- Prandlt number:

$$Pr = \frac{\mu_f C_{pf}}{K_f} \quad (A.20)$$

- Heat transfer enhancement: the following ratio of Nusselt numbers (with and without flow obstruction) are defined as a function of the non-dimensional downstream distance (z/d):

$$R_{Nu} = \frac{Nu_{\text{obs}}}{Nu_o} = \frac{Nu(z/d)}{Nu(\infty)} \approx \frac{Nu(z)}{Nu(z_{\text{max}})} \quad \left(\frac{z_{\text{max}}}{d} \approx 30 \right) \quad (A.21)$$

A.3.2 Error Analysis

- The following section describes the errors associated with instrumentation used in the single-phase heat transfer experiment. Errors resulting from this analysis are quoted

either as an RMS error or standard deviation (σ), combining both systematic and random errors. If one assumes these errors are perfectly random and normally distributed about the mean value measured, then 68% of the data will lie within $\pm 1\sigma$, and 95% within $\pm 2\sigma$. This is an important characteristic when considering the significance of measured data: if the error estimates are correct, about 70% of the data should fall within $\pm 1\sigma$, and all the data should fall within $\pm 2\sigma$, otherwise there is a systematic error unaccounted for.

- Thermocouple calibration: the fluid and wall temperature thermocouples were calibrated using a digital RTD thermometer at AECL (calibrated by the NRC on a regular basis) and a water bath ranging in temperature from 0–100°C. Standard thermocouple curves, used by the DAS and provided by the TC manufacturer, were post-corrected using a polynomial regression of these RTD vs. TC readings. The following RTD and TC accuracy is quoted:

RTD:	$\pm 0.03^\circ\text{C}$ (RMS)	$\pm 0.05^\circ\text{C}$ (MAX)
TC:	$\pm 0.06^\circ\text{C}$ (RMS)	$\pm 0.2^\circ\text{C}$ (MAX)

For the purpose of this error analysis, an RMS value of $\pm 0.1^\circ\text{C}$ is used for all the thermocouples.

- Mass flow rate: a Coriolis-type flow meter (Model D65 by Micro Motion), used in both the single-phase and CHF experiments, and is characterized as:

accuracy	=	$\pm 0.2\%$
repeatability	=	$\pm 0.05\%$
zero stability	=	± 0.23 g/s
A/D conversion	=	$\pm 0.1\%$ F.S. (F.S. = 1333 g/s)

The resultant RMS error in $\dot{m}$ (g/s) is given by:

$$\begin{aligned}\frac{\Delta \dot{m}}{\dot{m}} &= \sqrt{\left(\frac{0.2}{100}\right)^2 + \left(\frac{0.05}{100}\right)^2 + \left(\frac{0.23}{\dot{m}}\right)^2 + \left(\frac{1.33}{\dot{m}}\right)^2} \\ &= \sqrt{4.25 \times 10^{-6} + \left(\frac{1.82}{\dot{m}}\right)^2}\end{aligned}\tag{A.22}$$

which ranged from 0.4–5.0% in this experiment ($\dot{m} = 25\text{--}400$ g/s).

- Test section power (Q): measured by the voltage drop across the test section (U) and a current through the shunt resistor (I), the product of which gives the power; has the following measurement characteristics:

maximum offset voltage	=	±0.2%
uncertainty in current	=	±2.9A
A/D conversion	=	±0.14%

The RMS error can be calculated by:

$$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta U}{U}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\frac{0.14}{100}\right)^2} \quad (\text{A.23})$$

where the test section is assumed to have an average electrical resistance of 0.074 Ω for the purpose of these calculations:

$$\text{Ex) } Q = 2000 \text{ W: } I = \sqrt{\frac{Q}{R}} = \sqrt{\frac{2000}{0.074}} = 164.4 \text{ A} \quad (\text{A.24})$$

$$U = \frac{Q}{I} = \frac{2000}{164.4} = 12.2 \text{ V} \quad (\text{A.25})$$

$$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{0.2}{100}\right)^2 + \left(\frac{2.9}{164.4}\right)^2 + \left(\frac{0.14}{100}\right)^2} = 0.018 \quad (\text{A.26})$$

The uncertainty in Q ranged from 0.6–2.0% for this experiment where Q varied from 2 to 20 kW.

- Latent heat transfer rate: used in the energy balance to compute the heat losses:

$$Q_b = \dot{m} [H_f(T_{out}) - H_f(T_{in})] = \dot{m} (H_{fo} - H_{fi}) \quad (\text{A.27})$$

which has the following uncertainty:

$$\Delta Q_b = \sqrt{\left(\frac{\partial Q_b}{\partial \dot{m}} \Delta \dot{m}\right)^2 + \left(\frac{\partial Q_b}{\partial H_{fo}} \Delta H_{fo}\right)^2 + \left(\frac{\partial Q_b}{\partial H_{fi}} \Delta H_{fi}\right)^2} \quad (\text{A.28})$$

$$\frac{\partial Q_b}{\partial \dot{m}} = (H_{fo} - H_{fi}) ; \quad \frac{\partial Q_b}{\partial H_{fo}} = \frac{\partial Q_b}{\partial H_{fi}} = \dot{m} \quad (\text{A.29})$$

$$\therefore \Delta Q_b = \sqrt{[\Delta \dot{m} (H_{fo} - H_{fi})]^2 + [\dot{m} \Delta H_{fo}]^2 + [\dot{m} \Delta H_{fi}]^2} \quad (\text{A.30})$$

The uncertainty in the liquid enthalpy can be derived from the error in both fluid properties (Δf) and fluid temperature (ΔT):

$$\Delta H_f = \sqrt{\left[\frac{\Delta f(T_f)}{f(T_f)} H_f \right]^2 + \left(\frac{\partial H_f}{\partial T} \Delta T \right)^2} \quad (\text{A.31})$$

According to Hammouda et al. (1993): $\frac{\Delta f(T_f)}{f(T_f)} = \pm 0.14\%$; resulting in ΔH_f ranging from 0.2–0.3%, and ΔQ_b ranging from 3–140 W.

- Heat loss: combining errors in both power and latent heat transfer rates, the following uncertainty is calculated for heat loss:

$$\begin{aligned} \Delta Q_{loss} &= \sqrt{\left(\frac{\partial Q_{loss}}{\partial Q} \Delta Q \right)^2 + \left(\frac{\partial Q_{loss}}{\partial Q_b} \Delta Q_b \right)^2} \\ &= \sqrt{(\Delta Q)^2 + (\Delta Q_b)^2} \end{aligned} \quad (\text{A.32})$$

producing uncertainties ranging from 3–200 W.

- Inner wall temperature: the errors associated with the calculated inner surface wall temperature are:

$$\Delta T_{wi} = \sqrt{\left(\frac{\partial T_{wi}}{\partial T_{wo}} \Delta T_{wo} \right)^2 + \left(\frac{\partial T_{wi}}{\partial Q} \Delta Q \right)^2 + \left(\frac{\partial T_{wi}}{\partial Q_{loss}} \Delta Q_{loss} \right)^2} \quad (\text{A.33})$$

where:

$$\frac{\partial T_{wi}}{\partial T_{wo}} = 1, \quad \frac{\partial T_{wi}}{\partial Q} = C_w, \quad \frac{\partial T_{wi}}{\partial Q_{loss}} = \frac{r_o(T_{wo} - T_{\infty})}{K(AT)} \ln \left(\frac{d_o}{d_i} \right) \quad (\text{A.34})$$

which result in uncertainties ranging from 0.1–3.4°C.

- Local fluid temperature: similar to the latent heat transfer rate, the local fluid temperature used to calculate the tube convection heat transfer rate, is subject to the same uncertainties in liquid enthalpy:

$$\Delta T_f(z) = \frac{\partial T_f(z)}{\partial H_f(z)} \Delta H_f(z), \quad \frac{\partial T_f(z)}{\partial H_f(z)} = \frac{1}{\frac{\partial H_f}{\partial T_f}} = \frac{1}{C_{pf}(T)} \quad (\text{A.35})$$

where:

$$\Delta H_f(z) = \sqrt{\left(\frac{\partial H_f(z)}{\partial H_f} \Delta H_f\right)^2 + \left(\frac{\partial H_f(z)}{\partial Q} \Delta Q\right)^2 + \left(\frac{\partial H_f(z)}{\partial \dot{m}} \Delta \dot{m}\right)^2 + \left(\frac{\partial H_f(z)}{\partial z} \Delta z\right)^2 + \left(\frac{\partial H_f(z)}{\partial L_h} \Delta L_h\right)^2} \quad (\text{A.36})$$

$$\frac{\partial H_f(z)}{\partial H_f} = 1$$

$$\frac{\partial H_f(z)}{\partial Q} = \frac{1}{\dot{m}} \left(\frac{z}{L_h} \right)$$

$$\frac{\partial H_f(z)}{\partial \dot{m}} = \frac{-Q}{\dot{m}^2} \left(\frac{z}{L_h} \right) \quad \begin{array}{l} z = 0.930 \pm 0.0005 \\ L_h = 2.075 \pm 0.0005 \end{array} \quad (\text{A.37})$$

$$\frac{\partial H_f(z)}{\partial z} = \frac{Q}{\dot{m} L_h}$$

$$\frac{\partial H_f(z)}{\partial L_h} = -\frac{Q}{\dot{m}} \left(\frac{z}{L_h^2} \right)$$

resulting in uncertainties ranging from 0.1–0.8 °C.

- Convective heat transfer coefficient: the following relation describes the error associated with calculations of the tube-side heat transfer coefficient:

$$\Delta h = \sqrt{\left(\frac{\partial h}{\partial Q} \Delta Q\right)^2 + \left(\frac{\partial h}{\partial d_i} \Delta d_i\right)^2 + \left(\frac{\partial h}{\partial L_h} \Delta L_h\right)^2 + \left(\frac{\partial h}{\partial T_w} \Delta T_w\right)^2 + \left(\frac{\partial h}{\partial T_f} \Delta T_f\right)^2} \quad (\text{A.38})$$

$$\frac{\partial h}{\partial Q} = \frac{1}{\pi d_i L_h (T_w - T_f)}$$

$$\frac{\partial h}{\partial d_i} = \frac{-Q}{\pi d_i^2 L_h (T_w - T_f)}$$

$$\frac{\partial h}{\partial L_h} = \frac{-Q}{\pi d_i L_h^2 (T_w - T_f)}$$

$$\frac{\partial h}{\partial T} = \frac{\pm Q}{\pi d_i L_h (T_w - T_f)^2}$$

$$d_i = 0.008 \pm 0.00005$$

$$L_h = 2.075 \pm 0.0005$$

(A.39)

resulting in uncertainties ranging from 2–10%, which are assumed to be the same for the Nusselt number (i.e., error in d_i and K_f are negligible in comparison).

- Enhancement ratio: the following relation was derived for the uncertainties in local heat

transfer enhancement,

$$\begin{aligned}\Delta R_{Nu} &= \sqrt{\left[\frac{\partial R}{\partial Nu(z)} \Delta Nu(z) \right]^2 + \left[\frac{\partial R}{\partial Nu(\infty)} \Delta Nu(\infty) \right]^2} \\ &= \sqrt{\left[\frac{\Delta Nu(z)}{Nu(\infty)} \right]^2 + \left[R_{Nu} \frac{\Delta Nu(\infty)}{Nu(\infty)} \right]^2}\end{aligned}\tag{A.40}$$

with results ranging from 2–15%.

A.3.3 Calculated Data Tables

The analyzed data are presented in two spreadsheet tables:

Table A.3-1: Calculated heat loss data (661 points)

Table A.3-2: Convection data with power (383 points)

Table A.3-1: Calculated heat loss data

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
Reference Tube Tests													
28/01/94	11:12:54	0	0		38.4	1.35	145.6	10.9	-145.6	10.9	1.102	10.7	-0.67
28/01/94	12:13:43	0	0		74.2	1.36	220.0	19.7	-220.0	19.7	1.113	14.0	-0.47
28/01/94	14:26:45	0	0		207.6	1.42	4.9	48.9	-4.9	48.9	1.131	2.5	-1.21
28/01/94	14:28:31	0	0		207.8	1.42	6.7	49.0	-6.7	49.0	1.095	2.5	-1.22
28/01/94	14:31:12	0	0		204.6	1.41	-32.7	50.6	32.7	50.6	1.040	7.5	-0.90
28/01/94	14:32:01	0	0		204.6	1.41	-35.6	50.9	35.6	50.9	1.080	7.9	-0.88
28/01/94	14:36:57	0	0		204.1	1.41	-70.7	56.6	70.7	56.6	1.108	19.8	-0.11
28/01/94	14:37:53	0	0		204.1	1.41	-56.6	56.6	56.6	56.6	1.086	20.2	-0.10
28/01/94	14:39:36	0	0		204.2	1.41	-77.6	56.8	77.6	56.8	1.098	20.6	-0.07
28/01/94	14:49:49	0	0		204.7	1.41	-42.3	57.4	42.3	57.4	0.812	22.4	0.03
28/01/94	14:52:32	0	0		204.3	1.41	-37.6	57.0	37.6	57.0	0.978	21.9	0.01
28/01/94	14:54:31	0	0		204.4	1.41	-40.7	57.0	40.7	57.0	0.959	21.9	0.00
28/01/94	15:00:35	0	0		204.6	1.41	-47.3	57.1	47.3	57.1	0.986	21.8	0.00
28/01/94	15:01:38	0	0		204.7	1.41	-51.1	57.1	51.1	57.1	0.946	21.8	0.01
28/01/94	15:13:52	0	0		205.1	1.41	-40.8	57.2	40.8	57.2	0.962	21.9	-0.01
28/01/94	15:32:42	0	0		204.8	1.41	-41.4	57.2	41.4	57.2	0.577	22.8	0.02
28/01/94	15:32:42	0	0		204.8	1.41	-41.4	57.2	41.4	57.2	0.577	22.8	0.02
31/01/94	14:40:18	0	0		38.8	1.35	21.0	9.3	-21.0	9.3	1.164	3.2	-0.99
31/01/94	14:41:03	0	0		54.6	1.35	14.8	12.9	-14.8	12.9	1.156	3.1	-1.00
31/01/94	14:41:49	0	0		54.6	1.35	21.0	12.9	-21.0	12.9	1.153	3.0	-1.00
31/01/94	14:42:47	0	0		54.4	1.35	4.6	12.9	-4.6	12.9	1.201	2.9	-1.01
31/01/94	14:44:55	0	0		102.2	1.37	9.7	24.1	-9.7	24.1	1.199	2.5	-1.03
31/01/94	14:45:33	0	0		102.4	1.37	16.2	24.2	-16.2	24.2	1.224	2.4	-1.04
31/01/94	14:46:03	0	0		102.4	1.37	16.2	24.2	-16.2	24.2	1.172	2.4	-1.04
31/01/94	14:46:49	0	0		102.3	1.37	26.5	24.1	-26.5	24.1	1.142	2.3	-1.05
31/01/94	14:51:37	0	0		102.6	1.37	-0.3	25.1	0.3	25.1	1.097	6.1	-0.80
31/01/94	14:52:35	0	0		102.7	1.37	5.2	25.1	-5.2	25.1	1.111	6.3	-0.79
31/01/94	14:53:37	0	0		102.7	1.37	-3.2	25.1	3.2	25.1	1.080	6.4	-0.79
31/01/94	14:54:56	0	0		102.7	1.37	-0.6	25.2	0.6	25.2	1.056	6.5	-0.79
31/01/94	14:55:31	0	0		102.6	1.37	-4.1	25.1	4.1	25.1	1.086	6.5	-0.79
31/01/94	14:59:39	0	0		102.9	1.37	-40.5	26.7	40.5	26.7	0.965	12.3	-0.42
31/01/94	15:00:17	0	0		102.7	1.37	-21.0	26.6	21.0	26.6	0.883	12.6	-0.40
31/01/94	15:00:59	0	0		103.0	1.37	-12.1	26.7	12.1	26.7	0.895	12.8	-0.38
31/01/94	15:01:51	0	0		102.9	1.37	-17.9	26.7	17.9	26.7	0.895	13.0	-0.38
31/01/94	15:03:01	0	0		103.0	1.37	-16.3	26.7	16.3	26.7	0.950	13.2	-0.37
31/01/94	15:08:58	0	0		102.8	1.37	-12.5	26.7	12.5	26.7	0.842	13.5	-0.36
31/01/94	15:10:12	0	0		103.0	1.37	-11.6	26.8	11.6	26.8	0.810	13.6	-0.35
31/01/94	15:16:46	0	0		103.0	1.37	-23.8	28.3	23.8	28.3	0.524	19.8	0.03
31/01/94	15:17:36	0	0		102.9	1.37	-33.1	28.3	33.1	28.3	0.502	19.9	0.03
31/01/94	15:20:11	0	0		102.9	1.37	-29.5	28.3	29.5	28.3	0.552	20.0	0.04
31/01/94	15:22:27	0	0		103.1	1.37	-17.1	28.2	17.1	28.2	0.613	19.6	0.02
31/01/94	15:23:58	0	0		103.1	1.37	-14.8	28.1	14.8	28.1	0.478	19.6	0.01
31/01/94	15:27:13	0	0		103.0	1.37	-15.8	28.1	15.8	28.1	0.437	19.7	0.01
31/01/94	15:28:01	0	0		103.0	1.37	-23.5	28.1	23.5	28.1	0.470	19.6	0.01
31/01/94	15:29:46	0	0		103.0	1.37	-20.9	28.1	20.9	28.1	0.482	19.6	0.01
31/01/94	15:30:23	0	0		103.1	1.37	-18.2	28.1	18.2	28.1	0.434	19.7	0.01
31/01/94	15:34:13	0	0		202.6	1.41	3.4	52.8	-3.4	52.8	0.592	14.9	-0.30
31/01/94	15:35:57	0	0		202.7	1.41	-26.8	52.9	26.8	52.9	0.603	14.7	-0.31
31/01/94	15:38:40	0	0		202.7	1.41	-10.4	52.8	10.4	52.8	0.561	14.6	-0.32
31/01/94	15:42:08	0	0		202.6	1.41	-76.7	55.7	76.7	55.7	0.525	19.5	0.00
31/01/94	15:44:12	0	0		202.8	1.41	-26.7	55.8	26.7	55.8	0.469	20.0	0.03
31/01/94	15:47:09	0	0		202.6	1.41	-46.8	55.5	46.8	55.5	0.584	19.8	0.02
31/01/94	15:48:10	0	0		202.6	1.41	-36.6	55.5	36.6	55.5	0.591	19.8	0.02
31/01/94	15:49:48	0	0		202.7	1.41	-44.9	55.5	44.9	55.5	0.540	19.9	0.02
31/01/94	15:50:28	0	0		202.8	1.41	-48.0	55.6	48.0	55.6	0.494	19.9	0.02
31/01/94	15:52:33	0	0		203.0	1.41	-37.7	55.5	37.7	55.5	0.488	19.9	0.02
31/01/94	15:55:23	0	0		303.7	1.49	-81.4	83.4	81.4	83.4	0.464	20.0	0.03
31/01/94	15:56:12	0	0		303.9	1.49	-46.1	83.5	46.1	83.5	0.489	20.0	0.03
31/01/94	16:00:28	0	0		304.1	1.49	-43.1	83.1	43.1	83.1	0.441	19.9	0.02
31/01/94	16:01:17	0	0		304.1	1.49	-38.9	83.1	38.9	83.1	0.514	19.8	0.03

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
31/01/94	16:01:29	0	0	0	304.1	1.49	-44.0	83.1	44.0	83.1	0.540	19.8	0.03
31/01/94	16:01:48	0	0	0	304.1	1.49	-53.7	83.1	53.7	83.1	0.563	19.8	0.03
01/02/94	08:32:44	0	0	0	104.5	1.37	-22.0	28.5	22.0	28.5	0.582	19.0	0.02
01/02/94	08:33:58	0	0	0	104.3	1.37	-26.5	28.5	26.5	28.5	0.604	19.2	0.04
01/02/94	08:35:07	0	0	0	104.4	1.37	-23.2	28.5	23.2	28.5	0.452	19.3	0.04
01/02/94	08:37:44	0	0	0	104.4	1.37	-28.8	28.4	28.8	28.4	0.516	19.2	0.04
01/02/94	08:50:22	0	0	0	104.6	1.37	-23.7	28.5	23.7	28.5	0.513	19.4	0.04
01/02/94	08:51:11	0	0	0	104.7	1.37	-23.5	28.5	23.5	28.5	0.475	19.4	0.06
01/02/94	09:01:52	0	0	0	104.2	1.37	-57.2	31.9	57.2	31.9	0.465	32.3	0.89
01/02/94	09:02:04	0	0	0	104.3	1.37	-51.5	32.0	51.5	32.0	0.453	32.3	0.89
01/02/94	09:13:41	0	0	0	104.3	1.37	-50.6	32.0	50.6	32.0	0.374	32.8	0.91
01/02/94	09:14:06	0	0	0	104.2	1.37	-53.5	32.0	53.5	32.0	0.377	32.8	0.93
01/02/94	09:15:23	0	0	0	103.9	1.37	-53.1	31.9	53.1	31.9	0.430	32.7	0.91
01/02/94	09:23:13	0	0	0	103.4	1.37	-75.0	34.9	75.0	34.9	0.257	42.8	1.55
01/02/94	09:24:45	0	0	0	103.5	1.37	-77.8	34.9	77.8	34.9	0.242	43.0	1.56
01/02/94	09:25:52	0	0	0	103.5	1.37	-76.1	34.9	76.1	34.9	0.202	43.2	1.57
01/02/94	09:27:14	0	0	0	103.6	1.37	-70.1	34.9	70.1	34.9	0.138	43.2	1.57
01/02/94	09:34:56	0	0	0	102.1	1.37	-155.9	38.7	155.9	38.7	-0.442	55.0	2.30
01/02/94	09:37:28	0	0	0	106.5	1.37	-126.8	41.1	126.8	41.1	-0.228	56.8	2.43
01/02/94	09:43:28	0	0	0	102.7	1.37	-73.2	36.7	73.2	36.7	-0.057	50.1	2.00
01/02/94	09:51:11	0	0	0	102.7	1.37	-76.6	36.5	76.6	36.5	-0.273	49.3	1.94
01/02/94	09:54:19	0	0	0	102.8	1.37	-82.3	36.5	82.3	36.5	-0.234	49.2	1.93
01/02/94	09:57:31	0	0	0	102.9	1.37	-82.1	36.6	82.1	36.6	-0.214	49.1	1.92
01/02/94	10:01:31	0	0	0	103.0	1.37	-93.1	36.7	93.1	36.7	-0.198	49.4	1.95
01/02/94	10:07:05	0	0	0	103.0	1.37	-82.3	36.7	82.3	36.7	-0.248	49.4	1.94
01/02/94	10:20:37	0	0	0	201.2	1.41	-137.7	72.0	137.7	72.0	0.078	49.4	1.95
01/02/94	10:22:38	0	0	0	201.2	1.41	-144.4	72.2	144.4	72.2	0.001	50.1	2.00
01/02/94	10:23:34	0	0	0	201.3	1.41	-107.4	72.5	107.4	72.5	-0.039	50.4	2.01
01/02/94	10:25:25	0	0	0	201.4	1.41	-115.4	72.9	115.4	72.9	0.058	50.6	2.03
01/02/94	10:51:36	0	3	1	111.3	1.37	6.5	28.0	-3.3	28.0	0.924	10.4	-0.57
01/02/94	11:58:21	0	0	0	120.4	1.37	-21.3	32.6	21.3	32.6	0.934	19.0	0.01
01/02/94	13:05:18	0	0	0	119.2	1.37	-29.2	32.8	29.2	32.8	0.378	20.2	0.02
01/02/94	13:50:51	0	0	0	119.1	1.37	-19.2	32.7	19.2	32.7	0.690	20.0	0.03
01/02/94	14:40:17	0	0	0	118.6	1.37	-145.7	39.7	145.7	39.7	0.602	39.7	1.29
01/02/94	15:07:47	0	0	0	118.4	1.37	-81.8	40.1	81.8	40.1	0.517	43.6	1.51
01/02/94	15:07:47	0	0	0	118.4	1.37	-81.8	40.2	81.8	40.2	0.517	43.6	1.51
02/02/94	10:20:09	0	0	0	106.9	1.37	38.4	25.4	-38.4	25.4	0.652	4.7	-1.01
02/02/94	10:31:49	0	0	0	107.3	1.37	13.0	25.3	-13.0	25.3	0.803	2.8	-1.12
02/02/94	10:45:44	0	0	0	106.7	1.37	-4.6	26.1	4.6	26.1	0.825	6.6	-0.87
02/02/94	10:46:28	0	0	0	106.6	1.37	-7.6	26.1	7.6	26.1	0.848	6.6	-0.87
02/02/94	10:46:37	0	0	0	106.8	1.37	-5.5	26.1	5.5	26.1	0.939	6.6	-0.87
02/02/94	10:51:39	0	0	0	106.4	1.37	-49.4	29.3	49.4	29.3	0.523	19.3	-0.07
02/02/94	10:52:26	0	0	0	106.3	1.37	-41.2	29.3	41.2	29.3	0.524	19.6	-0.05
02/02/94	10:54:04	0	0	0	106.5	1.37	-28.7	29.4	28.7	29.4	0.423	20.2	-0.03
02/02/94	10:54:40	0	0	0	106.5	1.37	-38.7	29.4	38.7	29.4	0.404	20.3	-0.03
02/02/94	11:02:19	0	0	0	51.3	1.35	-8.8	14.3	8.8	14.3	-0.017	22.5	0.09
02/02/94	11:03:22	0	0	0	50.9	1.35	-10.1	14.2	10.1	14.2	-0.093	22.4	0.07
02/02/94	11:04:40	0	0	0	51.1	1.35	-9.2	14.2	9.2	14.2	-0.119	22.2	0.07
02/02/94	11:05:13	0	0	0	51.1	1.35	-7.0	14.2	7.0	14.2	-0.157	22.2	0.06
02/02/94	11:12:15	0	0	0	303.1	1.49	-22.0	74.9	22.0	74.9	0.452	8.7	-0.76
02/02/94	11:14:02	0	0	0	303.6	1.49	-10.4	75.3	10.4	75.3	0.456	8.8	-0.77
02/02/94	11:15:05	0	0	0	303.8	1.49	-0.5	75.5	0.5	75.5	0.548	8.7	-0.77
02/02/94	11:22:20	0	0	0	304.7	1.49	-65.8	84.5	65.8	84.5	0.256	21.3	0.03
02/02/94	11:23:31	0	0	0	304.5	1.49	-47.6	84.3	47.6	84.3	0.319	21.1	0.02
02/02/94	11:24:58	0	0	0	304.6	1.49	-39.7	84.1	39.7	84.1	0.217	21.0	0.01
02/02/94	11:25:27	0	0	0	304.9	1.49	-86.9	84.1	86.9	84.1	0.189	21.0	0.00
02/02/94	11:35:02	0	0	0	304.7	1.49	-89.2	92.7	89.2	92.7	-0.057	32.0	0.69
02/02/94	11:36:54	0	0	0	304.8	1.49	-90.6	92.8	90.6	92.8	-0.003	32.1	0.70
02/02/94	11:39:53	0	0	0	305.1	1.49	-106.1	93.1	106.1	93.1	-0.061	32.5	0.72
02/02/94	11:40:41	0	0	0	305.3	1.49	-110.5	93.1	110.5	93.1	-0.106	32.6	0.72
02/02/94	11:46:54	0	0	0	61.2	1.36	-32.2	18.5	32.2	18.5	0.331	31.1	0.68

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
02/02/94	11:47:59	0	0		61.3	1.36	-18.1	18.4	18.1	18.4	0.327	30.9	0.65
02/02/94	11:49:10	0	0		61.4	1.36	-23.8	18.4	23.8	18.4	0.239	30.6	0.62
02/02/94	12:01:09	0	0		61.3	1.36	-72.2	21.8	72.2	21.8	-0.034	48.2	1.74
02/02/94	12:38:23	0	0		60.8	1.36	-71.2	21.7	71.2	21.7	-0.314	49.6	1.80
02/02/94	12:38:57	0	0		60.8	1.36	-71.1	21.7	71.1	21.7	-0.271	49.6	1.82
02/02/94	12:39:33	0	0		60.9	1.36	-69.1	21.7	69.1	21.7	-0.316	49.6	1.81
02/02/94	12:52:57	0	0		300.9	1.49	-177.5	105.6	177.5	105.6	-0.301	48.2	1.71
02/02/94	12:54:27	0	0		300.9	1.49	-134.5	106.4	134.5	106.4	-0.337	48.7	1.72
02/02/94	12:56:15	0	0		301.2	1.49	-134.6	106.9	134.6	106.9	-0.364	49.2	1.74
02/02/94	12:58:45	0	0		301.2	1.49	-142.1	106.9	142.1	106.9	-0.312	49.3	1.74
02/02/94	13:01:06	0	0		301.5	1.49	-142.2	107.1	142.2	107.1	-0.395	49.5	1.77
02/02/94	13:06:20	0	0		302.5	1.49	-148.2	107.5	148.2	107.5	-0.400	49.7	1.77
02/02/94	13:27:08	1010	2030	36	51.0	1.35	2096.6	57.4	-66.6	67.7	11.538	26.9	1.10
02/02/94	13:28:06	1010	2038	36	51.0	1.35	2105.0	57.6	-66.6	67.9	11.695	27.2	1.12
02/02/94	13:28:55	1010	2037	36	51.0	1.35	2105.9	57.7	-69.3	68.0	11.749	27.4	1.14
02/02/94	13:29:35	1010	2050	36	51.1	1.35	2112.8	57.8	-63.0	68.1	11.751	27.5	1.15
02/02/94	13:30:25	1010	2046	36	51.1	1.35	2122.4	58.0	-76.1	68.3	11.874	27.4	1.15
02/02/94	13:35:05	1010	2068	36	51.0	1.35	2135.8	58.4	-67.8	68.8	11.845	27.6	1.16
02/02/94	13:36:46	1010	2058	36	51.0	1.35	2137.9	58.5	-79.6	68.8	11.743	27.7	1.16
02/02/94	13:37:13	1010	2061	36	51.0	1.35	2142.4	58.6	-81.4	68.9	11.765	27.7	1.16
02/02/94	13:37:40	1010	2067	36	51.0	1.35	2140.9	58.6	-73.6	68.9	11.857	27.6	1.16
02/02/94	13:38:39	1010	2067	36	51.0	1.35	2140.3	58.6	-73.5	68.9	11.819	27.6	1.16
02/02/94	13:45:00	1020	2093	36	99.5	1.37	2243.5	40.2	-150.7	54.3	6.850	19.6	0.29
02/02/94	13:46:39	1020	2091	36	100.2	1.37	2243.6	40.2	-152.8	54.2	7.085	19.0	0.27
02/02/94	13:47:21	1020	2090	36	100.2	1.37	2243.2	40.2	-153.2	54.2	7.047	19.0	0.27
02/02/94	13:48:12	1020	2090	36	100.1	1.37	2238.2	40.1	-148.4	54.2	7.160	18.9	0.27
02/02/94	13:50:29	1020	2025	36	100.2	1.37	2170.7	39.3	-145.4	53.2	7.191	18.2	0.23
02/02/94	13:54:38	1030	2012	36	200.8	1.41	2168.6	52.7	-156.4	63.7	4.190	14.0	-0.25
02/02/94	13:55:51	1030	2015	36	200.8	1.41	2175.5	52.8	-161.0	63.7	4.115	14.0	-0.26
02/02/94	13:56:44	1030	2003	36	200.8	1.41	2165.4	52.8	-162.8	63.7	4.045	14.0	-0.25
02/02/94	13:58:31	1030	2009	36	200.7	1.41	2144.4	52.7	-135.3	63.6	4.053	14.0	-0.26
02/02/94	14:00:06	1030	2016	36	200.6	1.41	2170.6	52.7	-154.6	63.7	3.969	14.0	-0.26
02/02/94	14:03:41	1040	2022	36	301.4	1.49	2172.3	75.8	-150.2	83.8	3.020	12.2	-0.44
02/02/94	14:06:08	1040	2017	36	301.6	1.49	2163.1	75.8	-146.6	83.8	3.019	12.0	-0.45
02/02/94	14:08:34	1040	2037	36	301.2	1.49	2178.6	75.7	-141.9	83.8	3.051	11.9	-0.46
02/02/94	14:09:27	1040	2038	36	301.1	1.49	2172.8	75.7	-134.5	83.8	3.020	11.9	-0.46
02/02/94	14:10:56	1040	2020	36	301.4	1.49	2177.3	75.7	-157.3	83.8	2.980	11.9	-0.47
02/02/94	15:16:11	1050	2007	36	50.4	1.35	2048.5	57.2	-41.3	67.4	11.187	38.9	1.86
02/02/94	15:17:22	1050	2008	36	50.5	1.35	2053.0	57.2	-45.3	67.4	11.197	38.8	1.85
02/02/94	15:18:49	1050	2010	36	50.3	1.35	2050.6	57.3	-40.8	67.5	11.059	38.9	1.85
02/02/94	15:19:59	1050	2014	36	50.0	1.35	2039.3	57.3	-25.6	67.5	11.008	39.1	1.85
02/02/94	15:21:03	1050	2010	36	50.0	1.35	2043.6	57.4	-33.2	67.6	11.011	39.1	1.85
02/02/94	15:27:03	1060	2002	36	100.5	1.37	2155.7	41.3	-153.5	54.5	6.682	31.2	1.05
02/02/94	15:28:59	1060	2019	36	100.6	1.37	2143.6	41.2	-125.0	54.6	6.456	31.3	1.04
02/02/94	15:31:40	1060	2010	36	100.4	1.37	2134.6	41.1	-124.2	54.5	6.315	31.4	1.03
02/02/94	15:33:20	1060	2015	36	100.5	1.37	2143.2	41.2	-128.0	54.5	6.264	31.4	1.03
02/02/94	15:36:03	1060	2012	36	100.5	1.37	2135.0	41.1	-122.9	54.5	6.399	31.2	1.02
02/02/94	15:44:49	1070	2025	36	201.2	1.41	2146.9	58.6	-121.7	68.7	3.480	27.2	0.57
02/02/94	15:47:23	1070	2016	36	201.6	1.41	2148.1	58.6	-132.4	68.6	3.437	27.1	0.55
02/02/94	15:49:47	1070	2019	36	201.3	1.41	2131.9	58.4	-113.1	68.5	3.479	26.9	0.55
02/02/94	15:51:57	1070	2012	36	201.4	1.41	2146.5	58.6	-134.3	68.7	3.434	27.0	0.55
02/02/94	15:52:52	1070	2024	36	201.6	1.41	2158.7	58.7	-134.9	68.8	3.454	27.0	0.54
02/02/94	15:58:53	1080	2012	36	303.1	1.49	2147.4	85.1	-135.3	92.3	2.401	25.4	0.37
02/02/94	16:03:20	1080	2026	36	301.7	1.49	2156.0	84.6	-129.7	91.9	2.453	25.2	0.36
02/02/94	16:05:37	1080	2027	36	302.2	1.49	2163.8	84.8	-136.4	92.1	2.483	25.2	0.36
02/02/94	16:07:48	1080	2020	36	302.3	1.49	2139.6	84.9	-119.2	92.1	2.474	25.2	0.36
02/02/94	16:11:09	1080	2015	36	302.9	1.49	2147.6	85.1	-132.3	92.3	2.399	25.3	0.36
03/02/94	08:18:53	0	0		114.6	1.37	7.7	28.9	-7.7	28.9	0.477	11.4	-0.73
03/02/94	08:36:14	0	0		101.5	1.37	-6.5	27.7	6.5	27.7	0.404	19.8	-0.18
03/02/94	08:36:40	0	0		101.5	1.37	-9.9	27.7	9.9	27.7	0.432	19.7	-0.19
03/02/94	08:37:46	0	3	1	101.5	1.37	-13.8	27.7	17.0	27.7	0.370	19.8	-0.20

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
03/02/94	10:16:56	0	0		202.2	1.41	-15.3	50.6	15.3	50.6	0.844	9.9	-0.86
03/02/94	10:17:11	0	0		202.3	1.41	-16.3	50.7	16.3	50.7	0.842	9.9	-0.86
18% Ring Tests													
04/02/94	10:54:24	1	0		50.2	1.35	16.3	12.3	-16.3	12.3	1.215	6.9	-1.05
04/02/94	10:54:36	1	0		50.2	1.35	18.6	12.3	-18.6	12.3	1.190	6.9	-1.05
04/02/94	10:57:49	2	0		100.6	1.37	-14.0	24.6	14.0	24.6	1.154	6.6	-1.07
04/02/94	10:58:10	2	0		100.5	1.37	-4.0	24.6	4.0	24.6	1.249	6.8	-1.05
04/02/94	10:58:35	2	0		100.6	1.37	16.7	24.6	-16.7	24.6	1.346	6.7	-1.04
04/02/94	10:59:03	2	0		100.5	1.37	23.2	24.6	-23.2	24.6	1.405	6.5	-1.05
04/02/94	11:00:54	3	0		200.7	1.41	8.3	49.0	-8.3	49.0	1.289	6.2	-1.09
04/02/94	11:01:07	3	0		200.8	1.41	-10.4	48.9	10.4	48.9	1.314	6.2	-1.08
04/02/94	11:01:30	3	0		200.9	1.41	8.0	49.0	-8.0	49.0	1.322	6.3	-1.08
04/02/94	11:02:51	4	0		302.4	1.49	-22.8	73.9	22.8	73.9	1.320	6.3	-1.08
04/02/94	11:03:08	4	0		302.5	1.49	-12.5	73.9	12.5	73.9	1.300	6.4	-1.07
04/02/94	11:03:25	4	0		302.6	1.49	-1.8	74.0	1.8	74.0	1.225	6.5	-1.07
04/02/94	11:04:52	5	0		402.5	1.58	8.9	98.5	-8.9	98.5	1.283	6.6	-1.06
04/02/94	11:05:16	5	0		402.8	1.58	-0.6	98.6	0.6	98.6	1.301	6.7	-1.05
04/02/94	11:21:27	6	0		50.7	1.35	3.3	13.9	-3.3	13.9	0.858	20.0	-0.22
04/02/94	11:21:38	6	0		50.7	1.35	1.8	13.9	-1.8	13.9	0.859	20.0	-0.22
04/02/94	11:22:00	6	0		50.6	1.35	2.0	13.8	-2.0	13.8	0.833	19.9	-0.23
04/02/94	11:27:11	7	0		101.6	1.37	-24.8	27.7	24.8	27.7	0.719	19.1	-0.30
04/02/94	11:27:27	7	0		101.5	1.37	-16.1	27.7	16.1	27.7	0.712	19.2	-0.29
04/02/94	11:27:44	7	0		101.4	1.37	-19.2	27.6	19.2	27.6	0.722	19.3	-0.28
04/02/94	11:31:36	8	0		201.9	1.41	-32.0	55.0	32.0	55.0	0.640	19.2	-0.30
04/02/94	11:31:48	8	0		201.8	1.41	-41.2	55.0	41.2	55.0	0.670	19.2	-0.30
04/02/94	11:32:01	8	0		201.9	1.41	-40.9	55.0	40.9	55.0	0.646	19.3	-0.29
04/02/94	11:34:03	9	0		303.0	1.49	-66.5	82.5	66.5	82.5	0.776	19.1	-0.29
04/02/94	11:34:16	9	0		302.9	1.49	-52.1	82.5	52.1	82.5	0.749	19.2	-0.29
04/02/94	11:34:29	9	0		302.9	1.49	-51.7	82.6	51.7	82.6	0.739	19.3	-0.28
04/02/94	11:36:47	10	0		405.5	1.59	-59.9	110.5	59.9	110.5	0.774	19.3	-0.27
04/02/94	11:36:58	10	0		405.1	1.59	-67.3	110.6	67.3	110.6	0.740	19.4	-0.26
04/02/94	11:37:32	10	0		405.9	1.59	-46.4	110.8	46.4	110.8	0.744	19.5	-0.26
04/02/94	13:12:39	1011	2012	36	50.5	1.35	2080.7	57.5	-68.3	67.7	12.294	27.3	1.00
04/02/94	13:15:02	1011	2022	36	50.4	1.35	2090.3	57.9	-68.1	68.1	12.221	27.8	1.04
04/02/94	13:16:49	1011	2025	36	50.4	1.35	2108.7	58.3	-83.8	68.5	12.393	27.2	1.01
04/02/94	13:21:26	1011	2027	36	50.4	1.35	2109.6	58.4	-82.5	68.5	12.303	26.6	0.96
04/02/94	13:23:42	1011	2027	36	50.3	1.35	2106.8	58.4	-79.3	68.5	12.444	26.5	0.98
04/02/94	13:30:10	1012	2018	36	50.2	1.35	2086.1	57.9	-68.1	68.1	12.324	26.6	0.96
04/02/94	13:31:17	1012	2024	36	50.4	1.35	2095.3	58.0	-71.3	68.2	12.362	26.7	0.97
04/02/94	13:32:07	1012	2032	36	50.3	1.35	2100.3	58.2	-68.0	68.4	12.351	26.7	0.97
04/02/94	13:32:58	1012	2028	36	50.5	1.35	2109.3	58.3	-81.4	68.4	12.396	26.7	0.97
04/02/94	13:33:57	1012	2029	36	50.3	1.35	2099.4	58.2	-70.4	68.3	12.436	26.6	0.97
04/02/94	13:36:28	1012	2040	36	50.4	1.35	2101.8	58.2	-61.4	68.4	12.379	26.7	0.97
04/02/94	13:37:33	1013	2038	36	50.3	1.35	2112.1	58.5	-73.8	68.7	12.328	26.9	0.98
04/02/94	13:38:09	1013	2033	36	50.3	1.35	2118.9	58.7	-86.0	68.8	12.331	26.9	0.97
04/02/94	13:39:00	1013	2050	36	50.3	1.35	2114.2	58.6	-64.0	68.8	12.358	26.9	0.98
04/02/94	13:40:24	1013	2046	36	50.2	1.35	2118.0	58.7	-71.9	68.9	12.389	26.9	0.98
04/02/94	13:41:09	1013	2043	36	50.3	1.35	2128.6	58.9	-85.3	69.1	12.387	26.9	0.97
04/02/94	13:43:29	1014	2039	36	50.1	1.35	2119.5	58.9	-80.7	69.0	12.357	26.9	0.97
04/02/94	13:44:28	1014	2037	36	50.1	1.35	2110.3	58.6	-73.4	68.8	12.394	26.8	0.97
04/02/94	13:46:15	1014	2039	36	50.2	1.35	2110.3	58.6	-70.9	68.7	12.347	26.8	0.96
04/02/94	13:47:03	1014	2047	36	50.2	1.35	2107.7	58.5	-60.3	68.7	12.246	26.9	0.96
04/02/94	13:49:55	1014	2045	36	50.1	1.35	2117.8	58.8	-72.9	69.0	12.204	27.0	0.96
04/02/94	13:52:33	1017	2049	36	50.1	1.35	2121.7	59.0	-73.0	69.1	11.797	26.5	0.90
04/02/94	13:53:57	1017	2060	36	50.2	1.35	2122.7	58.9	-63.0	69.1	11.729	26.5	0.89
04/02/94	13:55:20	1017	2054	36	50.1	1.35	2115.3	58.8	-61.3	69.0	11.788	26.5	0.89
04/02/94	13:56:13	1017	2018	36	50.2	1.35	2106.7	58.5	-88.5	68.6	11.725	26.2	0.87
04/02/94	13:57:37	1017	2017	36	50.3	1.35	2104.3	58.4	-87.5	68.4	11.511	26.4	0.86
04/02/94	14:06:47	1047	2021	36	302.2	1.49	2193.5	75.8	-172.2	83.8	2.872	12.5	-0.63
04/02/94	14:07:53	1047	2024	36	302.4	1.49	2181.3	75.9	-157.0	84.0	2.886	12.4	-0.63

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
04/02/94	14:10:14	1047	2033	36	302.6	1.49	2188.5	76.0	-155.5	84.1	2.923	12.2	-0.65
04/02/94	14:11:01	1047	2029	36	302.8	1.49	2185.9	76.1	-156.9	84.1	2.935	12.1	-0.65
04/02/94	14:12:38	1047	2034	36	303.2	1.49	2185.9	76.1	-152.2	84.2	2.870	12.1	-0.66
04/02/94	14:15:11	1044	2031	36	303.4	1.49	2203.4	76.2	-172.6	84.2	2.950	12.1	-0.65
04/02/94	14:16:31	1044	2041	36	303.4	1.49	2201.6	76.2	-160.8	84.3	3.004	12.0	-0.65
04/02/94	14:17:22	1044	2027	36	302.9	1.49	2182.3	76.1	-155.6	84.1	2.945	12.1	-0.65
04/02/94	14:17:51	1044	2029	36	303.0	1.49	2178.8	76.1	-149.4	84.1	2.950	12.0	-0.65
04/02/94	14:18:32	1044	2021	36	302.9	1.49	2180.0	76.1	-158.5	84.1	2.925	12.0	-0.66
04/02/94	14:19:38	1044	2026	36	303.1	1.49	2182.4	76.1	-156.0	84.1	3.046	11.9	-0.65
04/02/94	14:22:08	1043	2029	36	303.3	1.49	2202.3	76.2	-173.4	84.2	3.074	11.9	-0.65
04/02/94	14:24:30	1043	2028	36	303.5	1.49	2190.8	76.2	-163.2	84.2	3.035	11.9	-0.65
04/02/94	14:26:08	1043	2026	36	303.7	1.49	2186.8	76.3	-161.2	84.3	3.039	11.9	-0.65
04/02/94	14:26:46	1043	2029	36	303.8	1.49	2192.7	76.3	-164.1	84.3	2.998	11.9	-0.65
04/02/94	14:27:33	1043	2037	36	303.7	1.49	2195.1	76.3	-158.6	84.3	3.053	11.9	-0.65
04/02/94	14:28:19	1043	2037	36	303.5	1.49	2189.9	76.2	-153.4	84.3	3.036	11.9	-0.66
04/02/94	14:31:24	1042	2033	36	303.6	1.49	2193.2	76.3	-160.4	84.3	3.066	11.9	-0.66
04/02/94	14:32:58	1042	2039	36	303.7	1.49	2182.1	76.3	-142.8	84.3	3.054	11.9	-0.66
04/02/94	14:33:30	1042	2036	36	302.4	1.49	2182.9	76.0	-146.5	84.0	3.066	11.9	-0.65
04/02/94	14:35:37	1042	2038	36	302.6	1.49	2196.5	76.0	-158.1	84.1	3.064	11.8	-0.66
04/02/94	14:36:01	1042	2031	36	302.6	1.49	2195.7	76.0	-165.1	84.1	3.055	11.8	-0.66
04/02/94	14:38:50	1041	2045	36	302.8	1.49	2199.5	76.1	-154.8	84.2	3.111	11.8	-0.65
04/02/94	14:39:44	1041	2031	36	302.8	1.49	2187.0	76.0	-155.9	84.1	3.085	11.9	-0.65
04/02/94	14:41:25	1041	2035	36	303.0	1.49	2199.1	76.1	-164.4	84.2	3.148	11.8	-0.65
04/02/94	14:41:56	1041	2026	36	303.0	1.49	2187.2	76.1	-161.1	84.1	3.101	11.8	-0.66
04/02/94	14:42:51	1041	2026	36	303.0	1.49	2181.0	76.1	-155.4	84.1	3.156	11.7	-0.66
04/02/94	15:01:43	1031	2023	36	201.0	1.41	2180.2	52.8	-157.0	63.8	4.294	13.4	-0.47
04/02/94	15:02:56	1031	2023	36	201.0	1.41	2180.8	52.8	-157.7	63.8	4.320	13.4	-0.47
04/02/94	15:03:32	1031	2020	36	201.0	1.41	2170.3	52.7	-150.7	63.7	4.292	13.4	-0.47
04/02/94	15:04:02	1031	2012	36	200.9	1.41	2173.9	52.7	-162.3	63.7	4.324	13.4	-0.47
04/02/94	15:04:35	1031	2016	36	200.9	1.41	2180.3	52.8	-164.7	63.7	4.344	13.3	-0.48
04/02/94	15:06:34	1032	2019	36	200.9	1.41	2178.6	52.7	-159.2	63.7	4.246	13.4	-0.47
04/02/94	15:08:40	1032	2020	36	200.9	1.41	2182.8	52.8	-163.2	63.8	4.281	13.4	-0.47
04/02/94	15:09:47	1032	2008	36	200.7	1.41	2173.6	52.7	-165.6	63.7	4.274	13.4	-0.47
04/02/94	15:10:16	1032	2019	36	200.8	1.41	2178.7	52.7	-160.0	63.7	4.234	13.4	-0.47
04/02/94	15:12:17	1032	2018	36	200.8	1.41	2164.5	52.7	-146.7	63.7	4.384	13.3	-0.47
04/02/94	15:14:12	1033	2017	36	200.8	1.41	2183.9	52.7	-166.6	63.7	4.301	13.4	-0.47
04/02/94	15:15:49	1033	2018	36	200.9	1.41	2177.7	52.7	-159.8	63.7	4.239	13.4	-0.47
04/02/94	15:17:34	1033	2013	36	200.9	1.41	2176.8	52.7	-163.5	63.7	4.225	13.4	-0.47
04/02/94	15:18:24	1033	2022	36	200.7	1.41	2177.1	52.7	-155.1	63.7	4.179	13.5	-0.48
04/02/94	15:19:03	1033	2020	36	200.9	1.41	2175.9	52.7	-155.8	63.7	4.177	13.5	-0.48
04/02/94	15:21:02	1034	2018	36	201.0	1.41	2178.6	52.8	-161.0	63.8	4.229	13.4	-0.47
04/02/94	15:22:11	1034	2025	36	200.9	1.41	2181.8	52.8	-157.2	63.8	4.286	13.4	-0.47
04/02/94	15:23:44	1034	2020	36	200.8	1.41	2181.7	52.7	-161.8	63.7	4.246	13.4	-0.48
04/02/94	15:24:45	1034	2014	36	201.0	1.41	2173.0	52.8	-158.9	63.7	4.216	13.4	-0.48
04/02/94	15:26:10	1034	2021	36	200.8	1.41	2179.7	52.7	-159.0	63.7	4.245	13.4	-0.48
04/02/94	15:28:34	1035	2009	36	201.6	1.41	2184.4	52.9	-175.6	63.8	4.232	13.4	-0.47
04/02/94	15:33:46	1035	2017	36	201.3	1.41	2174.1	52.8	-156.8	63.8	4.251	13.4	-0.47
04/02/94	15:34:08	1035	2016	36	201.3	1.41	2169.5	52.8	-153.9	63.8	4.280	13.3	-0.47
04/02/94	15:34:28	1035	2024	36	201.0	1.41	2172.1	52.7	-148.1	63.7	4.267	13.3	-0.47
04/02/94	15:36:01	1035	2010	36	201.2	1.41	2185.2	52.8	-175.2	63.8	4.269	13.3	-0.47
04/02/94	15:37:37	1037	2012	36	201.3	1.41	2183.1	52.9	-171.0	63.8	4.186	13.3	-0.47
04/02/94	15:38:36	1037	2013	36	201.2	1.41	2178.8	52.8	-165.8	63.8	4.159	13.3	-0.48
04/02/94	15:39:21	1037	2014	36	201.3	1.41	2171.5	52.8	-157.8	63.8	4.162	13.3	-0.48
04/02/94	15:39:38	1037	2021	36	201.2	1.41	2172.9	52.8	-152.2	63.8	4.207	13.2	-0.48
04/02/94	15:40:40	1037	2015	36	201.2	1.41	2175.7	52.8	-160.6	63.8	4.138	13.3	-0.48
04/02/94	15:42:09	1037	2011	36	201.3	1.41	2175.0	52.8	-163.6	63.8	4.193	13.2	-0.48
04/02/94	15:48:30	1027	2030	36	101.2	1.37	2164.5	39.2	-134.2	53.2	6.829	17.3	-0.03
04/02/94	15:49:07	1027	2016	36	101.3	1.37	2165.5	39.2	-149.4	53.1	6.783	17.4	-0.03
04/02/94	15:50:54	1027	2016	36	101.3	1.37	2162.5	39.2	-146.6	53.1	6.972	17.3	-0.02
04/02/94	15:51:14	1027	2020	36	101.4	1.37	2160.8	39.2	-141.2	53.1	6.995	17.3	-0.02
04/02/94	15:51:36	1027	2019	36	101.3	1.37	2158.4	39.2	-139.1	53.1	6.970	17.3	-0.02

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
04/02/94	15:53:28	1025	2016	36	101.3	1.37	2159.8	39.2	-143.6	53.1	7.144	17.6	0.01
04/02/94	15:54:06	1025	2006	36	101.2	1.37	2163.8	39.2	-157.7	53.0	7.220	17.6	0.02
04/02/94	15:54:39	1025	2017	36	101.1	1.37	2160.9	39.2	-143.9	53.1	7.155	17.7	0.02
04/02/94	15:55:32	1025	2017	36	101.1	1.37	2162.1	39.2	-145.3	53.1	7.191	17.6	0.01
04/02/94	15:55:49	1025	2016	36	101.2	1.37	2162.4	39.2	-146.8	53.1	7.216	17.6	0.01
04/02/94	15:57:57	1024	2018	36	101.1	1.37	2162.6	39.2	-144.4	53.1	7.237	17.7	0.03
04/02/94	15:58:56	1024	2018	36	101.1	1.37	2153.6	39.1	-135.7	53.0	7.211	17.7	0.03
04/02/94	15:59:18	1024	2021	36	100.9	1.37	2160.4	39.2	-139.3	53.1	7.236	17.7	0.03
04/02/94	15:59:40	1024	2011	36	101.1	1.37	2166.1	39.3	-155.4	53.1	7.232	17.7	0.03
04/02/94	16:01:46	1024	2016	36	101.0	1.37	2154.6	39.1	-138.2	53.0	7.279	17.7	0.04
04/02/94	16:03:34	1023	2018	36	101.1	1.37	2165.0	39.2	-146.7	53.1	7.271	17.7	0.04
04/02/94	16:04:21	1023	2013	36	100.9	1.37	2160.2	39.2	-147.6	53.0	7.309	17.7	0.04
04/02/94	16:04:41	1023	2016	36	101.0	1.37	2160.5	39.2	-144.2	53.1	7.319	17.7	0.04
04/02/94	16:05:00	1023	2014	36	101.0	1.37	2162.9	39.2	-148.6	53.1	7.221	17.8	0.04
04/02/94	16:05:21	1023	2014	36	101.0	1.37	2164.9	39.2	-150.9	53.1	7.291	17.7	0.04
04/02/94	16:06:52	1022	2016	36	101.0	1.37	2156.0	39.2	-140.0	53.0	7.340	17.7	0.04
04/02/94	16:07:26	1022	2023	36	101.0	1.37	2159.0	39.2	-136.4	53.1	7.250	17.7	0.04
04/02/94	16:07:50	1022	2014	36	101.3	1.37	2165.7	39.2	-152.0	53.1	7.258	17.7	0.04
04/02/94	16:08:05	1022	2017	36	101.3	1.37	2161.8	39.2	-144.9	53.1	7.269	17.7	0.04
04/02/94	16:08:25	1022	2017	36	101.3	1.37	2160.7	39.2	-143.3	53.1	7.336	17.6	0.04
04/02/94	16:08:40	1022	2016	36	101.1	1.37	2157.1	39.2	-140.7	53.0	7.368	17.6	0.04
04/02/94	16:10:02	1021	2022	36	100.9	1.37	2165.3	39.3	-143.3	53.1	7.333	17.7	0.04
04/02/94	16:10:52	1021	2011	36	100.9	1.37	2157.0	39.2	-146.2	53.0	7.254	17.8	0.04
04/02/94	16:11:08	1021	2013	36	100.9	1.37	2160.9	39.2	-147.8	53.0	7.282	17.8	0.04
04/02/94	16:11:26	1021	2018	36	100.9	1.37	2161.1	39.2	-143.2	53.1	7.275	17.8	0.04
04/02/94	16:11:44	1021	2013	36	100.9	1.37	2165.7	39.3	-152.5	53.1	7.313	17.7	0.04
07/02/94	15:25:26	1057	1977	35	50.1	1.35	2012.2	56.5	-35.0	66.7	10.726	37.8	1.81
07/02/94	15:26:01	1057	1981	35	49.9	1.35	2012.3	56.7	-31.5	66.8	10.727	37.8	1.81
07/02/94	15:26:22	1057	1985	35	49.9	1.35	2012.4	56.7	-27.8	66.9	10.733	37.8	1.82
07/02/94	15:26:41	1057	1987	36	50.0	1.35	2018.7	56.8	-31.5	67.0	10.755	37.7	1.81
07/02/94	15:27:02	1057	1986	35	50.0	1.35	2017.7	56.7	-31.4	66.9	10.735	37.7	1.81
07/02/94	15:28:32	1055	1991	36	50.0	1.35	2017.9	56.8	-26.7	67.0	11.051	38.0	1.85
07/02/94	15:29:17	1055	1997	36	50.1	1.35	2027.5	56.9	-30.8	67.1	11.042	38.0	1.84
07/02/94	15:29:49	1055	1999	36	49.8	1.35	2021.7	57.0	-22.4	67.2	11.100	38.0	1.85
07/02/94	15:30:20	1055	1983	35	49.8	1.35	2007.1	56.7	-23.6	66.8	10.984	38.0	1.84
07/02/94	15:30:42	1055	1991	36	49.7	1.35	2010.3	56.8	-18.9	67.0	10.985	38.0	1.84
07/02/94	15:31:05	1055	1982	35	49.8	1.35	2005.4	56.6	-23.0	66.8	11.031	38.0	1.85
07/02/94	15:31:27	1055	1977	35	49.9	1.35	2008.0	56.5	-31.0	66.7	10.980	38.0	1.85
07/02/94	15:32:37	1054	1986	35	50.1	1.35	2010.3	56.5	-24.0	66.7	11.022	38.2	1.85
07/02/94	15:33:28	1054	1986	35	50.1	1.35	2008.2	56.4	-22.6	66.6	11.021	38.3	1.86
07/02/94	15:33:48	1054	1978	35	50.0	1.35	2002.0	56.4	-23.8	66.6	11.000	38.3	1.86
07/02/94	15:34:19	1054	1982	35	49.9	1.35	2006.6	56.5	-25.0	66.7	11.015	38.4	1.87
07/02/94	15:34:50	1054	1985	35	50.0	1.35	2008.0	56.5	-22.6	66.7	11.071	38.3	1.87
07/02/94	15:35:20	1054	1993	36	49.9	1.35	2009.6	56.6	-16.7	66.8	11.082	38.3	1.86
07/02/94	15:36:55	1054	1985	35	50.0	1.35	2011.0	56.6	-25.7	66.8	10.994	38.4	1.85
07/02/94	15:37:48	1053	1989	36	50.2	1.35	2016.7	56.5	-27.6	66.8	11.091	38.3	1.85
07/02/94	15:38:08	1053	2000	36	50.0	1.35	2014.6	56.6	-14.6	66.9	11.106	38.3	1.86
07/02/94	15:38:28	1053	1987	36	50.1	1.35	2011.9	56.5	-24.5	66.8	11.115	38.3	1.86
07/02/94	15:38:57	1053	1995	36	50.0	1.35	2013.5	56.6	-18.8	66.9	11.134	38.3	1.86
07/02/94	15:40:20	1052	1996	36	50.1	1.35	2016.2	56.6	-20.7	66.9	11.210	38.3	1.87
07/02/94	15:41:05	1052	1999	36	50.1	1.35	2022.0	56.7	-22.8	67.0	11.172	38.3	1.87
07/02/94	15:41:30	1052	1988	36	50.1	1.35	2021.9	56.7	-33.5	66.9	11.229	38.3	1.88
07/02/94	15:42:04	1052	1992	36	50.2	1.35	2020.3	56.7	-28.2	66.9	11.190	38.3	1.88
07/02/94	15:42:49	1052	1991	36	49.9	1.35	2010.5	56.6	-19.1	66.9	11.186	38.3	1.88
07/02/94	15:44:28	1052	1995	36	50.1	1.35	2020.3	56.8	-25.5	67.0	11.225	38.4	1.88
07/02/94	15:45:18	1051	1998	36	50.0	1.35	2017.6	56.8	-19.1	67.0	11.210	38.4	1.89
07/02/94	15:45:52	1051	2002	36	50.0	1.35	2018.4	56.7	-16.8	67.0	11.197	38.5	1.89
07/02/94	15:46:12	1051	1990	36	49.9	1.35	2011.9	56.7	-21.9	66.9	11.194	38.5	1.89
07/02/94	15:46:38	1051	2000	36	50.0	1.35	2012.9	56.6	-13.1	66.9	11.216	38.5	1.89
07/02/94	15:49:43	1051	1993	36	50.1	1.35	2022.3	56.8	-29.1	67.0	11.248	38.5	1.89
07/02/94	16:07:26	1081	1967	35	303.0	1.49	2083.9	83.7	-117.4	90.8	2.413	23.1	0.31

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	al (oC/m)	bl (oC)	AT (m2 oC)
07/02/94	16:08:08	1081	1970	35	303.1	1.49	2087.6	83.7	-117.4	90.9	2.565	23.1	0.32
07/02/94	16:08:27	1081	1966	35	303.2	1.49	2078.7	83.8	-113.1	90.9	2.625	23.1	0.32
07/02/94	16:08:46	1081	1967	35	303.2	1.49	2065.2	83.8	-97.9	90.9	2.724	23.0	0.32
07/02/94	16:09:05	1081	1964	35	302.9	1.49	2080.8	83.7	-116.7	90.8	2.766	23.0	0.32
07/02/94	16:09:20	1083	1963	35	303.2	1.49	2070.4	83.8	-107.2	90.9	2.775	23.0	0.32
07/02/94	16:09:43	1083	1967	35	303.4	1.49	2079.0	83.8	-112.0	91.0	2.763	23.0	0.32
07/02/94	16:11:05	1083	1970	35	303.0	1.49	2085.4	83.8	-115.7	90.9	2.849	23.0	0.32
07/02/94	16:11:32	1083	1974	35	303.3	1.49	2088.8	83.8	-114.9	91.0	2.883	22.9	0.32
07/02/94	16:11:48	1083	1970	35	303.2	1.49	2099.2	83.8	-129.3	91.0	2.848	23.0	0.31
07/02/94	16:12:02	1083	1958	35	303.3	1.49	2085.7	83.8	-127.2	90.9	2.838	23.0	0.32
07/02/94	16:12:17	1084	1957	35	303.4	1.49	2073.6	83.8	-116.4	90.9	2.843	23.0	0.32
07/02/94	16:13:25	1084	1975	35	303.4	1.49	2083.4	83.8	-107.9	91.0	2.909	22.9	0.32
07/02/94	16:13:53	1084	1968	35	303.6	1.49	2081.0	83.9	-113.2	91.0	2.884	22.9	0.32
07/02/94	16:14:07	1084	1968	35	302.9	1.49	2063.4	83.7	-95.7	90.8	2.913	22.9	0.33
07/02/94	16:14:21	1084	1967	35	302.4	1.49	2078.3	83.6	-110.9	90.7	2.923	22.9	0.33
07/02/94	16:14:35	1084	1965	35	302.5	1.49	2081.7	83.7	-116.7	90.8	3.007	22.8	0.33
07/02/94	16:15:53	1087	1971	35	302.4	1.49	2085.1	83.6	-113.9	90.7	2.778	22.9	0.31
07/02/94	16:16:23	1087	1973	35	302.5	1.49	2087.2	83.6	-114.0	90.8	2.850	22.9	0.32
07/02/94	16:16:39	1087	1960	35	302.6	1.49	2079.4	83.6	-119.3	90.8	2.876	22.9	0.32
07/02/94	16:16:53	1087	1970	35	302.6	1.49	2083.5	83.6	-113.7	90.8	2.888	22.8	0.32
07/02/94	16:17:11	1087	1968	35	302.4	1.49	2079.7	83.6	-112.0	90.7	2.857	22.9	0.31
30% Ring Tests													
21/02/94	15:12:23	11	0		50.3	1.35	21.8	11.9	-21.8	11.9	1.318	3.6	-1.32
21/02/94	15:13:13	11	0		50.2	1.35	21.7	11.9	-21.7	11.9	1.271	3.7	-1.31
21/02/94	15:13:27	11	0		50.3	1.35	20.5	11.9	-20.5	11.9	1.261	3.7	-1.31
21/02/94	15:13:57	11	0		50.1	1.35	15.2	11.9	-15.2	11.9	1.375	3.7	-1.30
21/02/94	15:14:39	12	0		100.2	1.37	15.2	23.7	-15.2	23.7	1.391	3.4	-1.32
21/02/94	15:14:52	12	0		100.1	1.37	16.0	23.7	-16.0	23.7	1.390	3.4	-1.32
21/02/94	15:15:03	12	0		100.2	1.37	14.9	23.7	-14.9	23.7	1.381	3.4	-1.32
21/02/94	15:15:24	12	0		100.3	1.37	21.1	23.7	-21.1	23.7	1.394	3.3	-1.32
21/02/94	15:16:19	13	0		150.6	1.39	13.0	35.6	-13.0	35.6	1.382	3.0	-1.33
21/02/94	15:16:37	13	0		150.3	1.38	16.5	35.5	-16.5	35.5	1.378	3.0	-1.34
21/02/94	15:16:48	13	0		150.7	1.39	22.2	35.6	-22.2	35.6	1.396	2.9	-1.34
21/02/94	15:17:14	13	0		150.2	1.38	22.0	35.4	-22.0	35.4	1.391	2.9	-1.34
21/02/94	15:17:57	14	0		200.4	1.41	31.3	47.2	-31.3	47.2	1.320	2.8	-1.36
21/02/94	15:18:27	14	0		200.2	1.41	35.7	47.2	-35.7	47.2	1.356	2.7	-1.37
21/02/94	15:18:36	14	0		200.1	1.41	35.1	47.2	-35.1	47.2	1.368	2.7	-1.37
21/02/94	15:19:42	15	0		251.7	1.45	15.8	59.2	-15.8	59.2	1.354	2.5	-1.38
21/02/94	15:19:51	15	0		251.8	1.45	31.2	59.2	-31.2	59.2	1.351	2.5	-1.38
21/02/94	15:20:00	15	0		251.8	1.45	15.4	59.2	-15.4	59.2	1.349	2.5	-1.38
21/02/94	15:20:46	16	0		301.9	1.49	18.5	71.0	-18.5	71.0	1.359	2.4	-1.38
21/02/94	15:20:57	16	0		301.9	1.49	13.7	71.1	-13.7	71.1	1.347	2.4	-1.39
21/02/94	15:21:16	16	0		301.6	1.49	9.7	71.0	-9.7	71.0	1.341	2.4	-1.38
21/02/94	15:21:38	16	0		301.6	1.49	8.8	70.9	-8.8	70.9	1.297	2.5	-1.38
21/02/94	15:22:11	17	0		352.2	1.53	-14.4	82.8	14.4	82.8	1.306	2.4	-1.38
21/02/94	15:22:48	17	0		353.1	1.53	-9.3	83.1	9.3	83.1	1.275	2.5	-1.38
21/02/94	15:22:58	17	0		353.2	1.53	-9.3	83.2	9.3	83.2	1.277	2.5	-1.38
21/02/94	15:23:34	18	0		401.1	1.58	-2.9	94.5	2.9	94.5	1.265	2.5	-1.38
21/02/94	15:23:51	18	0		401.4	1.58	16.4	94.6	-16.4	94.6	1.222	2.6	-1.38
21/02/94	15:24:22	18	0		401.7	1.58	12.9	94.7	-12.9	94.7	1.256	2.6	-1.37
21/02/94	15:24:58	18	0		402.1	1.58	-5.9	94.8	5.9	94.8	1.291	2.6	-1.36
21/02/94	15:25:34	18	0		402.8	1.58	16.5	95.0	-16.5	95.0	1.266	2.7	-1.36
21/02/94	15:26:21	18	0		402.8	1.58	11.8	95.0	-11.8	95.0	1.251	2.7	-1.36
21/02/94	15:26:43	18	0		403.2	1.59	15.3	95.1	-15.3	95.1	1.226	2.7	-1.37
23/02/94	09:02:07	4031	12664	94	200.5	1.41	12869.5	108.7	-205.4	143.7	14.469	53.9	3.07
23/02/94	09:02:26	4031	12668	94	200.6	1.41	12863.5	108.6	-195.6	143.7	14.586	53.8	3.08
23/02/94	09:03:37	4031	12699	94	200.6	1.41	12847.6	108.6	-148.7	143.7	14.537	54.0	3.09
23/02/94	09:05:11	4031	12707	94	200.7	1.41	12884.9	108.8	-177.6	143.9	14.465	54.2	3.10
23/02/94	09:05:43	4031	12676	94	200.6	1.41	12853.9	108.6	-178.3	143.7	14.406	54.3	3.10
23/02/94	09:06:13	4031	12721	94	200.6	1.41	12813.7	108.3	-92.9	143.6	14.517	54.1	3.10

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
23/02/94	09:09:13	4035	12744	94	200.9	1.41	12871.5	108.7	-127.7	143.9	13.637	54.1	3.04
23/02/94	09:09:51	4035	12736	94	200.9	1.41	12874.4	108.7	-138.9	143.9	13.594	54.1	3.03
23/02/94	09:11:10	4035	12744	94	200.9	1.41	12878.5	108.7	-134.4	143.9	13.466	54.2	3.03
23/02/94	09:11:24	4035	12753	94	200.9	1.41	12851.6	108.5	-98.6	143.8	13.516	54.2	3.03
23/02/94	09:11:36	4035	12776	94	200.9	1.41	12877.5	108.7	-101.6	144.0	13.479	54.2	3.03
23/02/94	09:11:48	4035	12756	94	200.8	1.41	12871.8	108.7	-116.2	143.9	13.478	54.2	3.03
23/02/94	09:13:24	4036	12774	94	201.0	1.41	12904.0	108.8	-129.7	144.1	13.106	54.1	3.00
23/02/94	09:13:50	4036	12768	94	201.0	1.41	12886.0	108.7	-117.8	144.0	13.117	54.0	3.00
23/02/94	09:15:57	4036	12805	95	201.1	1.41	12951.3	109.1	-146.0	144.4	12.891	54.4	3.00
23/02/94	09:16:18	4036	12796	95	201.2	1.41	12938.6	109.0	-143.0	144.3	12.806	54.5	3.00
23/02/94	09:16:41	4036	12850	95	201.0	1.41	12934.2	109.0	-83.8	144.5	12.749	54.5	2.99
23/02/94	09:17:00	4036	12812	95	201.0	1.41	12942.5	109.1	-130.5	144.4	12.760	54.5	3.00
23/02/94	09:18:48	4037	12845	95	201.2	1.41	12989.5	109.4	-144.0	144.7	12.288	54.2	2.95
23/02/94	09:19:10	4037	12820	95	201.3	1.41	12975.2	109.2	-155.1	144.5	12.302	54.1	2.95
23/02/94	09:19:25	4037	12820	95	201.2	1.41	12954.9	109.1	-134.9	144.5	12.281	54.2	2.95
23/02/94	09:21:39	4037	12817	95	201.4	1.41	12954.7	109.1	-137.9	144.4	12.293	54.1	2.94
23/02/94	09:21:52	4037	12810	95	201.4	1.41	12967.8	109.2	-157.5	144.4	12.258	54.2	2.94
23/02/94	09:22:03	4037	12802	95	201.6	1.41	12985.7	109.2	-183.7	144.5	12.222	54.2	2.94
23/02/94	09:24:50	4034	12801	95	201.2	1.41	12926.6	109.0	-126.0	144.3	13.296	54.8	3.05
23/02/94	09:26:37	4034	12794	95	201.2	1.41	12911.9	108.9	-117.6	144.2	13.356	54.7	3.05
23/02/94	09:26:55	4034	12762	94	201.1	1.41	12889.4	108.7	-127.6	144.0	13.403	54.6	3.05
23/02/94	10:13:48	4011	3946	50	53.0	1.35	3861.9	99.9	83.9	111.9	15.350	45.7	2.59
23/02/94	10:14:16	4011	3957	51	53.1	1.35	3856.6	99.6	100.8	111.7	15.406	45.6	2.59
23/02/94	10:14:24	4011	3945	50	53.1	1.35	3866.9	99.8	78.3	111.9	15.444	45.6	2.59
23/02/94	10:14:33	4011	3958	51	53.2	1.35	3870.9	99.8	87.0	111.9	15.536	45.5	2.59
23/02/94	10:14:41	4011	3952	51	53.1	1.35	3862.9	99.8	88.9	111.8	15.531	45.5	2.59
23/02/94	10:16:44	4014	3947	50	52.7	1.35	3857.2	100.3	89.9	112.3	14.870	45.2	2.53
23/02/94	10:17:07	4014	3971	51	52.9	1.35	3856.5	100.1	114.3	112.1	14.810	45.2	2.53
23/02/94	10:17:17	4014	3961	51	53.1	1.35	3872.2	100.0	89.1	112.0	14.749	45.2	2.52
23/02/94	10:17:30	4014	3956	51	52.9	1.35	3861.0	100.1	95.0	112.1	14.723	45.2	2.52
23/02/94	10:17:40	4014	3959	51	53.2	1.35	3881.1	100.1	77.7	112.2	14.729	45.2	2.52
23/02/94	10:17:49	4014	3959	51	53.1	1.35	3870.9	100.1	88.1	112.1	14.737	45.2	2.52
23/02/94	10:18:59	4015	3955	51	52.9	1.35	3862.6	100.2	92.0	112.2	14.414	45.0	2.48
23/02/94	10:19:22	4015	3957	51	52.8	1.35	3857.4	100.1	99.3	112.1	14.409	44.9	2.48
23/02/94	10:19:38	4015	3958	51	52.8	1.35	3870.1	100.5	88.3	112.5	14.427	44.9	2.48
23/02/94	10:19:54	4015	3953	51	52.8	1.35	3862.8	100.3	90.2	112.3	14.455	44.8	2.48
23/02/94	10:20:05	4015	3954	51	53.0	1.35	3873.7	100.2	79.8	112.2	14.400	44.9	2.48
23/02/94	10:20:57	4016	3940	50	53.1	1.35	3871.8	100.0	68.6	112.0	14.272	44.3	2.44
23/02/94	10:21:16	4016	3949	51	53.0	1.35	3864.8	100.0	84.6	112.0	14.247	44.3	2.44
23/02/94	10:21:27	4016	3957	51	53.1	1.35	3876.6	100.1	80.0	112.2	14.141	44.4	2.43
23/02/94	10:21:41	4016	3942	50	53.0	1.35	3863.3	100.0	78.5	112.0	14.271	44.3	2.43
23/02/94	10:21:49	4016	3945	50	52.9	1.35	3866.8	100.3	78.5	112.2	14.193	44.3	2.43
23/02/94	10:23:02	4017	3939	50	53.0	1.35	3862.4	100.0	76.7	112.0	13.802	43.9	2.37
23/02/94	10:23:14	4017	3935	50	52.8	1.35	3850.2	100.0	85.0	112.0	13.740	44.0	2.38
23/02/94	10:23:32	4017	3955	51	53.0	1.35	3876.5	100.3	78.9	112.3	13.721	44.0	2.38
23/02/94	10:23:41	4017	3948	50	53.1	1.35	3878.8	100.2	68.8	112.2	13.686	44.0	2.38
23/02/94	10:23:51	4017	3952	51	52.9	1.35	3868.9	100.3	83.4	112.3	13.662	44.1	2.38
23/02/94	10:30:48	4021	6998	68	100.8	1.37	7030.1	99.8	-32.6	120.9	15.972	47.7	2.78
23/02/94	10:30:57	4021	6975	68	100.6	1.37	7016.0	99.8	-41.1	120.8	16.027	47.7	2.78
23/02/94	10:31:07	4021	7007	68	100.6	1.37	7022.9	99.9	-15.9	121.0	15.972	47.8	2.79
23/02/94	10:31:16	4021	6982	68	100.8	1.37	7035.9	99.9	-53.9	120.9	16.025	47.8	2.79
23/02/94	10:31:26	4021	6983	68	100.6	1.37	7014.9	99.8	-31.9	120.8	16.067	47.7	2.79
23/02/94	10:31:36	4021	6966	68	100.7	1.37	7024.0	99.8	-58.0	120.8	16.041	47.8	2.79
23/02/94	10:32:52	4024	6961	68	100.6	1.37	7026.4	100.0	-65.8	120.9	15.314	47.8	2.74
23/02/94	10:33:13	4024	6960	68	100.6	1.37	7018.8	99.8	-58.3	120.8	15.264	47.9	2.74
23/02/94	10:33:21	4024	6968	68	100.6	1.37	7010.2	99.7	-42.3	120.7	15.284	47.8	2.74
23/02/94	10:33:30	4024	6953	68	100.6	1.37	6993.9	99.5	-40.7	120.5	15.356	47.7	2.73
23/02/94	10:33:39	4024	6963	68	100.6	1.37	6990.0	99.4	-27.0	120.5	15.331	47.7	2.73
23/02/94	10:33:50	4024	6952	68	100.6	1.37	6981.2	99.4	-29.5	120.4	15.383	47.6	2.73
23/02/94	10:34:58	4025	6963	68	100.7	1.37	6985.3	99.4	-22.4	120.4	15.004	47.5	2.70
23/02/94	10:35:17	4025	6954	68	100.6	1.37	6976.0	99.3	-22.3	120.3	14.958	47.6	2.69

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
23/02/94	10:35:33	4025	6948	68	100.7	1.37	6979.9	99.3	-31.5	120.3	14.986	47.5	2.69
23/02/94	10:35:46	4025	6958	68	100.6	1.37	6977.1	99.3	-18.8	120.4	15.017	47.5	2.69
23/02/94	10:36:04	4025	6955	68	100.8	1.37	6971.9	99.1	-16.9	120.2	14.991	47.4	2.69
23/02/94	10:36:31	4025	6968	68	100.7	1.37	6989.8	99.4	-21.6	120.4	14.961	47.5	2.69
23/02/94	10:37:32	4025	6931	68	100.7	1.37	6960.6	99.0	-30.0	120.0	14.998	47.3	2.68
23/02/94	10:37:44	4025	6943	68	100.6	1.37	6961.9	99.1	-18.4	120.1	15.056	47.3	2.68
23/02/94	10:39:05	4026	6928	68	100.8	1.37	6955.5	98.9	-27.9	119.9	14.715	46.9	2.64
23/02/94	10:39:27	4026	6914	68	100.7	1.37	6961.5	99.1	-47.7	120.0	14.695	46.9	2.63
23/02/94	10:39:37	4026	6922	68	100.6	1.37	6958.2	99.1	-36.2	120.0	14.650	47.0	2.63
23/02/94	10:39:54	4026	6916	68	100.6	1.37	6944.0	98.9	-27.6	119.9	14.634	47.0	2.63
23/02/94	10:40:11	4026	6909	68	100.6	1.37	6944.8	98.9	-36.1	119.8	14.675	46.9	2.62
23/02/94	10:40:37	4026	6906	68	100.7	1.37	6943.5	98.8	-38.0	119.8	14.640	47.0	2.62
23/02/94	10:41:39	4027	6924	68	100.7	1.37	6968.0	99.1	-43.8	120.1	14.284	46.5	2.57
23/02/94	10:42:08	4027	6921	68	100.7	1.37	6961.9	99.0	-41.3	120.0	14.199	46.6	2.57
23/02/94	10:42:52	4027	6926	68	100.7	1.37	6958.3	99.0	-32.1	119.9	14.198	46.6	2.57
23/02/94	10:43:22	4027	6951	68	100.8	1.37	6946.6	98.8	4.0	119.9	14.173	46.5	2.57
23/02/94	10:44:11	4027	6904	68	100.7	1.37	6947.3	98.9	-43.4	119.8	14.250	46.5	2.56
23/02/94	10:48:18	4023	7039	68	100.6	1.37	7057.5	100.4	-18.3	121.5	15.001	48.4	2.74
23/02/94	10:48:34	4023	7035	68	100.6	1.37	7053.4	100.3	-18.9	121.4	14.968	48.5	2.74
23/02/94	10:48:49	4023	7026	68	100.5	1.37	7049.3	100.3	-23.7	121.4	14.979	48.5	2.74
23/02/94	10:48:59	4023	7028	68	100.6	1.37	7048.1	100.2	-20.4	121.3	14.980	48.5	2.74
23/02/94	10:49:20	4023	7024	68	100.6	1.37	7058.9	100.4	-34.6	121.4	15.007	48.5	2.75
23/02/94	10:55:39	4013	3974	51	53.0	1.35	3885.4	100.5	88.1	112.5	13.824	46.5	2.53
23/02/94	10:55:59	4013	3975	51	53.3	1.35	3901.0	100.4	73.9	112.5	13.915	46.4	2.54
23/02/94	10:56:09	4013	3989	51	53.2	1.35	3893.1	100.4	95.6	112.5	13.949	46.3	2.54
23/02/94	10:56:25	4013	3977	51	53.3	1.35	3896.5	100.3	80.2	112.4	13.996	46.2	2.53
23/02/94	10:56:35	4013	3965	51	53.1	1.35	3879.6	100.2	85.7	112.3	14.024	46.1	2.53
23/02/94	10:57:04	4013	3984	51	53.2	1.35	3886.2	100.2	97.8	112.3	13.999	46.1	2.52
23/02/94	11:01:47	4031	11902	91	202.0	1.41	12052.4	103.1	-150.3	137.4	16.299	48.0	2.80
23/02/94	11:02:11	4031	11920	91	201.9	1.41	12049.6	103.1	-130.1	137.4	16.401	48.1	2.82
23/02/94	11:02:23	4031	11925	91	201.8	1.41	12024.2	102.9	-98.9	137.3	16.459	48.2	2.83
23/02/94	11:02:51	4031	11879	91	201.9	1.41	12048.2	103.1	-169.0	137.3	16.595	48.2	2.84
23/02/94	11:03:09	4031	11897	91	201.9	1.41	12059.8	103.2	-162.7	137.4	16.593	48.3	2.85
23/02/94	11:03:19	4031	11901	91	201.8	1.41	12072.8	103.2	-172.2	137.5	16.593	48.4	2.85
23/02/94	11:03:28	4031	11917	91	201.9	1.41	12074.3	103.2	-157.4	137.6	16.637	48.4	2.85
23/02/94	11:04:42	4033	11856	91	201.7	1.41	12022.8	103.0	-167.1	137.2	16.554	48.1	2.82
23/02/94	11:04:57	4033	11886	91	201.8	1.41	12037.8	103.1	-152.0	137.3	16.601	48.1	2.82
23/02/94	11:05:08	4033	11905	91	201.6	1.41	12027.8	103.0	-122.9	137.4	16.623	48.1	2.83
23/02/94	11:05:22	4033	11885	91	201.7	1.41	12030.9	103.0	-145.4	137.3	16.554	48.2	2.83
23/02/94	11:05:32	4033	11910	91	201.9	1.41	12044.1	103.1	-134.4	137.4	16.604	48.1	2.83
23/02/94	11:06:06	4033	11858	91	201.7	1.41	12045.0	103.1	-186.8	137.3	16.599	48.2	2.83
23/02/94	11:06:31	4033	11883	91	201.9	1.41	12053.3	103.2	-170.4	137.4	16.619	48.2	2.83
23/02/94	11:07:12	4033	11880	91	201.8	1.41	12040.8	103.1	-161.0	137.3	16.607	48.2	2.84
23/02/94	11:09:12	4034	11892	91	201.7	1.41	12040.0	103.1	-147.7	137.4	16.573	48.2	2.84
23/02/94	11:09:42	4034	11916	91	201.9	1.41	12042.4	103.1	-126.5	137.4	16.545	48.2	2.84
23/02/94	11:10:00	4034	11884	91	201.8	1.41	12039.2	103.1	-155.7	137.4	16.428	48.3	2.83
23/02/94	11:10:22	4034	11868	91	201.8	1.41	12039.4	103.1	-171.8	137.3	16.560	48.2	2.84
23/02/94	11:10:39	4034	11895	91	201.9	1.41	12035.4	103.1	-140.2	137.4	16.586	48.2	2.84
23/02/94	11:11:05	4034	11887	91	201.8	1.41	12051.0	103.2	-164.0	137.4	16.510	48.3	2.84
23/02/94	11:11:29	4034	11873	91	201.9	1.41	12044.1	103.1	-170.8	137.3	16.434	48.4	2.84
23/02/94	11:15:18	4035	11895	91	201.6	1.41	12035.7	103.2	-140.2	137.5	16.221	48.4	2.82
23/02/94	11:15:45	4035	11898	91	201.6	1.41	12038.4	103.2	-140.1	137.5	16.240	48.5	2.83
23/02/94	11:16:13	4035	11883	91	201.7	1.41	12041.5	103.2	-158.8	137.4	16.212	48.5	2.83
23/02/94	11:16:29	4035	11897	91	201.6	1.41	12029.9	103.2	-133.0	137.4	16.265	48.5	2.83
23/02/94	11:16:39	4035	11873	91	201.7	1.41	12016.2	103.1	-142.9	137.3	16.256	48.5	2.83
23/02/94	11:17:37	4036	11866	91	201.7	1.41	12017.8	103.1	-151.5	137.3	15.887	48.4	2.80
23/02/94	11:17:54	4036	11866	91	201.7	1.41	12009.3	103.0	-143.7	137.3	15.912	48.4	2.80
23/02/94	11:18:03	4036	11857	91	201.6	1.41	12006.9	103.0	-150.2	137.2	15.903	48.4	2.80
23/02/94	11:18:12	4036	11868	91	201.8	1.41	12017.5	103.1	-149.3	137.3	15.896	48.4	2.80
23/02/94	11:18:23	4036	11855	91	201.6	1.41	12018.1	103.1	-163.3	137.3	15.876	48.4	2.80
23/02/94	11:19:24	4037	11851	91	201.6	1.41	11995.4	103.0	-144.5	137.2	15.512	48.0	2.75

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	al (oC/m)	bl (oC)	AT (m2 oC)
23/02/94	11:19:44	4037	11864	91	202.0	1.41	12035.5	103.2	-171.7	137.4	15.419	48.0	2.75
23/02/94	11:20:34	4037	11857	91	201.8	1.41	12015.4	103.1	-158.1	137.3	15.511	48.0	2.75
23/02/94	11:20:44	4037	11834	91	201.8	1.41	12020.8	103.1	-186.6	137.2	15.456	48.0	2.75
23/02/94	11:20:57	4037	11849	91	201.8	1.41	11998.7	103.0	-149.4	137.2	15.417	48.1	2.75
23/02/94	11:28:38	4041	15495	105	304.3	1.49	15737.5	117.6	-242.4	157.8	14.945	49.8	2.82
23/02/94	11:28:58	4041	15530	105	304.1	1.49	15735.4	117.7	-205.7	158.0	15.005	50.0	2.84
23/02/94	11:29:10	4041	15498	105	304.2	1.49	15704.8	117.6	-206.4	157.8	15.155	49.9	2.84
23/02/94	11:29:23	4041	15516	105	303.9	1.49	15673.3	117.5	-157.5	157.8	15.172	50.0	2.85
23/02/94	11:29:35	4041	15508	105	304.2	1.49	15687.4	117.6	-179.4	157.8	15.179	50.0	2.86
23/02/94	11:31:19	4043	15524	105	303.8	1.49	15733.6	117.8	-209.3	158.0	15.218	50.1	2.86
23/02/94	11:31:33	4043	15478	105	304.0	1.49	15733.4	117.8	-255.3	157.9	15.233	50.1	2.86
23/02/94	11:32:19	4043	15539	105	303.9	1.49	15730.4	117.8	-191.3	158.1	15.330	50.1	2.87
23/02/94	11:33:01	4043	15498	105	304.1	1.49	15710.8	117.8	-213.3	157.9	15.492	50.0	2.87
23/02/94	11:33:39	4043	15521	105	304.1	1.49	15728.9	117.8	-207.7	158.0	15.373	50.0	2.88
23/02/94	11:35:33	4044	15518	105	304.1	1.49	15680.5	117.6	-162.6	157.9	15.524	50.0	2.88
23/02/94	11:35:55	4044	15552	105	304.3	1.49	15699.9	117.7	-147.5	158.1	15.592	50.0	2.88
23/02/94	11:36:08	4044	15531	105	304.3	1.49	15694.7	117.7	-163.4	158.0	15.545	50.0	2.88
23/02/94	11:36:22	4044	15566	106	304.3	1.49	15711.0	117.8	-144.7	158.1	15.509	50.1	2.88
23/02/94	11:36:37	4044	15531	105	304.4	1.49	15700.0	117.7	-169.5	158.0	15.437	50.1	2.88
23/02/94	11:36:48	4044	15547	105	304.4	1.49	15696.9	117.7	-149.5	158.0	15.441	50.2	2.88
23/02/94	11:37:44	4045	15568	106	304.5	1.49	15745.8	117.9	-177.7	158.3	15.294	50.2	2.87
23/02/94	11:38:06	4045	15563	105	304.8	1.49	15781.5	118.1	-218.7	158.4	15.294	50.3	2.88
23/02/94	11:38:17	4045	15580	106	304.6	1.49	15777.7	118.1	-197.7	158.4	15.326	50.2	2.88
23/02/94	11:38:28	4045	15539	105	304.7	1.49	15791.0	118.1	-252.3	158.3	15.257	50.3	2.88
23/02/94	11:38:39	4045	15580	106	304.8	1.49	15799.0	118.2	-219.0	158.5	15.228	50.3	2.88
23/02/94	11:39:43	4046	15572	106	304.6	1.49	15752.4	118.0	-180.2	158.3	14.966	50.2	2.85
23/02/94	11:40:07	4046	15564	105	304.7	1.49	15776.5	118.1	-212.9	158.3	14.994	50.2	2.85
23/02/94	11:40:19	4046	15562	105	304.7	1.49	15770.3	118.1	-208.0	158.3	14.945	50.3	2.85
23/02/94	11:40:29	4046	15584	106	304.8	1.49	15778.2	118.1	-194.7	158.4	14.895	50.3	2.85
23/02/94	11:40:44	4046	15534	105	304.8	1.49	15757.6	118.0	-223.9	158.2	14.977	50.2	2.85
23/02/94	11:40:55	4046	15605	106	304.9	1.49	15733.5	117.9	-128.5	158.3	14.966	50.2	2.85
23/02/94	11:42:04	4047	15584	106	304.6	1.49	15716.1	117.8	-132.0	158.2	14.476	50.0	2.81
23/02/94	11:42:26	4047	15562	105	304.8	1.49	15731.1	117.9	-169.2	158.2	14.524	49.9	2.81
23/02/94	11:42:38	4047	15554	105	305.1	1.49	15794.1	118.2	-239.9	158.4	14.522	49.9	2.80
23/02/94	11:42:51	4047	15547	105	305.2	1.49	15795.2	118.2	-248.0	158.4	14.476	49.9	2.80
23/02/94	11:43:03	4047	15541	105	304.9	1.49	15796.5	118.2	-255.5	158.4	14.517	49.9	2.80
23/02/94	11:43:26	4047	15519	105	304.9	1.49	15762.3	118.0	-243.3	158.2	14.561	49.9	2.80
23/02/94	11:43:45	4047	15580	106	305.3	1.49	15780.5	118.1	-200.8	158.4	14.557	49.8	2.81
23/02/94	11:44:09	4047	15552	105	304.9	1.49	15770.5	118.1	-219.0	158.3	14.446	50.0	2.80
23/02/94	13:54:43	1	0		25.1	1.35	-16.1	7.2	16.1	7.2	0.068	24.5	0.15
23/02/94	13:54:55	1	0		25.1	1.35	-16.5	7.2	16.5	7.2	0.054	24.5	0.15
23/02/94	13:55:04	1	0		25.1	1.35	-16.8	7.2	16.8	7.2	0.042	24.6	0.15
23/02/94	13:55:13	1	0		25.0	1.35	-16.0	7.2	16.0	7.2	0.013	24.6	0.16
23/02/94	13:55:22	1	0		25.2	1.35	-17.5	7.3	17.5	7.3	0.032	24.6	0.16
23/02/94	14:04:42	2	0		50.3	1.35	5.0	13.2	-5.0	13.2	0.745	15.9	-0.35
23/02/94	14:05:04	2	0		50.6	1.35	3.7	13.3	-3.7	13.3	0.781	15.8	-0.36
23/02/94	14:05:28	2	0		50.8	1.35	7.4	13.4	-7.4	13.4	0.738	15.8	-0.37
23/02/94	14:05:41	2	0		50.5	1.35	5.7	13.3	-5.7	13.3	0.718	15.7	-0.38
23/02/94	14:05:53	2	0		49.9	1.35	2.5	13.1	-2.5	13.1	0.699	15.7	-0.38
23/02/94	14:06:02	2	0		50.8	1.35	4.4	13.4	-4.4	13.4	0.689	15.7	-0.38
23/02/94	14:12:36	3	0		74.8	1.36	5.9	19.0	-5.9	19.0	0.877	11.8	-0.63
23/02/94	14:12:49	3	0		74.9	1.36	4.3	19.0	-4.3	19.0	0.873	11.8	-0.63
23/02/94	14:13:06	3	0		75.0	1.36	4.5	19.1	-4.5	19.1	0.853	11.8	-0.63
23/02/94	14:13:23	3	0		74.9	1.36	4.3	19.0	-4.3	19.0	0.816	11.8	-0.63
23/02/94	14:13:35	3	0		74.9	1.36	5.8	19.0	-5.8	19.0	0.841	11.7	-0.63
23/02/94	14:20:50	4	0		100.6	1.37	-3.2	25.5	3.2	25.5	0.860	10.8	-0.69
23/02/94	14:20:59	4	0		100.4	1.37	-4.7	25.4	4.7	25.4	0.803	10.8	-0.69
23/02/94	14:21:07	4	0		100.6	1.37	-3.6	25.5	3.6	25.5	0.793	10.9	-0.69
23/02/94	14:21:15	4	0		100.7	1.37	-4.1	25.5	4.1	25.5	0.802	10.9	-0.69
23/02/94	14:21:26	4	0		100.6	1.37	-5.9	25.5	5.9	25.5	0.808	10.9	-0.69
23/02/94	14:26:00	5	0		125.3	1.37	-11.4	31.4	11.4	31.4	0.888	10.1	-0.74

Table A.3-1: Calculated heat loss data (cont.'d)

Date	Time	RunID	Q (W)	dQ (W)	m (g/s)	dm (g/s)	Qb (W)	dQb (W)	Qloss (W)	dQloss (W)	a1 (oC/m)	b1 (oC)	AT (m2 oC)
23/02/94	14:26:10	5	0		125.3	1.37	-8.4	31.4	8.4	31.4	0.909	10.1	-0.73
23/02/94	14:34:55	5	0		153.7	1.39	-0.5	38.3	0.5	38.3	0.958	9.1	-0.80
23/02/94	14:35:19	5	0		153.2	1.39	-5.2	38.2	5.2	38.2	0.927	9.1	-0.80
23/02/94	14:35:45	6	0		153.4	1.39	-2.5	38.2	2.5	38.2	0.946	9.1	-0.80
23/02/94	14:35:54	6	0		153.8	1.39	-0.5	38.3	0.5	38.3	0.933	9.1	-0.80
23/02/94	14:42:40	7	0		201.6	1.41	-14.6	49.6	14.6	49.6	1.095	7.8	-0.87
23/02/94	14:42:50	7	0		201.7	1.41	-13.7	49.7	13.7	49.7	1.089	7.8	-0.87
23/02/94	14:43:33	7	0		201.6	1.41	-17.0	49.6	17.0	49.6	1.157	7.7	-0.88
23/02/94	14:43:43	7	0		201.8	1.41	-16.4	49.7	16.4	49.7	1.153	7.7	-0.88
23/02/94	14:47:29	8	0		251.9	1.45	-11.5	61.8	11.5	61.8	1.183	7.0	-0.92
23/02/94	14:48:00	8	0		251.8	1.45	-13.8	61.7	13.8	61.7	1.177	7.0	-0.92
23/02/94	14:48:17	8	0		251.8	1.45	-3.7	61.7	3.7	61.7	1.192	7.0	-0.92
23/02/94	14:48:33	8	0		251.8	1.45	-11.9	61.7	11.9	61.7	1.194	7.0	-0.92
23/02/94	14:48:47	8	0		251.9	1.45	-11.9	61.8	11.9	61.8	1.185	7.0	-0.92
23/02/94	14:52:03	9	0		303.4	1.49	-18.4	74.2	18.4	74.2	1.195	6.6	-0.95
23/02/94	14:52:57	9	0		303.5	1.49	-21.1	74.2	21.1	74.2	1.125	6.7	-0.95
23/02/94	14:53:08	9	0		303.4	1.49	-15.7	74.2	15.7	74.2	1.115	6.7	-0.95
23/02/94	14:53:17	9	0		303.7	1.49	-21.1	74.2	21.1	74.2	1.117	6.7	-0.95
23/02/94	15:08:29	10	0		305.6	1.49	-10.7	72.2	10.7	72.2	1.427	2.6	-1.19
23/02/94	15:17:10	11	0		305.7	1.49	-25.3	74.6	25.3	74.6	1.183	6.2	-0.97
23/02/94	15:17:19	11	0		305.7	1.49	-27.6	74.6	27.6	74.6	1.195	6.2	-0.97
23/02/94	15:17:29	11	0		305.7	1.49	-21.2	74.6	21.2	74.6	1.197	6.2	-0.97
23/02/94	15:17:40	11	0		305.8	1.49	-18.1	74.7	18.1	74.7	1.185	6.2	-0.97
23/02/94	15:18:17	11	0		305.5	1.49	-4.5	74.6	4.5	74.6	1.195	6.2	-0.97
23/02/94	15:37:23	12	0		305.0	1.49	-47.2	81.8	47.2	81.8	0.445	17.8	-0.26
23/02/94	15:37:31	12	0		304.9	1.49	-50.0	81.8	50.0	81.8	0.439	17.8	-0.26
23/02/94	15:37:40	12	0		305.0	1.49	-38.4	81.8	38.4	81.8	0.436	17.8	-0.26
23/02/94	15:37:48	12	0		304.9	1.49	-44.4	81.8	44.4	81.8	0.424	17.8	-0.26
23/02/94	15:52:59	13	0		305.1	1.49	-40.7	84.4	40.7	84.4	0.186	21.3	-0.05
23/02/94	15:53:08	13	0		305.3	1.49	-36.5	84.5	36.5	84.5	0.248	21.3	-0.05
23/02/94	15:53:18	13	0		305.5	1.49	-41.7	84.5	41.7	84.5	0.265	21.3	-0.05
23/02/94	15:53:27	13	0		305.2	1.49	-42.1	84.4	42.1	84.4	0.272	21.3	-0.05
23/02/94	15:53:37	13	0		305.3	1.49	-36.5	84.5	36.5	84.5	0.276	21.3	-0.05
23/02/94	16:05:43	14	0		303.3	1.49	-70.2	91.6	70.2	91.6	-0.140	31.5	0.57
23/02/94	16:06:19	14	0		303.6	1.49	-67.4	91.7	67.4	91.7	-0.129	31.6	0.58
23/02/94	16:06:36	14	0		303.3	1.49	-74.9	91.6	74.9	91.6	-0.156	31.6	0.58
23/02/94	16:10:15	14	0		303.6	1.49	-84.5	91.8	84.5	91.8	-0.123	31.8	0.59
23/02/94	16:10:33	14	0		303.4	1.49	-83.0	91.7	83.0	91.7	-0.139	31.8	0.59
23/02/94	16:11:50	14	0		303.5	1.49	-83.2	92.0	83.2	92.0	-0.090	31.8	0.60
23/02/94	16:12:31	14	0		303.6	1.49	-90.2	91.9	90.2	91.9	-0.157	31.9	0.60
23/02/94	16:28:21	15	0		251.0	1.45	-77.5	78.4	77.5	78.4	-0.272	35.3	0.82
23/02/94	16:28:37	15	0		251.1	1.45	-75.9	78.5	75.9	78.5	-0.253	35.4	0.82
23/02/94	16:31:04	15	0		250.9	1.45	-84.2	78.6	84.2	78.6	-0.301	35.6	0.84
23/02/94	16:31:18	15	0		250.9	1.45	-75.5	78.5	75.5	78.5	-0.294	35.6	0.85
23/02/94	16:39:09	16	0		205.5	1.41	-84.0	66.6	84.0	66.6	-0.529	39.8	1.09
23/02/94	16:39:17	16	0		205.5	1.41	-81.0	66.7	81.0	66.7	-0.530	39.8	1.09
23/02/94	16:39:40	16	0		205.4	1.41	-83.0	66.7	83.0	66.7	-0.527	39.8	1.09
23/02/94	16:40:16	16	0		205.5	1.41	-79.0	66.7	79.0	66.7	-0.544	39.8	1.09
23/02/94	16:40:41	16	0		205.6	1.41	-79.1	66.8	79.1	66.8	-0.542	39.9	1.09
23/02/94	16:52:02	17	0		153.5	1.39	-79.2	53.3	79.2	53.3	-0.806	47.2	1.56
23/02/94	16:52:11	17	0		153.5	1.39	-84.5	53.2	84.5	53.2	-0.808	47.2	1.56
23/02/94	16:52:20	17	0		153.8	1.39	-78.1	53.3	78.1	53.3	-0.739	47.1	1.56
23/02/94	17:06:34	18	0		113.5	1.37	-106.9	44.6	106.9	44.6	-1.399	60.1	2.36
23/02/94	17:06:46	18	0		113.0	1.37	-99.6	44.4	99.6	44.4	-1.346	60.0	2.36
23/02/94	17:06:55	18	0		112.0	1.37	-95.8	44.0	95.8	44.0	-1.335	60.0	2.37
23/02/94	17:07:05	18	0		109.7	1.37	-86.4	43.1	86.4	43.1	-1.336	60.1	2.37

Table A.3-2: Convection data with power

Date	Time	RunID	ObsLoc (mm)	Tw (oC)	dTw (oC)	Tf (oC)	dTf (oC)	h (W/m2 oC)	dh (W/m2 oC)	Nu	Rnu	dRnu
Reference Tube Tests												
02/02/94	13:27:08	1010		38.36	0.13	19.15	0.42	2167		65	197	
02/02/94	13:28:06	1010		38.75	0.13	19.49	0.42	2169		65	198	
02/02/94	13:28:55	1010		38.99	0.13	19.60	0.42	2153		64	196	
02/02/94	13:29:35	1010		39.06	0.13	19.61	0.42	2160		65	197	
02/02/94	13:30:25	1010		39.08	0.13	19.54	0.42	2145		64	196	
02/02/94	13:35:05	1010		39.08	0.13	19.24	0.42	2134		63	194	
02/02/94	13:36:46	1010		39.05	0.13	19.17	0.42	2119		63	193	
02/02/94	13:37:13	1010		39.05	0.13	19.14	0.42	2120		63	193	
02/02/94	13:37:40	1010		39.02	0.13	19.12	0.42	2128		63	193	
02/02/94	13:38:39	1010		39.01	0.13	19.09	0.43	2125		63	193	
02/02/94	13:45:00	1020		25.95	0.11	12.84	0.20	3392		88	297	
02/02/94	13:46:39	1020		25.71	0.11	12.74	0.19	3431		89	300	
02/02/94	13:47:21	1020		25.68	0.13	12.71	0.19	3429		91	300	
02/02/94	13:48:12	1020		25.71	0.12	12.72	0.19	3424		90	299	
02/02/94	13:50:29	1020		25.05	0.15	12.45	0.19	3419		95	298	
02/02/94	13:54:38	1030		17.71	0.16	9.38	0.14	5438		190	466	
02/02/94	13:55:51	1030		17.71	0.19	9.44	0.14	5494		211	471	
02/02/94	13:56:44	1030		17.67	0.19	9.46	0.14	5498		212	472	
02/02/94	13:58:31	1030		17.65	0.21	9.44	0.14	5522		221	474	
02/02/94	14:00:06	1030		17.65	0.20	9.52	0.14	5607		225	481	
02/02/94	14:03:41	1040		14.87	0.21	8.24	0.13	7200		358	613	
02/02/94	14:06:08	1040		14.80	0.20	8.25	0.13	7274		355	620	
02/02/94	14:08:34	1040		14.77	0.22	8.19	0.13	7331		379	624	
02/02/94	14:09:27	1040		14.72	0.22	8.17	0.13	7369		385	627	
02/02/94	14:10:56	1040		14.70	0.22	8.16	0.13	7303		380	622	
02/02/94	15:16:11	1050		49.88	0.26	32.11	0.40	2326		79	230	
02/02/94	15:17:22	1050		49.75	0.20	31.95	0.40	2324		75	230	
02/02/94	15:18:49	1050		49.70	0.22	31.95	0.40	2333		77	230	
02/02/94	15:19:59	1050		49.79	0.29	31.94	0.41	2324		81	230	
02/02/94	15:21:03	1050		49.81	0.29	31.97	0.41	2321		81	229	
02/02/94	15:27:03	1060		37.41	0.12	26.30	0.19	3883		112	369	
02/02/94	15:28:59	1060		37.33	0.12	26.27	0.19	3941		114	375	
02/02/94	15:31:40	1060		37.43	0.15	26.46	0.19	3957		122	377	
02/02/94	15:33:20	1060		37.39	0.21	26.36	0.19	3945		134	376	
02/02/94	15:36:03	1060		37.31	0.12	26.33	0.19	3958		116	377	
02/02/94	15:44:49	1070		30.42	0.13	23.36	0.15	6680		255	624	
02/02/94	15:47:23	1070		30.29	0.17	23.25	0.15	6650		283	620	
02/02/94	15:49:47	1070		30.20	0.15	23.19	0.15	6703		271	625	
02/02/94	15:51:57	1070		30.27	0.21	23.29	0.15	6721		324	627	
02/02/94	15:52:52	1070		30.31	0.15	23.31	0.15	6739		276	629	
02/02/94	15:58:53	1080		27.70	0.16	22.26	0.14	9165		488	850	
02/02/94	16:03:20	1080		27.64	0.16	22.18	0.14	9206		489	853	
02/02/94	16:05:37	1080		27.63	0.15	22.16	0.14	9207		472	853	
02/02/94	16:07:48	1080		27.66	0.15	22.25	0.14	9290		478	861	
02/02/94	16:11:09	1080		27.75	0.15	22.36	0.14	9305		482	863	
18% Ring Tests												
04/02/94	13:12:39	1011	234	39.43	0.15	20.03	0.42	2124		64	194	1.02 0.03
04/02/94	13:15:02	1011	234	39.80	0.13	20.39	0.42	2134		64	196	1.02 0.03
04/02/94	13:16:49	1011	234	39.21	0.21	19.27	0.43	2077		64	189	0.99 0.03
04/02/94	13:21:26	1011	234	38.40	0.16	18.50	0.43	2083		63	189	0.99 0.03
04/02/94	13:23:42	1011	234	38.47	0.18	18.52	0.43	2078		64	188	0.98 0.03
04/02/94	13:30:10	1012	117	38.25	0.29	18.65	0.43	2107		70	191	1.00 0.03
04/02/94	13:31:17	1012	117	38.34	0.20	18.66	0.43	2104		66	191	1.00 0.03
04/02/94	13:32:07	1012	117	38.38	0.19	18.67	0.43	2111		66	191	1.00 0.03
04/02/94	13:32:58	1012	117	38.35	0.27	18.65	0.43	2107		69	191	1.00 0.03
04/02/94	13:33:57	1012	117	38.35	0.28	18.64	0.43	2106		69	191	1.00 0.03
04/02/94	13:36:28	1012	117	38.33	0.41	18.67	0.43	2126		78	193	1.01 0.04
04/02/94	13:37:33	1013	78	38.46	0.40	18.80	0.43	2123		77	193	1.01 0.04
04/02/94	13:38:09	1013	78	38.46	0.37	18.79	0.43	2115		75	192	1.00 0.04

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc (mm)	Tw (oC)	dTw (oC)	Tf (oC)	dTf (oC)	h (W/m2 oC)	dh (W/m2 oC)	Nu	Rnu	dRnu
04/02/94	13:39:00	1013	78	38.50	0.32	18.74	0.43	2124	72	193	1.01	0.03
04/02/94	13:40:24	1013	78	38.49	0.30	18.69	0.43	2116	71	192	1.00	0.03
04/02/94	13:41:09	1013	78	38.49	0.30	18.70	0.43	2114	71	192	1.00	0.03
04/02/94	13:43:29	1014	39	38.24	0.43	18.67	0.43	2135	80	194	1.01	0.04
04/02/94	13:44:28	1014	39	38.16	0.43	18.61	0.43	2134	80	193	1.01	0.04
04/02/94	13:46:15	1014	39	38.10	0.49	18.59	0.43	2142	85	194	1.02	0.04
04/02/94	13:47:03	1014	39	38.12	0.50	18.56	0.43	2146	86	194	1.02	0.04
04/02/94	13:49:55	1014	39	38.18	0.45	18.63	0.43	2143	83	194	1.02	0.04
04/02/94	13:52:33	1017	0	33.72	0.42	18.66	0.43	2844	135	258	1.35	0.06
04/02/94	13:53:57	1017	0	33.57	0.33	18.63	0.43	2887	126	262	1.37	0.06
04/02/94	13:55:20	1017	0	33.51	0.36	18.61	0.43	2887	130	262	1.37	0.06
04/02/94	13:56:13	1017	0	33.34	0.67	18.51	0.43	2848	175	258	1.35	0.08
04/02/94	13:57:37	1017	0	33.25	0.71	18.45	0.43	2851	181	258	1.35	0.09
04/02/94	14:06:47	1047	0	14.22	0.32	8.03	0.13	7826	565	666	1.11	0.08
04/02/94	14:07:53	1047	0	14.22	0.31	8.10	0.13	7941	569	676	1.12	0.08
04/02/94	14:10:14	1047	0	14.19	0.26	8.12	0.13	8080	517	688	1.14	0.07
04/02/94	14:11:01	1047	0	14.17	0.28	8.12	0.13	8098	541	689	1.14	0.08
04/02/94	14:12:38	1047	0	14.15	0.27	8.11	0.13	8134	527	692	1.15	0.07
04/02/94	14:15:11	1044	39	14.77	0.34	8.14	0.13	7225	500	615	1.02	0.07
04/02/94	14:16:31	1044	39	14.79	0.31	8.16	0.13	7285	474	620	1.03	0.07
04/02/94	14:17:22	1044	39	14.75	0.28	8.13	0.13	7235	437	616	1.02	0.06
04/02/94	14:17:51	1044	39	14.74	0.25	8.13	0.13	7244	402	617	1.02	0.06
04/02/94	14:18:32	1044	39	14.72	0.24	8.13	0.13	7233	393	616	1.02	0.06
04/02/94	14:19:38	1044	39	14.72	0.30	8.15	0.13	7286	463	620	1.03	0.07
04/02/94	14:22:08	1043	78	14.82	0.32	8.18	0.13	7205	484	613	1.02	0.07
04/02/94	14:24:30	1043	78	14.74	0.27	8.13	0.13	7241	430	616	1.02	0.06
04/02/94	14:26:08	1043	78	14.75	0.29	8.16	0.13	7261	457	618	1.03	0.06
04/02/94	14:26:46	1043	78	14.71	0.27	8.13	0.13	7287	433	620	1.03	0.06
04/02/94	14:27:33	1043	78	14.75	0.28	8.14	0.13	7285	443	620	1.03	0.06
04/02/94	14:28:19	1043	78	14.75	0.26	8.10	0.13	7234	411	616	1.02	0.06
04/02/94	14:31:24	1042	117	14.78	0.29	8.13	0.13	7206	439	613	1.02	0.06
04/02/94	14:32:58	1042	117	14.76	0.27	8.10	0.13	7234	420	616	1.02	0.06
04/02/94	14:33:30	1042	117	14.77	0.27	8.12	0.13	7223	417	615	1.02	0.06
04/02/94	14:35:37	1042	117	14.75	0.26	8.12	0.13	7268	411	619	1.03	0.06
04/02/94	14:36:01	1042	117	14.75	0.25	8.11	0.13	7222	405	615	1.02	0.06
04/02/94	14:38:50	1041	234	14.91	0.29	8.12	0.13	7085	430	603	1.00	0.06
04/02/94	14:39:44	1041	234	14.92	0.23	8.12	0.13	7009	358	597	0.99	0.05
04/02/94	14:41:25	1041	234	14.87	0.27	8.12	0.13	7094	408	604	1.00	0.06
04/02/94	14:41:56	1041	234	14.83	0.24	8.10	0.13	7079	372	602	1.00	0.05
04/02/94	14:42:51	1041	234	14.81	0.27	8.11	0.13	7112	409	605	1.01	0.06
04/02/94	15:01:43	1031	234	17.64	0.22	9.32	0.14	5479	223	470	1.00	0.04
04/02/94	15:02:56	1031	234	17.63	0.23	9.31	0.14	5480	230	470	1.00	0.04
04/02/94	15:03:32	1031	234	17.58	0.20	9.26	0.14	5463	211	468	1.00	0.04
04/02/94	15:04:02	1031	234	17.58	0.28	9.28	0.14	5460	262	468	1.00	0.05
04/02/94	15:04:35	1031	234	17.58	0.25	9.29	0.14	5477	243	469	1.00	0.04
04/02/94	15:06:34	1032	117	17.53	0.21	9.27	0.14	5509	222	472	1.01	0.04
04/02/94	15:08:40	1032	117	17.51	0.21	9.29	0.14	5551	226	476	1.01	0.04
04/02/94	15:09:47	1032	117	17.50	0.21	9.29	0.14	5518	223	473	1.01	0.04
04/02/94	15:10:16	1032	117	17.50	0.21	9.29	0.14	5550	226	476	1.01	0.04
04/02/94	15:12:17	1032	117	17.49	0.29	9.28	0.14	5547	272	475	1.01	0.05
04/02/94	15:14:12	1033	78	17.50	0.30	9.29	0.14	5542	282	475	1.01	0.05
04/02/94	15:15:49	1033	78	17.49	0.26	9.30	0.14	5562	255	477	1.02	0.05
04/02/94	15:17:34	1033	78	17.47	0.24	9.29	0.14	5556	244	476	1.02	0.04
04/02/94	15:18:24	1033	78	17.46	0.20	9.27	0.14	5583	219	478	1.02	0.04
04/02/94	15:19:03	1033	78	17.44	0.20	9.26	0.14	5580	219	478	1.02	0.04
04/02/94	15:21:02	1034	39	17.48	0.24	9.29	0.14	5570	245	477	1.02	0.04
04/02/94	15:22:11	1034	39	17.46	0.25	9.30	0.14	5614	253	481	1.03	0.05
04/02/94	15:23:44	1034	39	17.45	0.24	9.28	0.14	5592	246	479	1.02	0.04
04/02/94	15:24:45	1034	39	17.44	0.25	9.27	0.14	5571	249	477	1.02	0.05
04/02/94	15:26:10	1034	39	17.43	0.23	9.29	0.14	5609	242	481	1.03	0.04
04/02/94	15:28:34	1035	19.5	17.40	0.30	9.28	0.14	5596	290	479	1.02	0.05

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc (mm)	Tw (oC)	dTw (oC)	Tf (oC)	dTf (oC)	h (W/m2 oC)	dh (W/m2 oC)	Nu	Rnu	dRnu
04/02/94	15:33:46	1035	19.5	17.36	0.25	9.28	0.14	5658	259	485	1.03	0.05
04/02/94	15:34:08	1035	19.5	17.35	0.26	9.27	0.14	5645	262	484	1.03	0.05
04/02/94	15:34:28	1035	19.5	17.34	0.26	9.25	0.14	5666	264	485	1.04	0.05
04/02/94	15:36:01	1035	19.5	17.35	0.25	9.28	0.14	5638	257	483	1.03	0.05
04/02/94	15:37:37	1037	0	16.60	0.32	9.30	0.14	6368	384	546	1.16	0.07
04/02/94	15:38:36	1037	0	16.53	0.31	9.28	0.14	6412	384	549	1.17	0.07
04/02/94	15:39:21	1037	0	16.52	0.31	9.27	0.14	6425	377	551	1.17	0.07
04/02/94	15:39:38	1037	0	16.53	0.31	9.29	0.14	6465	386	554	1.18	0.07
04/02/94	15:40:40	1037	0	16.51	0.31	9.30	0.14	6457	386	553	1.18	0.07
04/02/94	15:42:09	1037	0	16.47	0.30	9.28	0.14	6482	382	555	1.18	0.07
04/02/94	15:48:30	1027	0	22.35	0.50	12.49	0.19	4521	295	395	1.32	0.09
04/02/94	15:49:07	1027	0	22.37	0.52	12.47	0.19	4462	296	390	1.30	0.09
04/02/94	15:50:54	1027	0	22.39	0.63	12.45	0.19	4438	344	387	1.30	0.10
04/02/94	15:51:14	1027	0	22.39	0.66	12.44	0.19	4448	360	388	1.30	0.11
04/02/94	15:51:36	1027	0	22.37	0.64	12.40	0.19	4434	349	387	1.29	0.10
04/02/94	15:53:28	1025	19.5	24.18	0.41	12.39	0.19	3663	169	320	1.07	0.05
04/02/94	15:54:06	1025	19.5	24.24	0.31	12.42	0.19	3632	142	317	1.06	0.04
04/02/94	15:54:39	1025	19.5	24.28	0.33	12.40	0.19	3635	147	317	1.06	0.04
04/02/94	15:55:32	1025	19.5	24.30	0.36	12.39	0.19	3622	152	316	1.06	0.04
04/02/94	15:55:49	1025	19.5	24.30	0.34	12.39	0.19	3622	147	316	1.06	0.04
04/02/94	15:57:57	1024	39	24.61	0.26	12.41	0.19	3530	121	308	1.03	0.04
04/02/94	15:58:56	1024	39	24.67	0.28	12.36	0.19	3495	125	305	1.02	0.04
04/02/94	15:59:18	1024	39	24.68	0.30	12.41	0.19	3515	129	307	1.03	0.04
04/02/94	15:59:40	1024	39	24.68	0.27	12.42	0.19	3496	123	305	1.02	0.04
04/02/94	16:01:46	1024	39	24.68	0.28	12.41	0.19	3504	125	306	1.02	0.04
04/02/94	16:03:34	1023	78	24.76	0.25	12.40	0.19	3479	117	304	1.02	0.03
04/02/94	16:04:21	1023	78	24.79	0.26	12.45	0.19	3475	119	303	1.01	0.03
04/02/94	16:04:41	1023	78	24.79	0.26	12.45	0.19	3481	118	304	1.02	0.03
04/02/94	16:05:00	1023	78	24.76	0.26	12.41	0.19	3475	118	303	1.01	0.03
04/02/94	16:05:21	1023	78	24.75	0.25	12.39	0.19	3471	116	303	1.01	0.03
04/02/94	16:06:52	1022	117	24.78	0.16	12.39	0.19	3465	99	302	1.01	0.03
04/02/94	16:07:26	1022	117	24.76	0.16	12.37	0.19	3480	99	304	1.02	0.03
04/02/94	16:07:50	1022	117	24.73	0.15	12.36	0.19	3467	98	302	1.01	0.03
04/02/94	16:08:05	1022	117	24.74	0.15	12.35	0.19	3469	97	303	1.01	0.03
04/02/94	16:08:25	1022	117	24.75	0.17	12.40	0.19	3480	101	304	1.02	0.03
04/02/94	16:08:40	1022	117	24.74	0.14	12.39	0.19	3478	96	304	1.02	0.03
04/02/94	16:10:02	1021	234	24.92	0.14	12.42	0.19	3444	95	301	1.01	0.03
04/02/94	16:10:52	1021	234	24.91	0.15	12.38	0.19	3413	95	298	1.00	0.03
04/02/94	16:11:08	1021	234	24.91	0.17	12.39	0.19	3422	98	299	1.00	0.03
04/02/94	16:11:26	1021	234	24.91	0.15	12.39	0.19	3431	95	299	1.00	0.03
04/02/94	16:11:44	1021	234	24.92	0.15	12.40	0.19	3419	96	298	1.00	0.03
07/02/94	15:25:26	1057	0	45.16	0.36	31.82	0.40	3126	150	308	1.34	0.06
07/02/94	15:26:01	1057	0	45.11	0.35	31.78	0.40	3137	149	309	1.35	0.06
07/02/94	15:26:22	1057	0	45.06	0.31	31.71	0.41	3138	143	310	1.35	0.06
07/02/94	15:26:41	1057	0	45.05	0.33	31.76	0.40	3157	147	311	1.36	0.06
07/02/94	15:27:02	1057	0	45.03	0.34	31.69	0.40	3142	149	310	1.35	0.06
07/02/94	15:28:32	1055	19.5	47.92	0.39	31.61	0.41	2531	105	249	1.09	0.05
07/02/94	15:29:17	1055	19.5	47.92	0.45	31.56	0.41	2530	111	249	1.09	0.05
07/02/94	15:29:49	1055	19.5	47.97	0.46	31.59	0.41	2530	113	249	1.09	0.05
07/02/94	15:30:20	1055	19.5	47.88	0.55	31.48	0.41	2506	121	247	1.08	0.05
07/02/94	15:30:42	1055	19.5	47.96	0.53	31.54	0.41	2514	120	248	1.08	0.05
07/02/94	15:31:05	1055	19.5	47.93	0.52	31.56	0.41	2508	118	247	1.08	0.05
07/02/94	15:31:27	1055	19.5	47.94	0.54	31.57	0.40	2502	120	246	1.07	0.05
07/02/94	15:32:37	1054	39	48.74	0.56	31.71	0.40	2409	113	238	1.04	0.05
07/02/94	15:33:28	1054	39	48.85	0.65	31.79	0.40	2402	124	237	1.03	0.05
07/02/94	15:33:48	1054	39	48.89	0.63	31.87	0.40	2400	121	237	1.03	0.05
07/02/94	15:34:19	1054	39	48.98	0.71	31.90	0.40	2395	131	236	1.03	0.06
07/02/94	15:34:50	1054	39	48.91	0.70	31.88	0.40	2408	131	238	1.04	0.06
07/02/94	15:35:20	1054	39	48.91	0.68	31.84	0.41	2411	128	238	1.04	0.05
07/02/94	15:36:55	1054	39	49.08	0.33	31.76	0.40	2364	87	233	1.02	0.04
07/02/94	15:37:48	1053	78	49.10	0.14	31.73	0.40	2361	75	233	1.02	0.03

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc (mm)	Tw (oC)	dTw (oC)	Tf (oC)	dTf (oC)	h (W/m2 oC)	dh (W/m2 oC)	Nu	Rnu	dRnu
07/02/94	15:38:08	1053	78	49.10	0.13	31.75	0.41	2378	76	235	1.02	0.03
07/02/94	15:38:28	1053	78	49.13	0.13	31.74	0.40	2357	75	233	1.01	0.03
07/02/94	15:38:57	1053	78	49.12	0.15	31.71	0.41	2363	76	233	1.02	0.03
07/02/94	15:40:20	1052	117	49.19	0.13	31.74	0.41	2358	75	233	1.01	0.03
07/02/94	15:41:05	1052	117	49.19	0.13	31.80	0.40	2373	75	234	1.02	0.03
07/02/94	15:41:30	1052	117	49.17	0.13	31.77	0.40	2356	75	232	1.01	0.03
07/02/94	15:42:04	1052	117	49.18	0.13	31.78	0.40	2360	75	233	1.02	0.03
07/02/94	15:42:49	1052	117	49.15	0.13	31.77	0.41	2363	75	233	1.02	0.03
07/02/94	15:44:28	1052	117	49.46	0.25	31.83	0.40	2331	79	230	1.00	0.03
07/02/94	15:45:18	1051	234	49.48	0.33	31.86	0.41	2338	85	231	1.01	0.04
07/02/94	15:45:52	1051	234	49.57	0.39	31.90	0.41	2334	90	230	1.00	0.04
07/02/94	15:46:12	1051	234	49.57	0.39	31.87	0.41	2315	89	229	1.00	0.04
07/02/94	15:46:38	1051	234	49.60	0.37	31.90	0.41	2327	88	230	1.00	0.04
07/02/94	15:49:43	1051	234	49.70	0.34	31.87	0.40	2302	84	227	0.99	0.04
07/02/94	16:07:26	1081	234	25.63	0.26	20.45	0.14	9477	716	869	1.02	0.08
07/02/94	16:08:08	1081	234	25.75	0.21	20.51	0.14	9374	608	860	1.01	0.07
07/02/94	16:08:27	1081	234	25.80	0.19	20.52	0.14	9258	567	849	0.99	0.06
07/02/94	16:08:46	1081	234	25.80	0.16	20.51	0.14	9235	514	847	0.99	0.06
07/02/94	16:09:05	1081	234	25.83	0.15	20.53	0.14	9191	485	843	0.99	0.05
07/02/94	16:09:20	1083	78	25.84	0.15	20.51	0.14	9138	475	838	0.98	0.05
07/02/94	16:09:43	1083	78	25.86	0.15	20.53	0.14	9130	474	837	0.98	0.05
07/02/94	16:11:05	1083	78	25.92	0.15	20.57	0.14	9115	472	836	0.98	0.05
07/02/94	16:11:32	1083	78	25.92	0.16	20.58	0.14	9174	493	842	0.99	0.05
07/02/94	16:11:48	1083	78	25.90	0.16	20.55	0.14	9118	497	836	0.98	0.05
07/02/94	16:12:02	1083	78	25.90	0.16	20.55	0.14	9033	495	829	0.97	0.05
07/02/94	16:12:17	1084	39	25.90	0.17	20.56	0.14	9071	506	832	0.97	0.05
07/02/94	16:13:25	1084	39	25.84	0.16	20.54	0.14	9268	507	850	1.00	0.05
07/02/94	16:13:53	1084	39	25.86	0.16	20.57	0.14	9234	506	847	0.99	0.05
07/02/94	16:14:07	1084	39	25.86	0.15	20.57	0.14	9227	497	846	0.99	0.05
07/02/94	16:14:21	1084	39	25.89	0.14	20.59	0.14	9212	481	845	0.99	0.05
07/02/94	16:14:35	1084	39	25.90	0.14	20.62	0.14	9245	485	848	0.99	0.05
07/02/94	16:15:53	1087	0	25.47	0.32	20.54	0.14	10146	971	931	1.09	0.10
07/02/94	16:16:23	1087	0	25.48	0.31	20.55	0.14	10156	951	932	1.09	0.10
07/02/94	16:16:39	1087	0	25.49	0.26	20.57	0.14	10108	829	927	1.09	0.09
07/02/94	16:16:53	1087	0	25.49	0.27	20.57	0.14	10161	860	932	1.09	0.09
07/02/94	16:17:11	1087	0	25.49	0.30	20.56	0.14	10152	918	931	1.09	0.10
30% Ring Tests												
23/02/94	09:02:07	4031	234	69.71	0.99	26.06	0.23	6767	199	643	1.00	0.03
23/02/94	09:02:26	4031	234	69.76	1.03	26.09	0.23	6765	205	643	1.00	0.03
23/02/94	09:03:37	4031	234	69.80	0.99	26.07	0.23	6773	199	644	1.00	0.03
23/02/94	09:05:11	4031	234	69.92	0.97	26.12	0.23	6766	194	643	1.00	0.03
23/02/94	09:05:43	4031	234	69.91	0.98	26.08	0.23	6740	195	640	1.00	0.03
23/02/94	09:06:13	4031	234	69.84	0.99	26.04	0.23	6775	198	644	1.00	0.03
23/02/94	09:09:13	4035	19.5	66.03	2.71	26.13	0.23	7616	649	724	1.13	0.10
23/02/94	09:09:51	4035	19.5	65.98	2.74	26.15	0.23	7626	657	725	1.13	0.10
23/02/94	09:11:10	4035	19.5	65.89	2.75	26.15	0.23	7653	664	727	1.13	0.10
23/02/94	09:11:24	4035	19.5	65.87	2.73	26.11	0.23	7657	659	728	1.13	0.10
23/02/94	09:11:36	4035	19.5	65.87	2.70	26.14	0.23	7680	656	730	1.14	0.10
23/02/94	09:11:48	4035	19.5	65.89	2.78	26.14	0.23	7660	672	728	1.13	0.10
23/02/94	09:13:24	4036	9.75	63.45	2.28	26.20	0.23	8326	653	792	1.23	0.10
23/02/94	09:13:50	4036	9.75	63.37	2.35	26.18	0.23	8339	674	793	1.23	0.10
23/02/94	09:15:57	4036	9.75	63.50	2.32	26.29	0.23	8364	666	796	1.24	0.10
23/02/94	09:16:18	4036	9.75	63.54	2.36	26.27	0.23	8336	674	793	1.23	0.10
23/02/94	09:16:41	4036	9.75	63.54	2.37	26.29	0.23	8387	684	798	1.24	0.10
23/02/94	09:17:00	4036	9.75	63.53	2.43	26.27	0.23	8355	696	795	1.24	0.10
23/02/94	09:18:48	4037	0	59.44	1.77	26.32	0.23	9753	692	928	1.44	0.10
23/02/94	09:19:10	4037	0	59.43	1.78	26.28	0.23	9722	694	925	1.44	0.10
23/02/94	09:19:25	4037	0	59.41	1.79	26.27	0.23	9723	696	925	1.44	0.10
23/02/94	09:21:39	4037	0	59.39	1.74	26.25	0.23	9718	680	924	1.44	0.10
23/02/94	09:21:52	4037	0	59.41	1.72	26.27	0.23	9713	669	924	1.44	0.10

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc	Tw	dTw	Tf	dTf	h	dh	Nu	Rnu	dRnu
			(mm)	(oC)	(oC)	(oC)	(oC)	(W/m2 oC)	(W/m2 oC)			
23/02/94	09:22:03	4037	0	59.39	1.70	26.28	0.23	9720	666	925	1.44	0.10
23/02/94	09:24:50	4034	39	67.03	2.64	26.25	0.23	7452	602	709	1.10	0.09
23/02/94	09:26:37	4034	39	67.03	2.52	26.21	0.23	7439	574	707	1.10	0.08
23/02/94	09:26:55	4034	39	67.03	2.49	26.19	0.23	7411	563	705	1.10	0.08
23/02/94	10:13:48	4011	234	61.52	0.89	25.28	0.66	2238	79	212	1.00	0.04
23/02/94	10:14:16	4011	234	61.48	0.93	25.17	0.66	2239	81	212	1.00	0.04
23/02/94	10:14:24	4011	234	61.51	0.96	25.22	0.66	2234	82	211	1.00	0.04
23/02/94	10:14:33	4011	234	61.52	0.94	25.21	0.66	2239	81	212	1.00	0.04
23/02/94	10:14:41	4011	234	61.49	0.92	25.17	0.66	2236	80	211	1.00	0.04
23/02/94	10:16:44	4014	39	57.78	1.65	25.11	0.67	2501	151	236	1.12	0.07
23/02/94	10:17:07	4014	39	57.67	1.71	25.04	0.67	2521	157	238	1.13	0.07
23/02/94	10:17:17	4014	39	57.63	1.78	25.00	0.66	2515	162	237	1.12	0.07
23/02/94	10:17:30	4014	39	57.57	1.82	25.03	0.67	2519	165	238	1.12	0.07
23/02/94	10:17:40	4014	39	57.55	1.78	25.02	0.66	2521	162	238	1.13	0.07
23/02/94	10:17:49	4014	39	57.56	1.75	24.99	0.66	2518	160	238	1.12	0.07
23/02/94	10:18:59	4015	19.5	55.11	1.94	24.97	0.67	2736	206	258	1.22	0.09
23/02/94	10:19:22	4015	19.5	54.97	1.89	24.94	0.67	2749	202	259	1.23	0.09
23/02/94	10:19:38	4015	19.5	54.97	1.92	25.02	0.67	2758	207	260	1.23	0.09
23/02/94	10:19:54	4015	19.5	54.88	1.95	24.97	0.67	2758	210	260	1.23	0.09
23/02/94	10:20:05	4015	19.5	54.88	2.00	24.94	0.66	2755	214	260	1.23	0.10
23/02/94	10:20:57	4016	9.75	52.15	1.59	24.87	0.66	3040	214	287	1.36	0.10
23/02/94	10:21:16	4016	9.75	52.07	1.59	24.91	0.66	3061	217	289	1.37	0.10
23/02/94	10:21:27	4016	9.75	52.03	1.58	24.92	0.66	3073	217	290	1.37	0.10
23/02/94	10:21:41	4016	9.75	51.99	1.61	24.87	0.66	3061	219	289	1.37	0.10
23/02/94	10:21:49	4016	9.75	51.96	1.62	24.93	0.67	3075	222	290	1.37	0.10
23/02/94	10:23:02	4017	0	48.36	0.92	24.84	0.66	3580	198	337	1.60	0.09
23/02/94	10:23:14	4017	0	48.32	0.93	24.85	0.67	3582	199	338	1.60	0.09
23/02/94	10:23:32	4017	0	48.29	0.95	24.90	0.67	3618	205	341	1.61	0.09
23/02/94	10:23:41	4017	0	48.29	0.93	24.87	0.66	3604	202	340	1.61	0.09
23/02/94	10:23:51	4017	0	48.27	0.94	24.87	0.67	3613	204	341	1.61	0.09
23/02/94	10:30:48	4021	234	64.12	0.63	24.41	0.38	3788	87	356	1.00	0.02
23/02/94	10:30:57	4021	234	64.14	0.64	24.41	0.38	3773	88	355	1.00	0.02
23/02/94	10:31:07	4021	234	64.17	0.68	24.46	0.38	3793	91	357	1.00	0.02
23/02/94	10:31:16	4021	234	64.22	0.70	24.44	0.38	3772	92	355	1.00	0.02
23/02/94	10:31:26	4021	234	64.22	0.66	24.45	0.38	3773	89	355	1.00	0.02
23/02/94	10:31:36	4021	234	64.22	0.65	24.46	0.38	3764	88	354	1.00	0.02
23/02/94	10:32:52	4024	39	61.36	1.83	24.54	0.38	4100	239	386	1.09	0.06
23/02/94	10:33:13	4024	39	61.28	1.89	24.52	0.38	4107	247	386	1.09	0.07
23/02/94	10:33:21	4024	39	61.24	1.87	24.50	0.38	4116	245	387	1.09	0.06
23/02/94	10:33:30	4024	39	61.15	1.89	24.45	0.38	4109	247	386	1.09	0.07
23/02/94	10:33:39	4024	39	61.06	1.90	24.43	0.38	4126	251	388	1.09	0.07
23/02/94	10:33:50	4024	39	61.02	1.90	24.42	0.38	4123	250	388	1.09	0.07
23/02/94	10:34:58	4025	19.5	59.02	2.24	24.45	0.38	4405	333	414	1.17	0.09
23/02/94	10:35:17	4025	19.5	58.93	2.28	24.42	0.38	4408	339	414	1.17	0.09
23/02/94	10:35:33	4025	19.5	58.86	2.24	24.43	0.37	4415	335	415	1.17	0.09
23/02/94	10:35:46	4025	19.5	58.82	2.32	24.47	0.38	4434	349	417	1.17	0.09
23/02/94	10:36:04	4025	19.5	58.75	2.31	24.38	0.37	4430	347	416	1.17	0.09
23/02/94	10:36:31	4025	19.5	58.75	2.34	24.46	0.38	4451	354	419	1.18	0.09
23/02/94	10:37:32	4025	19.5	58.50	2.29	24.36	0.37	4446	348	418	1.18	0.09
23/02/94	10:37:44	4025	19.5	58.50	2.29	24.40	0.38	4461	350	419	1.18	0.09
23/02/94	10:39:05	4026	9.75	55.78	2.02	24.36	0.37	4889	373	459	1.29	0.10
23/02/94	10:39:27	4026	9.75	55.73	2.08	24.39	0.37	4893	385	460	1.30	0.10
23/02/94	10:39:37	4026	9.75	55.74	2.08	24.41	0.37	4900	385	461	1.30	0.10
23/02/94	10:39:54	4026	9.75	55.69	2.08	24.35	0.37	4894	384	460	1.29	0.10
23/02/94	10:40:11	4026	9.75	55.68	2.09	24.36	0.37	4891	386	460	1.29	0.10
23/02/94	10:40:37	4026	9.75	55.63	2.14	24.34	0.37	4895	397	460	1.30	0.11
23/02/94	10:41:39	4027	0	51.86	1.17	24.40	0.37	5719	308	538	1.51	0.08
23/02/94	10:42:08	4027	0	51.78	1.20	24.38	0.37	5729	317	538	1.52	0.08
23/02/94	10:42:52	4027	0	51.76	1.23	24.37	0.37	5738	323	539	1.52	0.09
23/02/94	10:43:22	4027	0	51.70	1.16	24.31	0.37	5764	310	541	1.52	0.08
23/02/94	10:44:11	4027	0	51.68	1.06	24.36	0.37	5733	286	539	1.52	0.08

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc	Tw	dTw	Tf	dTf	h	dh	Nu	Rnu	dRnu
			(mm)	(oC)	(oC)	(oC)	(oC)	(W/m2 oC)	(W/m2 oC)			
23/02/94	10:48:18	4023	78	61.68	1.54	24.66	0.38	4127	204	389	1.09	0.05
23/02/94	10:48:34	4023	78	61.74	1.42	24.63	0.38	4112	188	387	1.09	0.05
23/02/94	10:48:49	4023	78	61.78	1.43	24.62	0.38	4100	189	386	1.09	0.05
23/02/94	10:48:59	4023	78	61.83	1.42	24.62	0.38	4095	188	385	1.09	0.05
23/02/94	10:49:20	4023	78	61.85	1.42	24.64	0.38	4093	187	385	1.08	0.05
23/02/94	10:55:39	4013	78	59.37	1.12	25.32	0.67	2410	104	228	1.08	0.05
23/02/94	10:55:59	4013	78	59.35	1.03	25.29	0.66	2410	98	228	1.08	0.04
23/02/94	10:56:09	4013	78	59.28	1.14	25.25	0.67	2422	106	229	1.08	0.05
23/02/94	10:56:25	4013	78	59.17	1.08	25.17	0.66	2416	102	228	1.08	0.05
23/02/94	10:56:35	4013	78	59.15	1.14	25.14	0.66	2408	105	227	1.08	0.05
23/02/94	10:57:04	4013	78	59.05	1.16	25.06	0.67	2421	108	229	1.08	0.05
23/02/94	11:01:47	4031	234	64.70	1.23	24.10	0.22	6852	263	643	1.01	0.04
23/02/94	11:02:11	4031	234	64.87	1.20	24.14	0.22	6838	255	642	1.00	0.04
23/02/94	11:02:23	4031	234	64.95	1.19	24.12	0.22	6822	252	640	1.00	0.04
23/02/94	11:02:51	4031	234	65.13	1.18	24.25	0.22	6780	248	637	1.00	0.04
23/02/94	11:03:09	4031	234	65.25	1.15	24.30	0.22	6778	242	637	1.00	0.04
23/02/94	11:03:19	4031	234	65.28	1.10	24.33	0.22	6780	233	637	1.00	0.03
23/02/94	11:03:28	4031	234	65.32	1.12	24.34	0.22	6786	235	638	1.00	0.03
23/02/94	11:04:42	4033	78	63.34	1.75	24.40	0.22	7177	403	675	1.06	0.06
23/02/94	11:04:57	4033	78	63.29	1.81	24.43	0.22	7217	420	678	1.06	0.06
23/02/94	11:05:08	4033	78	63.30	1.82	24.43	0.22	7229	424	680	1.06	0.06
23/02/94	11:05:22	4033	78	63.27	1.77	24.42	0.22	7221	411	679	1.06	0.06
23/02/94	11:05:32	4033	78	63.25	1.75	24.43	0.22	7245	409	681	1.07	0.06
23/02/94	11:06:06	4033	78	63.25	1.77	24.46	0.22	7214	412	678	1.06	0.06
23/02/94	11:06:31	4033	78	63.26	1.85	24.46	0.22	7231	431	680	1.06	0.06
23/02/94	11:07:12	4033	78	63.24	1.78	24.47	0.22	7234	416	680	1.06	0.06
23/02/94	11:09:12	4034	39	62.91	2.33	24.54	0.22	7335	554	690	1.08	0.08
23/02/94	11:09:42	4034	39	62.92	2.24	24.50	0.22	7342	534	691	1.08	0.08
23/02/94	11:10:00	4034	39	62.93	2.28	24.53	0.22	7323	542	689	1.08	0.08
23/02/94	11:10:22	4034	39	62.95	2.27	24.56	0.22	7314	540	688	1.08	0.08
23/02/94	11:10:39	4034	39	62.96	2.16	24.55	0.22	7329	515	690	1.08	0.08
23/02/94	11:11:05	4034	39	62.97	2.25	24.57	0.22	7325	535	689	1.08	0.08
23/02/94	11:11:29	4034	39	63.02	2.23	24.55	0.22	7300	528	687	1.07	0.08
23/02/94	11:15:18	4035	19.5	62.06	2.32	24.87	0.22	7628	596	719	1.13	0.09
23/02/94	11:15:45	4035	19.5	62.08	2.29	24.97	0.22	7651	594	722	1.13	0.09
23/02/94	11:16:13	4035	19.5	62.08	2.30	24.98	0.22	7643	594	721	1.13	0.09
23/02/94	11:16:29	4035	19.5	62.06	2.27	24.99	0.22	7659	591	723	1.13	0.09
23/02/94	11:16:39	4035	19.5	62.04	2.27	24.98	0.22	7643	588	721	1.13	0.09
23/02/94	11:17:37	4036	9.75	60.09	2.13	25.01	0.22	8182	632	772	1.21	0.09
23/02/94	11:17:54	4036	9.75	60.07	2.08	25.02	0.22	8192	619	773	1.21	0.09
23/02/94	11:18:03	4036	9.75	60.06	2.10	25.03	0.22	8190	626	773	1.21	0.09
23/02/94	11:18:12	4036	9.75	60.07	2.10	25.04	0.22	8199	626	774	1.21	0.09
23/02/94	11:18:23	4036	9.75	60.06	2.15	25.05	0.22	8194	641	773	1.21	0.09
23/02/94	11:19:24	4037	0	56.25	1.52	25.06	0.22	9498	614	897	1.40	0.09
23/02/94	11:19:44	4037	0	56.21	1.54	25.08	0.22	9535	626	900	1.41	0.09
23/02/94	11:20:34	4037	0	56.18	1.56	25.11	0.22	9555	636	902	1.41	0.09
23/02/94	11:20:44	4037	0	56.18	1.51	25.11	0.22	9528	613	900	1.41	0.09
23/02/94	11:20:57	4037	0	56.17	1.52	25.09	0.22	9539	620	901	1.41	0.09
23/02/94	11:28:38	4041	234	64.93	1.86	24.69	0.18	9664	592	910	1.00	0.06
23/02/94	11:28:58	4041	234	65.12	1.82	24.77	0.18	9656	578	910	1.00	0.06
23/02/94	11:29:10	4041	234	65.19	1.82	24.75	0.18	9602	572	905	1.00	0.06
23/02/94	11:29:23	4041	234	65.29	1.81	24.80	0.18	9605	569	905	1.00	0.06
23/02/94	11:29:35	4041	234	65.33	1.79	24.83	0.18	9594	561	904	1.00	0.06
23/02/94	11:31:19	4043	78	63.77	1.45	25.04	0.18	10188	515	962	1.06	0.05
23/02/94	11:31:33	4043	78	63.75	1.48	25.04	0.18	10156	522	958	1.06	0.05
23/02/94	11:32:19	4043	78	63.78	1.38	25.06	0.18	10206	493	963	1.06	0.05
23/02/94	11:33:01	4043	78	63.79	1.40	25.06	0.18	10168	497	960	1.06	0.05
23/02/94	11:33:39	4043	78	63.79	1.44	25.09	0.18	10196	512	963	1.06	0.05
23/02/94	11:35:33	4044	39	63.42	1.54	25.03	0.18	10302	557	972	1.07	0.06
23/02/94	11:35:55	4044	39	63.43	1.56	25.08	0.18	10347	569	977	1.08	0.06
23/02/94	11:36:08	4044	39	63.41	1.50	25.09	0.18	10339	548	976	1.08	0.06

Table A.3-2: Convection data with power (cont.'d)

Date	Time	RunID	ObsLoc (mm)	Tw (oC)	dTw (oC)	Tf (oC)	dTf (oC)	h (W/m2 oC)	dh (W/m2 oC)	Nu	Rnu	dRnu
23/02/94	11:36:22	4044	39	63.41	1.56	25.10	0.18	10376	572	980	1.08	0.06
23/02/94	11:36:37	4044	39	63.38	1.61	25.06	0.18	10341	584	976	1.08	0.06
23/02/94	11:36:48	4044	39	63.40	1.67	25.07	0.18	10350	607	977	1.08	0.06
23/02/94	11:37:44	4045	19.5	62.93	1.68	25.15	0.18	10570	636	998	1.10	0.07
23/02/94	11:38:06	4045	19.5	62.98	1.70	25.17	0.18	10553	642	997	1.10	0.07
23/02/94	11:38:17	4045	19.5	63.00	1.72	25.17	0.18	10561	651	998	1.10	0.07
23/02/94	11:38:28	4045	19.5	62.99	1.75	25.21	0.18	10541	659	996	1.10	0.07
23/02/94	11:38:39	4045	19.5	63.01	1.73	25.21	0.18	10574	654	999	1.10	0.07
23/02/94	11:39:43	4046	9.75	61.51	1.14	25.16	0.18	11141	484	1052	1.16	0.05
23/02/94	11:40:07	4046	9.75	61.50	1.10	25.19	0.18	11147	469	1053	1.16	0.05
23/02/94	11:40:19	4046	9.75	61.52	1.02	25.19	0.18	11140	438	1052	1.16	0.05
23/02/94	11:40:29	4046	9.75	61.50	1.09	25.18	0.18	11162	465	1054	1.16	0.05
23/02/94	11:40:44	4046	9.75	61.50	1.00	25.16	0.18	11107	427	1049	1.16	0.04
23/02/94	11:40:55	4046	9.75	61.49	1.06	25.14	0.18	11170	455	1055	1.16	0.05
23/02/94	11:42:04	4047	0	58.01	0.66	25.13	0.18	12809	384	1210	1.33	0.04
23/02/94	11:42:26	4047	0	57.98	0.56	25.13	0.18	12801	336	1209	1.33	0.03
23/02/94	11:42:38	4047	0	57.97	0.55	25.19	0.18	12832	333	1212	1.34	0.03
23/02/94	11:42:51	4047	0	57.98	0.52	25.19	0.18	12814	316	1211	1.34	0.03
23/02/94	11:43:03	4047	0	57.96	0.52	25.21	0.18	12828	316	1212	1.34	0.03
23/02/94	11:43:26	4047	0	57.98	0.49	25.19	0.18	12779	299	1207	1.33	0.03
23/02/94	11:43:45	4047	0	57.98	0.51	25.17	0.18	12841	310	1213	1.34	0.03
23/02/94	11:44:09	4047	0	58.01	0.60	25.19	0.18	12809	358	1210	1.33	0.04

A.4 Pressure Drop Analysis

A.4.1 Analysis Procedures

- Mass flux:

$$G = \frac{\dot{m}}{A_x} = \frac{4 \dot{m}}{\pi d^2} \quad (\text{A.41})$$

- Bulk fluid temperature (over DP cell):

$$T_b = \frac{1}{2} [T_f(z_1) + T_f(z_2)] \quad (\text{A.42})$$

where $T_f(z)$ is determined using equation (A.12) and (A.13), and

z_1 = location of first pressure tap

z_2 = location of second pressure tap

- Fluid kinetic energy:

$$\text{K.E.} = \rho \frac{u^2}{2} = \frac{1}{2} \frac{G^2}{\rho} = \frac{1}{2} \nu G^2 \quad (\text{A.43})$$

- Frictional pressure drop (wall only):

$$\tau_w = f \left(\rho \frac{u^2}{2} \right) \quad (\text{A.44})$$

$$\left(\frac{\partial P}{\partial z} \right)_f = \tau_w \frac{P_w}{A_x} = \tau_w \left(\frac{\pi d}{\pi d^2} \right) = \tau_w \left(\frac{4}{d} \right) \quad (\text{A.45})$$

$$(\Delta P)_f = \left(\frac{\partial P}{\partial z} \right)_f \cdot \Delta L = f \left(\rho \frac{u^2}{2} \right) \left(\frac{4 L}{d} \right) \quad (\text{A.46})$$

- Flow obstruction pressure drop:

$$\Delta P_{obs} = \Delta P_{tot} - \Delta P_f = K_{obs} \rho \frac{u^2}{2} \quad (A.47)$$

$$\therefore K_{obs} = \frac{\Delta P_{tot} - \Delta P_f}{\rho \frac{u^2}{2}} \quad (A.48)$$

- Reference tube correlation (Prandtl formula from White, 1991):

$$\frac{1}{4f} = 2.0 \log_{10} \left(Re_d \sqrt{4f} \right) - 0.8 \quad (A.49)$$

A.4.2 Error Analysis

- Mass flux:

$$\begin{aligned} \Delta G &= \sqrt{\left(\frac{\partial G}{\partial \dot{m}} \Delta \dot{m} \right)^2 + \left(\frac{\partial G}{\partial A_x} \Delta A_x \right)^2} \\ &= \sqrt{\left(\frac{\Delta \dot{m}}{A_x} \right)^2 + \left(G \cdot \frac{\Delta A_x}{A_x} \right)^2} \\ &= G \sqrt{\left(\frac{\Delta \dot{m}}{\dot{m}} \right)^2 + \left(\frac{\Delta A_x}{A_x} \right)^2} \end{aligned} \quad (A.50)$$

where

$$\frac{\Delta A_x}{A_x} = \frac{2 \Delta d}{d} = 0.0125 \quad (A.51)$$

The resultant uncertainty in mass flux ranged from 1.3–3.0%.

- Bulk fluid temperature: the effect of uncertainty in temperature, used to compute the bulk fluid properties (ex., specific volume, v_f), was determined to be insignificant in comparison to the other terms in the pressured-drop equation.

- Kinetic energy:

$$\Delta K.E. = \sqrt{\left(\frac{\partial K.E.}{\partial v_f} \Delta v_f\right)^2 + \left(\frac{\partial K.E.}{\partial G} \Delta G\right)^2} \quad (A.52)$$

$$\approx \left(\frac{\partial K.E.}{\partial G} \Delta G\right) = \frac{2 K.E.}{G} \Delta G$$

$$\therefore \frac{\Delta K.E.}{K.E.} = 2 \frac{\Delta G}{G} \quad (A.53)$$

resulting in uncertainties ranging from 2.9–6.1%.

- Static pressure drop: the differential pressure transducers (DP1 and DP2) used in this experiment have the following characteristics:

accuracy	=	±0.2% F.S.
bridge accuracy	=	±0.1%
A/D conversion	=	±0.1% F.S.

with the following F.S. values for each cell:

DP cell #1 (DP1):	F.S.	=	690 kPa
DP cell #2 (DP2):	F.S.	=	40 kPa

producing the following error relation:

$$\Delta(\Delta P) = \sqrt{\left(\frac{0.2}{100} \text{ F.S.}\right)^2 + \left(\frac{0.1}{100} \Delta P\right)^2 + \left(\frac{0.1}{100} \text{ F.S.}\right)^2} \quad (A.54)$$

resulting in uncertainties of $\Delta P = 1.55$ kPa, $\Delta P = 0.09$ kPa for DP cells #1 and #2, respectively.

- Flow obstruction K-factor:

$$\Delta K_{obs} = \sqrt{\left(\frac{\partial K_{obs}}{\partial (\Delta P_{obs})} \Delta(\Delta P_{obs})\right)^2 + \left(\frac{\partial K_{obs}}{\partial K.E.} \Delta K.E.\right)^2} \quad (A.55)$$

An error analysis on the ΔP_f data in the reference tube (i.e., predicted versus measured), since the predicted values are used to compute ΔP_f in equation (A.48), produced the following results:

	DP cell #1	DP cell #2
$\left(\Delta P_f - \Delta \hat{P}_f \right)_{\text{RMS}}$	1.19 kPa	0.60 kPa
$\left(\Delta P_f - \Delta \hat{P}_f \right)_\sigma$	1.15 kPa	0.32 kPa
$\left(\overline{\Delta P_f - \Delta \hat{P}_f} \right)$	-0.37 kPa	0.51 kPa

Since ΔP_{obs} only ranged from 0–2 kPa for the 18% ring, and 0–4 kPa for the 30% ring, the DP cell #1 data was dropped in favour of DP cell #2 which has twice the accuracy. The following RMS error was applied to ΔP_{obs} :

$$\Delta(\Delta P_{obs}) = \pm 0.60 \text{ kPa}$$

It should be noted that this error is 6–7 times larger than the estimated uncertainty in the DP cell #2, and can be attributed to inaccuracies of the Prandtl formula. The error in K_{obs} is now defined as:

$$\Delta K_{obs} = \sqrt{\left(\frac{\Delta(\Delta P_{obs})}{\text{K.E.}} \right)^2 + \left(K_{obs} \cdot \frac{\Delta \text{K.E.}}{\text{K.E.}} \right)^2} \quad (\text{A.56})$$

in which average uncertainties in K_{obs} of 39% and 23% are obtained for the 18% ring and 30% ring, respectively. Only pressure drop data with ΔP_{obs} greater than $\Delta(\Delta P_{obs})$ were used to estimate K_{obs} , limiting useful data to $G = 4\text{--}6 \text{ Mg/m}^2\cdot\text{s}$.

A.4.3 Calculated Data

The following spreadsheet table contains the pressure drop calculations for the reference tube and ring data:

Table A.4-1: Calculated pressure drop data (383 points)

Table A.4-1: Calculated pressure drop data

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
Reference Tube												
02/02/94	13:27:08	1010	1015	30	20.4	0.000835	0.43	0.03	0.0056	3.12	0.40	17.5
02/02/94	13:28:06	1010	1016	30	20.7	0.000836	0.43	0.03	0.0056	3.12	0.49	17.8
02/02/94	13:28:55	1010	1015	30	20.8	0.000837	0.43	0.03	0.0056	3.12	0.47	17.9
02/02/94	13:29:35	1010	1016	30	20.8	0.000837	0.43	0.03	0.0056	3.13	0.49	17.9
02/02/94	13:30:25	1010	1016	30	20.8	0.000837	0.43	0.03	0.0056	3.13	0.47	17.9
02/02/94	13:35:05	1010	1015	30	20.5	0.000836	0.43	0.03	0.0056	3.12	0.47	17.5
02/02/94	13:36:46	1010	1014	30	20.4	0.000836	0.43	0.03	0.0056	3.12	0.41	17.5
02/02/94	13:37:13	1010	1014	30	20.4	0.000835	0.43	0.03	0.0056	3.11	0.42	17.4
02/02/94	13:37:40	1010	1014	30	20.4	0.000835	0.43	0.03	0.0056	3.12	0.39	17.4
02/02/94	13:38:39	1010	1014	30	20.3	0.000835	0.43	0.03	0.0056	3.11	0.53	17.4
02/02/94	13:45:00	1020	1980	37	13.6	0.000817	1.60	0.06	0.0049	10.12	-0.27	11.9
02/02/94	13:46:39	1020	1994	37	13.5	0.000817	1.62	0.06	0.0049	10.25	-0.26	11.8
02/02/94	13:47:21	1020	1993	37	13.4	0.000816	1.62	0.06	0.0049	10.23	-0.28	11.8
02/02/94	13:48:12	1020	1991	37	13.5	0.000816	1.62	0.06	0.0049	10.21	-0.30	11.8
02/02/94	13:50:29	1020	1993	37	13.2	0.000816	1.62	0.06	0.0049	10.24	-0.29	11.6
02/02/94	13:54:38	1030	3995	57	9.8	0.000807	6.44	0.18	0.0043	35.37	-1.06	8.9
02/02/94	13:55:51	1030	3995	57	9.8	0.000807	6.44	0.18	0.0043	35.37	-1.08	9.0
02/02/94	13:56:44	1030	3995	57	9.8	0.000807	6.44	0.18	0.0043	35.36	-1.11	9.0
02/02/94	13:58:31	1030	3993	57	9.8	0.000807	6.43	0.18	0.0043	35.33	-1.09	9.0
02/02/94	14:00:06	1030	3991	57	9.9	0.000808	6.43	0.18	0.0043	35.33	-1.02	9.1
02/02/94	14:03:41	1040	5996	81	8.5	0.000804	14.45	0.39	0.0039	73.35	-2.30	7.9
02/02/94	14:06:08	1040	6001	81	8.5	0.000804	14.48	0.39	0.0039	73.44	-2.35	8.0
02/02/94	14:08:34	1040	5992	81	8.4	0.000804	14.43	0.39	0.0039	73.27	-2.43	7.9
02/02/94	14:09:27	1040	5990	80	8.4	0.000804	14.42	0.39	0.0039	73.22	-2.46	7.9
02/02/94	14:10:56	1040	5995	81	8.4	0.000804	14.45	0.39	0.0039	73.33	-2.38	7.9
02/02/94	15:16:11	1050	1002	30	33.3	0.000877	0.44	0.03	0.0055	3.13	1.69	30.5
02/02/94	15:17:22	1050	1004	30	33.1	0.000877	0.44	0.03	0.0055	3.14	1.70	30.4
02/02/94	15:18:49	1050	1002	30	33.1	0.000877	0.44	0.03	0.0055	3.13	1.56	30.4
02/02/94	15:19:59	1050	995	30	33.1	0.000877	0.43	0.03	0.0055	3.09	1.72	30.3
02/02/94	15:21:03	1050	996	30	33.2	0.000877	0.43	0.03	0.0055	3.10	1.67	30.4
02/02/94	15:27:03	1060	1999	37	27.0	0.000856	1.71	0.06	0.0048	10.55	1.06	25.4
02/02/94	15:28:59	1060	2001	37	27.0	0.000856	1.71	0.06	0.0048	10.56	1.11	25.4
02/02/94	15:31:40	1060	1998	37	27.1	0.000856	1.71	0.06	0.0048	10.54	1.11	25.6
02/02/94	15:33:20	1060	1999	37	27.0	0.000856	1.71	0.06	0.0048	10.54	1.14	25.5
02/02/94	15:36:03	1060	1999	37	27.0	0.000856	1.71	0.06	0.0048	10.55	1.11	25.5
02/02/94	15:44:49	1070	4003	57	23.7	0.000845	6.77	0.19	0.0042	36.32	0.52	22.9
02/02/94	15:47:23	1070	4010	57	23.6	0.000845	6.79	0.19	0.0042	36.44	0.73	22.8
02/02/94	15:49:47	1070	4005	57	23.5	0.000845	6.78	0.19	0.0042	36.36	0.54	22.8
02/02/94	15:51:57	1070	4007	57	23.7	0.000845	6.78	0.19	0.0042	36.40	0.60	22.9
02/02/94	15:52:52	1070	4010	57	23.7	0.000845	6.80	0.19	0.0042	36.45	0.67	22.9
02/02/94	15:58:53	1080	6030	81	22.5	0.000842	15.31	0.41	0.0038	75.87	-0.18	22.0
02/02/94	16:03:20	1080	6002	81	22.4	0.000841	15.15	0.41	0.0038	75.17	-0.39	21.9
02/02/94	16:05:37	1080	6013	81	22.4	0.000841	15.20	0.41	0.0038	75.41	-0.15	21.9
02/02/94	16:07:48	1080	6015	81	22.5	0.000842	15.23	0.41	0.0038	75.53	-0.18	22.0
02/02/94	16:11:09	1080	6026	81	22.6	0.000842	15.29	0.41	0.0038	75.78	0.01	22.1
18% Ring												
04/02/94	13:12:39	1011	1005	30	21.3	0.000838	0.42	0.03	0.0056	3.07	0.41	18.4
04/02/94	13:15:02	1011	1003	30	21.6	0.000839	0.42	0.03	0.0056	3.06	0.43	18.7
04/02/94	13:16:49	1011	1003	30	20.5	0.000836	0.42	0.02	0.0056	3.05	0.32	17.6
04/02/94	13:21:26	1011	1002	30	19.8	0.000834	0.42	0.02	0.0056	3.05	0.26	16.8
04/02/94	13:23:42	1011	1000	30	19.8	0.000834	0.42	0.02	0.0056	3.04	0.27	16.8
04/02/94	13:30:10	1012	1000	30	19.9	0.000834	0.42	0.02	0.0056	3.03	0.28	17.0
04/02/94	13:31:17	1012	1002	30	19.9	0.000834	0.42	0.02	0.0056	3.05	0.31	17.0
04/02/94	13:32:07	1012	1000	30	19.9	0.000834	0.42	0.02	0.0056	3.04	0.30	17.0
04/02/94	13:32:58	1012	1004	30	19.9	0.000834	0.42	0.02	0.0056	3.06	0.28	17.0
04/02/94	13:33:57	1012	1001	30	19.9	0.000834	0.42	0.02	0.0056	3.04	0.26	17.0
04/02/94	13:36:28	1012	1002	30	19.9	0.000834	0.42	0.02	0.0056	3.05	0.30	17.0
04/02/94	13:37:33	1013	1000	30	20.0	0.000834	0.42	0.02	0.0056	3.04	0.32	17.1
04/02/94	13:38:09	1013	1001	30	20.0	0.000834	0.42	0.02	0.0056	3.04	0.28	17.1

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
Reference Tube										
02/02/94	13:27:08	1010	0.000827	0.43	0.02	0.0057	0.61	0.26		
02/02/94	13:28:06	1010	0.000828	0.43	0.03	0.0056	0.61	0.28		
02/02/94	13:28:55	1010	0.000829	0.43	0.03	0.0056	0.61	0.27		
02/02/94	13:29:35	1010	0.000829	0.43	0.03	0.0056	0.61	0.27		
02/02/94	13:30:25	1010	0.000828	0.43	0.03	0.0056	0.61	0.27		
02/02/94	13:35:05	1010	0.000827	0.43	0.02	0.0057	0.61	0.27		
02/02/94	13:36:46	1010	0.000827	0.43	0.02	0.0057	0.61	0.26		
02/02/94	13:37:13	1010	0.000827	0.43	0.02	0.0057	0.61	0.26		
02/02/94	13:37:40	1010	0.000827	0.43	0.02	0.0057	0.61	0.25		
02/02/94	13:38:39	1010	0.000827	0.43	0.02	0.0057	0.61	0.27		
02/02/94	13:45:00	1020	0.000813	1.59	0.06	0.0049	1.97	0.03		
02/02/94	13:46:39	1020	0.000812	1.61	0.06	0.0049	2.00	0.01		
02/02/94	13:47:21	1020	0.000812	1.61	0.06	0.0049	2.00	0.01		
02/02/94	13:48:12	1020	0.000812	1.61	0.06	0.0049	1.99	-0.02		
02/02/94	13:50:29	1020	0.000812	1.61	0.06	0.0049	2.00	0.01		
02/02/94	13:54:38	1030	0.000805	6.42	0.18	0.0043	6.90	0.43		
02/02/94	13:55:51	1030	0.000805	6.43	0.18	0.0043	6.90	0.41		
02/02/94	13:56:44	1030	0.000805	6.42	0.18	0.0043	6.90	0.40		
02/02/94	13:58:31	1030	0.000805	6.42	0.18	0.0043	6.89	0.42		
02/02/94	14:00:06	1030	0.000806	6.42	0.18	0.0043	6.89	0.42		
02/02/94	14:03:41	1040	0.000803	14.44	0.39	0.0039	14.32	0.62		
02/02/94	14:06:08	1040	0.000803	14.46	0.39	0.0039	14.34	0.62		
02/02/94	14:08:34	1040	0.000803	14.42	0.39	0.0039	14.31	0.58		
02/02/94	14:09:27	1040	0.000803	14.41	0.39	0.0039	14.30	0.57		
02/02/94	14:10:56	1040	0.000803	14.43	0.39	0.0039	14.32	0.59		
02/02/94	15:16:11	1050	0.000867	0.44	0.03	0.0055	0.61	0.53		
02/02/94	15:17:22	1050	0.000867	0.44	0.03	0.0055	0.61	0.52		
02/02/94	15:18:49	1050	0.000867	0.43	0.03	0.0055	0.61	0.49		
02/02/94	15:19:59	1050	0.000867	0.43	0.03	0.0055	0.60	0.50		
02/02/94	15:21:03	1050	0.000867	0.43	0.03	0.0055	0.60	0.52		
02/02/94	15:27:03	1060	0.000851	1.70	0.06	0.0048	2.05	0.29		
02/02/94	15:28:59	1060	0.000851	1.70	0.06	0.0048	2.06	0.29		
02/02/94	15:31:40	1060	0.000851	1.70	0.06	0.0048	2.05	0.31		
02/02/94	15:33:20	1060	0.000851	1.70	0.06	0.0048	2.05	0.30		
02/02/94	15:36:03	1060	0.000851	1.70	0.06	0.0048	2.05	0.31		
02/02/94	15:44:49	1070	0.000843	6.75	0.19	0.0042	7.09	0.79		
02/02/94	15:47:23	1070	0.000843	6.78	0.19	0.0042	7.11	0.83		
02/02/94	15:49:47	1070	0.000843	6.76	0.19	0.0042	7.10	0.79		
02/02/94	15:51:57	1070	0.000843	6.77	0.19	0.0042	7.10	0.80		
02/02/94	15:52:52	1070	0.000843	6.78	0.19	0.0042	7.11	0.81		
02/02/94	15:58:53	1080	0.000840	15.27	0.41	0.0038	14.80	0.94		
02/02/94	16:03:20	1080	0.000840	15.13	0.41	0.0038	14.68	0.90		
02/02/94	16:05:37	1080	0.000840	15.18	0.41	0.0038	14.72	0.97		
02/02/94	16:07:48	1080	0.000840	15.20	0.41	0.0038	14.73	0.94		
02/02/94	16:11:09	1080	0.000840	15.25	0.41	0.0038	14.78	1.01		
18% Ring										
04/02/94	13:12:39	1011	0.000830	0.42	0.02	0.0057	0.60	0.14		
04/02/94	13:15:02	1011	0.000831	0.42	0.02	0.0057	0.60	0.15		
04/02/94	13:16:49	1011	0.000828	0.42	0.02	0.0057	0.59	0.13		
04/02/94	13:21:26	1011	0.000825	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:23:42	1011	0.000825	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:30:10	1012	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:31:17	1012	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:32:07	1012	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:32:58	1012	0.000826	0.42	0.02	0.0057	0.59	0.10		
04/02/94	13:33:57	1012	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:36:28	1012	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:37:33	1013	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:38:09	1013	0.000826	0.41	0.02	0.0057	0.59	0.10		

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
04/02/94	13:39:00	1013	1000	30	20.0	0.000834	0.42	0.02	0.0056	3.04	0.30	17.0
04/02/94	13:40:24	1013	1000	30	20.0	0.000834	0.42	0.02	0.0056	3.03	0.26	17.0
04/02/94	13:41:09	1013	1001	30	20.0	0.000834	0.42	0.02	0.0056	3.04	0.25	17.0
04/02/94	13:43:29	1014	997	30	19.9	0.000834	0.41	0.02	0.0056	3.02	0.23	17.0
04/02/94	13:44:28	1014	997	30	19.9	0.000834	0.41	0.02	0.0056	3.02	0.28	16.9
04/02/94	13:46:15	1014	998	30	19.8	0.000834	0.42	0.02	0.0056	3.03	0.26	16.9
04/02/94	13:47:03	1014	998	30	19.8	0.000834	0.42	0.02	0.0056	3.03	0.27	16.9
04/02/94	13:49:55	1014	997	30	19.9	0.000834	0.41	0.02	0.0056	3.02	0.26	16.9
04/02/94	13:52:33	1017	997	30	19.9	0.000834	0.41	0.02	0.0056	3.02	0.22	16.9
04/02/94	13:53:57	1017	999	30	19.9	0.000834	0.42	0.02	0.0056	3.03	0.22	16.9
04/02/94	13:55:20	1017	997	30	19.9	0.000834	0.41	0.02	0.0056	3.02	0.22	16.9
04/02/94	13:56:13	1017	998	30	19.8	0.000834	0.42	0.02	0.0056	3.03	0.23	16.8
04/02/94	13:57:37	1017	1000	30	19.7	0.000833	0.42	0.02	0.0056	3.03	0.19	16.8
04/02/94	14:06:47	1047	6013	81	8.3	0.000804	14.54	0.39	0.0039	73.74	-3.81	7.7
04/02/94	14:07:53	1047	6016	81	8.3	0.000804	14.55	0.39	0.0039	73.80	-3.86	7.8
04/02/94	14:10:14	1047	6020	81	8.4	0.000804	14.57	0.39	0.0039	73.89	-3.98	7.8
04/02/94	14:11:01	1047	6025	81	8.4	0.000804	14.59	0.39	0.0039	73.99	-3.96	7.8
04/02/94	14:12:38	1047	6032	81	8.4	0.000804	14.63	0.39	0.0039	74.15	-3.95	7.8
04/02/94	14:15:11	1044	6035	81	8.4	0.000804	14.64	0.39	0.0039	74.22	-3.88	7.8
04/02/94	14:16:31	1044	6036	81	8.4	0.000804	14.65	0.39	0.0039	74.23	-4.09	7.9
04/02/94	14:17:22	1044	6026	81	8.4	0.000804	14.60	0.39	0.0039	74.02	-3.90	7.8
04/02/94	14:17:51	1044	6027	81	8.4	0.000804	14.60	0.39	0.0039	74.05	-3.82	7.8
04/02/94	14:18:32	1044	6027	81	8.4	0.000804	14.60	0.39	0.0039	74.04	-3.95	7.8
04/02/94	14:19:38	1044	6029	81	8.4	0.000804	14.61	0.39	0.0039	74.09	-3.96	7.9
04/02/94	14:22:08	1043	6034	81	8.4	0.000804	14.64	0.39	0.0039	74.18	-3.92	7.9
04/02/94	14:24:30	1043	6038	81	8.4	0.000804	14.66	0.39	0.0039	74.28	-3.98	7.8
04/02/94	14:26:08	1043	6041	81	8.4	0.000804	14.67	0.39	0.0039	74.37	-3.98	7.9
04/02/94	14:26:46	1043	6043	81	8.4	0.000804	14.68	0.39	0.0039	74.39	-4.08	7.8
04/02/94	14:27:33	1043	6042	81	8.4	0.000804	14.68	0.39	0.0039	74.39	-3.99	7.8
04/02/94	14:28:19	1043	6037	81	8.4	0.000804	14.65	0.39	0.0039	74.26	-4.18	7.8
04/02/94	14:31:24	1042	6041	81	8.4	0.000804	14.67	0.39	0.0039	74.35	-3.88	7.8
04/02/94	14:32:58	1042	6042	81	8.4	0.000804	14.67	0.39	0.0039	74.37	-4.05	7.8
04/02/94	14:33:30	1042	6016	81	8.4	0.000804	14.55	0.39	0.0039	73.80	-4.05	7.8
04/02/94	14:35:37	1042	6020	81	8.4	0.000804	14.57	0.39	0.0039	73.88	-4.11	7.8
04/02/94	14:36:01	1042	6021	81	8.4	0.000804	14.57	0.39	0.0039	73.89	-4.02	7.8
04/02/94	14:38:50	1041	6025	81	8.4	0.000804	14.59	0.39	0.0039	73.99	-4.00	7.8
04/02/94	14:39:44	1041	6024	81	8.4	0.000804	14.59	0.39	0.0039	73.97	-4.06	7.8
04/02/94	14:41:25	1041	6027	81	8.4	0.000804	14.60	0.39	0.0039	74.05	-4.18	7.8
04/02/94	14:41:56	1041	6028	81	8.3	0.000804	14.61	0.39	0.0039	74.08	-4.16	7.8
04/02/94	14:42:51	1041	6027	81	8.4	0.000804	14.60	0.39	0.0039	74.05	-4.05	7.8
04/02/94	15:01:43	1031	3999	57	9.7	0.000807	6.45	0.19	0.0043	35.43	-1.96	8.9
04/02/94	15:02:56	1031	3999	57	9.7	0.000807	6.45	0.19	0.0043	35.43	-1.88	8.9
04/02/94	15:03:32	1031	3998	57	9.6	0.000807	6.45	0.19	0.0043	35.43	-1.92	8.8
04/02/94	15:04:02	1031	3998	57	9.7	0.000807	6.45	0.18	0.0043	35.42	-1.87	8.8
04/02/94	15:04:35	1031	3998	57	9.7	0.000807	6.45	0.18	0.0043	35.42	-1.96	8.8
04/02/94	15:06:34	1032	3997	57	9.6	0.000807	6.45	0.18	0.0043	35.41	-1.88	8.8
04/02/94	15:08:40	1032	3997	57	9.7	0.000807	6.45	0.18	0.0043	35.42	-1.95	8.8
04/02/94	15:09:47	1032	3994	57	9.7	0.000807	6.44	0.18	0.0043	35.35	-1.95	8.8
04/02/94	15:10:16	1032	3995	57	9.7	0.000807	6.44	0.18	0.0043	35.37	-1.93	8.8
04/02/94	15:12:17	1032	3994	57	9.6	0.000807	6.44	0.18	0.0043	35.36	-1.95	8.8
04/02/94	15:14:12	1033	3995	57	9.7	0.000807	6.44	0.18	0.0043	35.36	-2.00	8.8
04/02/94	15:15:49	1033	3996	57	9.7	0.000807	6.44	0.18	0.0043	35.39	-1.95	8.9
04/02/94	15:17:34	1033	3996	57	9.7	0.000807	6.44	0.18	0.0043	35.40	-1.93	8.8
04/02/94	15:18:24	1033	3994	57	9.6	0.000807	6.44	0.18	0.0043	35.36	-1.92	8.8
04/02/94	15:19:03	1033	3997	57	9.6	0.000807	6.45	0.18	0.0043	35.41	-1.86	8.8
04/02/94	15:21:02	1034	3998	57	9.7	0.000807	6.45	0.18	0.0043	35.42	-1.94	8.8
04/02/94	15:22:11	1034	3997	57	9.7	0.000807	6.45	0.18	0.0043	35.41	-1.86	8.9
04/02/94	15:23:44	1034	3996	57	9.7	0.000807	6.44	0.18	0.0043	35.38	-2.01	8.8
04/02/94	15:24:45	1034	3998	57	9.6	0.000807	6.45	0.18	0.0043	35.43	-1.95	8.8
04/02/94	15:26:10	1034	3995	57	9.7	0.000807	6.44	0.18	0.0043	35.37	-1.85	8.8
04/02/94	15:28:34	1035	4010	57	9.7	0.000807	6.49	0.19	0.0043	35.62	-1.82	8.8

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
04/02/94	13:39:00	1013	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:40:24	1013	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:41:09	1013	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:43:29	1014	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:44:28	1014	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:46:15	1014	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:47:03	1014	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:49:55	1014	0.000826	0.41	0.02	0.0057	0.59	0.11		
04/02/94	13:52:33	1017	0.000826	0.41	0.02	0.0057	0.59	0.09		
04/02/94	13:53:57	1017	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:55:20	1017	0.000826	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:56:13	1017	0.000825	0.41	0.02	0.0057	0.59	0.10		
04/02/94	13:57:37	1017	0.000825	0.41	0.02	0.0057	0.59	0.09		
04/02/94	14:06:47	1047	0.000802	14.50	0.39	0.0039	14.38	-1.81	0.125	0.042
04/02/94	14:07:53	1047	0.000802	14.51	0.39	0.0039	14.39	-1.82	0.126	0.042
04/02/94	14:10:14	1047	0.000803	14.55	0.39	0.0039	14.43	-1.85	0.127	0.041
04/02/94	14:11:01	1047	0.000803	14.57	0.39	0.0039	14.45	-1.83	0.126	0.041
04/02/94	14:12:38	1047	0.000803	14.61	0.39	0.0039	14.48	-1.84	0.126	0.041
04/02/94	14:15:11	1044	0.000803	14.62	0.39	0.0039	14.49	-1.87	0.128	0.041
04/02/94	14:16:31	1044	0.000803	14.63	0.39	0.0039	14.50	-1.86	0.127	0.041
04/02/94	14:17:22	1044	0.000803	14.58	0.39	0.0039	14.45	-1.79	0.123	0.041
04/02/94	14:17:51	1044	0.000803	14.58	0.39	0.0039	14.46	-1.78	0.122	0.041
04/02/94	14:18:32	1044	0.000803	14.58	0.39	0.0039	14.46	-1.80	0.123	0.041
04/02/94	14:19:38	1044	0.000803	14.60	0.39	0.0039	14.47	-1.77	0.121	0.041
04/02/94	14:22:08	1043	0.000803	14.62	0.39	0.0039	14.49	-1.75	0.120	0.041
04/02/94	14:24:30	1043	0.000803	14.64	0.39	0.0039	14.51	-1.76	0.120	0.041
04/02/94	14:26:08	1043	0.000803	14.65	0.39	0.0039	14.52	-1.77	0.121	0.041
04/02/94	14:26:46	1043	0.000803	14.66	0.39	0.0039	14.53	-1.81	0.123	0.041
04/02/94	14:27:33	1043	0.000803	14.66	0.39	0.0039	14.52	-1.81	0.124	0.041
04/02/94	14:28:19	1043	0.000803	14.63	0.39	0.0039	14.50	-1.84	0.126	0.041
04/02/94	14:31:24	1042	0.000803	14.65	0.39	0.0039	14.52	-1.84	0.125	0.041
04/02/94	14:32:58	1042	0.000803	14.65	0.39	0.0039	14.52	-1.78	0.122	0.041
04/02/94	14:33:30	1042	0.000803	14.53	0.39	0.0039	14.41	-1.81	0.125	0.041
04/02/94	14:35:37	1042	0.000803	14.55	0.39	0.0039	14.43	-1.79	0.123	0.041
04/02/94	14:36:01	1042	0.000803	14.55	0.39	0.0039	14.43	-1.76	0.121	0.041
04/02/94	14:38:50	1041	0.000803	14.57	0.39	0.0039	14.45	-1.82	0.125	0.041
04/02/94	14:39:44	1041	0.000803	14.57	0.39	0.0039	14.45	-1.78	0.122	0.041
04/02/94	14:41:25	1041	0.000803	14.59	0.39	0.0039	14.46	-1.87	0.129	0.041
04/02/94	14:41:56	1041	0.000802	14.57	0.39	0.0039	14.45	-1.87	0.129	0.041
04/02/94	14:42:51	1041	0.000803	14.59	0.39	0.0039	14.46	-1.89	0.130	0.041
04/02/94	15:01:43	1031	0.000805	6.44	0.18	0.0043	6.91	-0.87	0.135	0.093
04/02/94	15:02:56	1031	0.000805	6.44	0.18	0.0043	6.91	-0.84	0.131	0.093
04/02/94	15:03:32	1031	0.000805	6.43	0.18	0.0043	6.91	-0.84	0.130	0.093
04/02/94	15:04:02	1031	0.000805	6.43	0.18	0.0043	6.91	-0.85	0.132	0.094
04/02/94	15:04:35	1031	0.000805	6.43	0.18	0.0043	6.91	-0.83	0.130	0.094
04/02/94	15:06:34	1032	0.000805	6.43	0.18	0.0043	6.91	-0.83	0.129	0.094
04/02/94	15:08:40	1032	0.000805	6.43	0.18	0.0043	6.91	-0.84	0.131	0.094
04/02/94	15:09:47	1032	0.000805	6.42	0.18	0.0043	6.90	-0.84	0.131	0.094
04/02/94	15:10:16	1032	0.000805	6.42	0.18	0.0043	6.90	-0.85	0.132	0.094
04/02/94	15:12:17	1032	0.000805	6.42	0.18	0.0043	6.90	-0.82	0.128	0.094
04/02/94	15:14:12	1033	0.000805	6.42	0.18	0.0043	6.90	-0.84	0.130	0.094
04/02/94	15:15:49	1033	0.000805	6.43	0.18	0.0043	6.91	-0.83	0.129	0.094
04/02/94	15:17:34	1033	0.000805	6.43	0.18	0.0043	6.91	-0.81	0.127	0.094
04/02/94	15:18:24	1033	0.000805	6.42	0.18	0.0043	6.90	-0.81	0.127	0.094
04/02/94	15:19:03	1033	0.000805	6.43	0.18	0.0043	6.91	-0.79	0.122	0.094
04/02/94	15:21:02	1034	0.000805	6.43	0.18	0.0043	6.91	-0.81	0.126	0.093
04/02/94	15:22:11	1034	0.000805	6.43	0.18	0.0043	6.91	-0.81	0.127	0.094
04/02/94	15:23:44	1034	0.000805	6.43	0.18	0.0043	6.90	-0.86	0.134	0.094
04/02/94	15:24:45	1034	0.000805	6.43	0.18	0.0043	6.91	-0.81	0.125	0.093
04/02/94	15:26:10	1034	0.000805	6.42	0.18	0.0043	6.90	-0.78	0.121	0.094
04/02/94	15:28:34	1035	0.000805	6.47	0.19	0.0043	6.95	-0.81	0.124	0.093

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
04/02/94	15:33:46	1035	4005	57	9.7	0.000807	6.47	0.19	0.0043	35.54	-1.94	8.8
04/02/94	15:34:08	1035	4005	57	9.6	0.000807	6.47	0.19	0.0043	35.54	-1.91	8.8
04/02/94	15:34:28	1035	4000	57	9.6	0.000807	6.45	0.19	0.0043	35.45	-2.02	8.8
04/02/94	15:36:01	1035	4002	57	9.7	0.000807	6.46	0.19	0.0043	35.49	-1.84	8.8
04/02/94	15:37:37	1037	4004	57	9.7	0.000807	6.47	0.19	0.0043	35.52	-1.90	8.9
04/02/94	15:38:36	1037	4003	57	9.7	0.000807	6.47	0.19	0.0043	35.50	-1.93	8.8
04/02/94	15:39:21	1037	4004	57	9.6	0.000807	6.47	0.19	0.0043	35.51	-1.94	8.8
04/02/94	15:39:38	1037	4002	57	9.7	0.000807	6.46	0.19	0.0043	35.49	-1.94	8.8
04/02/94	15:40:40	1037	4002	57	9.7	0.000807	6.46	0.19	0.0043	35.49	-1.94	8.9
04/02/94	15:42:09	1037	4005	57	9.7	0.000807	6.47	0.19	0.0043	35.54	-1.87	8.8
04/02/94	15:48:30	1027	2014	37	13.2	0.000816	1.65	0.06	0.0049	10.43	-0.66	11.6
04/02/94	15:49:07	1027	2015	37	13.2	0.000816	1.66	0.06	0.0049	10.44	-0.63	11.6
04/02/94	15:50:54	1027	2016	37	13.1	0.000816	1.66	0.06	0.0049	10.45	-0.66	11.6
04/02/94	15:51:14	1027	2018	37	13.1	0.000816	1.66	0.06	0.0049	10.47	-0.62	11.6
04/02/94	15:51:36	1027	2015	37	13.1	0.000816	1.66	0.06	0.0049	10.44	-0.60	11.5
04/02/94	15:53:28	1025	2015	37	13.1	0.000816	1.66	0.06	0.0049	10.44	-0.63	11.5
04/02/94	15:54:06	1025	2014	37	13.1	0.000816	1.65	0.06	0.0049	10.43	-0.64	11.5
04/02/94	15:54:39	1025	2012	37	13.1	0.000816	1.65	0.06	0.0049	10.42	-0.63	11.5
04/02/94	15:55:32	1025	2011	37	13.1	0.000816	1.65	0.06	0.0049	10.41	-0.67	11.5
04/02/94	15:55:49	1025	2012	37	13.1	0.000816	1.65	0.06	0.0049	10.42	-0.62	11.5
04/02/94	15:57:57	1024	2011	37	13.1	0.000816	1.65	0.06	0.0049	10.41	-0.61	11.5
04/02/94	15:58:56	1024	2011	37	13.1	0.000815	1.65	0.06	0.0049	10.39	-0.62	11.5
04/02/94	15:59:18	1024	2008	37	13.1	0.000816	1.64	0.06	0.0049	10.37	-0.65	11.5
04/02/94	15:59:40	1024	2011	37	13.1	0.000816	1.65	0.06	0.0049	10.40	-0.69	11.5
04/02/94	16:01:46	1024	2010	37	13.1	0.000816	1.65	0.06	0.0049	10.40	-0.72	11.5
04/02/94	16:03:34	1023	2011	37	13.1	0.000816	1.65	0.06	0.0049	10.41	-0.65	11.5
04/02/94	16:04:21	1023	2008	37	13.1	0.000816	1.65	0.06	0.0049	10.38	-0.66	11.6
04/02/94	16:04:41	1023	2009	37	13.2	0.000816	1.65	0.06	0.0049	10.38	-0.65	11.6
04/02/94	16:05:00	1023	2009	37	13.1	0.000816	1.65	0.06	0.0049	10.38	-0.61	11.5
04/02/94	16:05:21	1023	2010	37	13.1	0.000816	1.65	0.06	0.0049	10.40	-0.60	11.5
04/02/94	16:06:52	1022	2010	37	13.1	0.000816	1.65	0.06	0.0049	10.39	-0.64	11.5
04/02/94	16:07:26	1022	2009	37	13.1	0.000816	1.65	0.06	0.0049	10.39	-0.69	11.5
04/02/94	16:07:50	1022	2016	37	13.1	0.000815	1.66	0.06	0.0049	10.44	-0.64	11.5
04/02/94	16:08:05	1022	2015	37	13.1	0.000815	1.65	0.06	0.0049	10.43	-0.59	11.5
04/02/94	16:08:25	1022	2015	37	13.1	0.000816	1.66	0.06	0.0049	10.44	-0.67	11.5
04/02/94	16:08:40	1022	2011	37	13.1	0.000816	1.65	0.06	0.0049	10.40	-0.67	11.5
04/02/94	16:10:02	1021	2007	37	13.1	0.000816	1.64	0.06	0.0049	10.37	-0.64	11.5
04/02/94	16:10:52	1021	2007	37	13.1	0.000816	1.64	0.06	0.0049	10.37	-0.67	11.5
04/02/94	16:11:08	1021	2008	37	13.1	0.000816	1.65	0.06	0.0049	10.38	-0.72	11.5
04/02/94	16:11:26	1021	2007	37	13.1	0.000816	1.64	0.06	0.0049	10.36	-0.64	11.5
04/02/94	16:11:44	1021	2008	37	13.1	0.000816	1.64	0.06	0.0049	10.38	-0.65	11.5
07/02/94	15:25:26	1057	996	30	33.0	0.000876	0.43	0.03	0.0055	3.10	1.69	30.2
07/02/94	15:26:01	1057	993	30	33.0	0.000876	0.43	0.03	0.0055	3.08	1.59	30.2
07/02/94	15:26:22	1057	993	30	32.9	0.000876	0.43	0.03	0.0055	3.08	1.64	30.1
07/02/94	15:26:41	1057	994	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.64	30.2
07/02/94	15:27:02	1057	995	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.70	30.1
07/02/94	15:28:32	1055	994	30	32.8	0.000876	0.43	0.03	0.0055	3.08	1.66	30.0
07/02/94	15:29:17	1055	996	30	32.7	0.000875	0.43	0.03	0.0055	3.09	1.71	30.0
07/02/94	15:29:49	1055	991	30	32.8	0.000875	0.43	0.03	0.0055	3.06	1.71	30.0
07/02/94	15:30:20	1055	991	30	32.7	0.000875	0.43	0.03	0.0055	3.06	1.59	29.9
07/02/94	15:30:42	1055	989	30	32.7	0.000875	0.43	0.03	0.0055	3.05	1.67	30.0
07/02/94	15:31:05	1055	990	30	32.7	0.000875	0.43	0.03	0.0055	3.06	1.56	30.0
07/02/94	15:31:27	1055	994	30	32.7	0.000875	0.43	0.03	0.0055	3.08	1.59	30.0
07/02/94	15:32:37	1054	996	30	32.9	0.000876	0.43	0.03	0.0055	3.10	1.61	30.1
07/02/94	15:33:28	1054	997	30	33.0	0.000876	0.44	0.03	0.0055	3.10	1.74	30.2
07/02/94	15:33:48	1054	994	30	33.0	0.000876	0.43	0.03	0.0055	3.08	1.70	30.3
07/02/94	15:34:19	1054	993	30	33.1	0.000877	0.43	0.03	0.0055	3.08	1.76	30.3
07/02/94	15:34:50	1054	994	30	33.1	0.000876	0.43	0.03	0.0055	3.08	1.69	30.3
07/02/94	15:35:20	1054	994	30	33.0	0.000876	0.43	0.03	0.0055	3.08	1.67	30.3
07/02/94	15:36:55	1054	995	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.68	30.2
07/02/94	15:37:48	1053	998	30	32.9	0.000876	0.44	0.03	0.0055	3.11	1.73	30.2

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
04/02/94	15:33:46	1035	0.000805	6.46	0.19	0.0043	6.93	-0.81	0.126	0.093
04/02/94	15:34:08	1035	0.000805	6.46	0.19	0.0043	6.93	-0.83	0.129	0.093
04/02/94	15:34:28	1035	0.000805	6.44	0.18	0.0043	6.92	-0.80	0.124	0.093
04/02/94	15:36:01	1035	0.000805	6.45	0.18	0.0043	6.93	-0.80	0.124	0.093
04/02/94	15:37:37	1037	0.000805	6.45	0.19	0.0043	6.93	-0.81	0.126	0.093
04/02/94	15:38:36	1037	0.000805	6.45	0.18	0.0043	6.93	-0.80	0.124	0.093
04/02/94	15:39:21	1037	0.000805	6.45	0.18	0.0043	6.93	-0.77	0.119	0.093
04/02/94	15:39:38	1037	0.000805	6.45	0.18	0.0043	6.93	-0.84	0.130	0.093
04/02/94	15:40:40	1037	0.000805	6.45	0.18	0.0043	6.93	-0.78	0.122	0.093
04/02/94	15:42:09	1037	0.000805	6.46	0.19	0.0043	6.93	-0.76	0.117	0.093
04/02/94	15:48:30	1027	0.000812	1.65	0.06	0.0049	2.03	-0.26		
04/02/94	15:49:07	1027	0.000812	1.65	0.06	0.0049	2.04	-0.25		
04/02/94	15:50:54	1027	0.000812	1.65	0.06	0.0049	2.04	-0.27		
04/02/94	15:51:14	1027	0.000812	1.65	0.06	0.0049	2.04	-0.26		
04/02/94	15:51:36	1027	0.000812	1.65	0.06	0.0049	2.04	-0.26		
04/02/94	15:53:28	1025	0.000812	1.65	0.06	0.0049	2.04	-0.27		
04/02/94	15:54:06	1025	0.000812	1.65	0.06	0.0049	2.03	-0.29		
04/02/94	15:54:39	1025	0.000812	1.64	0.06	0.0049	2.03	-0.26		
04/02/94	15:55:32	1025	0.000812	1.64	0.06	0.0049	2.03	-0.28		
04/02/94	15:55:49	1025	0.000812	1.64	0.06	0.0049	2.03	-0.28		
04/02/94	15:57:57	1024	0.000812	1.64	0.06	0.0049	2.03	-0.30		
04/02/94	15:58:56	1024	0.000812	1.64	0.06	0.0049	2.03	-0.25		
04/02/94	15:59:18	1024	0.000812	1.64	0.06	0.0049	2.02	-0.28		
04/02/94	15:59:40	1024	0.000812	1.64	0.06	0.0049	2.03	-0.29		
04/02/94	16:01:46	1024	0.000812	1.64	0.06	0.0049	2.03	-0.28		
04/02/94	16:03:34	1023	0.000812	1.64	0.06	0.0049	2.03	-0.27		
04/02/94	16:04:21	1023	0.000812	1.64	0.06	0.0049	2.02	-0.29		
04/02/94	16:04:41	1023	0.000812	1.64	0.06	0.0049	2.02	-0.26		
04/02/94	16:05:00	1023	0.000812	1.64	0.06	0.0049	2.02	-0.28		
04/02/94	16:05:21	1023	0.000812	1.64	0.06	0.0049	2.03	-0.30		
04/02/94	16:06:52	1022	0.000812	1.64	0.06	0.0049	2.03	-0.29		
04/02/94	16:07:26	1022	0.000812	1.64	0.06	0.0049	2.03	-0.28		
04/02/94	16:07:50	1022	0.000811	1.65	0.06	0.0049	2.03	-0.27		
04/02/94	16:08:05	1022	0.000811	1.65	0.06	0.0049	2.03	-0.26		
04/02/94	16:08:25	1022	0.000812	1.65	0.06	0.0049	2.04	-0.30		
04/02/94	16:08:40	1022	0.000812	1.64	0.06	0.0049	2.03	-0.28		
04/02/94	16:10:02	1021	0.000812	1.64	0.06	0.0049	2.02	-0.26		
04/02/94	16:10:52	1021	0.000812	1.64	0.06	0.0049	2.02	-0.28		
04/02/94	16:11:08	1021	0.000812	1.64	0.06	0.0049	2.02	-0.30		
04/02/94	16:11:26	1021	0.000812	1.63	0.06	0.0049	2.02	-0.27		
04/02/94	16:11:44	1021	0.000812	1.64	0.06	0.0049	2.02	-0.27		
07/02/94	15:25:26	1057	0.000867	0.43	0.03	0.0055	0.60	0.56		
07/02/94	15:26:01	1057	0.000866	0.43	0.03	0.0056	0.60	0.52		
07/02/94	15:26:22	1057	0.000866	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:26:41	1057	0.000866	0.43	0.03	0.0056	0.60	0.52		
07/02/94	15:27:02	1057	0.000866	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:28:32	1055	0.000866	0.43	0.03	0.0056	0.60	0.53		
07/02/94	15:29:17	1055	0.000866	0.43	0.03	0.0056	0.60	0.53		
07/02/94	15:29:49	1055	0.000866	0.42	0.03	0.0056	0.59	0.55		
07/02/94	15:30:20	1055	0.000865	0.42	0.03	0.0056	0.59	0.51		
07/02/94	15:30:42	1055	0.000866	0.42	0.03	0.0056	0.59	0.54		
07/02/94	15:31:05	1055	0.000866	0.42	0.03	0.0056	0.59	0.52		
07/02/94	15:31:27	1055	0.000866	0.43	0.03	0.0056	0.60	0.51		
07/02/94	15:32:37	1054	0.000866	0.43	0.03	0.0055	0.60	0.53		
07/02/94	15:33:28	1054	0.000866	0.43	0.03	0.0055	0.60	0.54		
07/02/94	15:33:48	1054	0.000867	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:34:19	1054	0.000867	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:34:50	1054	0.000867	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:35:20	1054	0.000867	0.43	0.03	0.0056	0.60	0.55		
07/02/94	15:36:55	1054	0.000866	0.43	0.03	0.0056	0.60	0.52		
07/02/94	15:37:48	1053	0.000866	0.43	0.03	0.0055	0.60	0.55		

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
07/02/94	15:38:08	1053	995	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.68	30.2
07/02/94	15:38:28	1053	996	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.66	30.2
07/02/94	15:38:57	1053	995	30	32.9	0.000876	0.43	0.03	0.0055	3.09	1.60	30.1
07/02/94	15:40:20	1052	996	30	32.9	0.000876	0.43	0.03	0.0055	3.10	1.65	30.2
07/02/94	15:41:05	1052	997	30	33.0	0.000876	0.44	0.03	0.0055	3.10	1.60	30.2
07/02/94	15:41:30	1052	998	30	32.9	0.000876	0.44	0.03	0.0055	3.10	1.68	30.2
07/02/94	15:42:04	1052	998	30	33.0	0.000876	0.44	0.03	0.0055	3.11	1.69	30.2
07/02/94	15:42:49	1052	993	30	32.9	0.000876	0.43	0.03	0.0055	3.08	1.64	30.2
07/02/94	15:44:28	1052	996	30	33.0	0.000876	0.43	0.03	0.0055	3.09	1.69	30.2
07/02/94	15:45:18	1051	994	30	33.0	0.000876	0.43	0.03	0.0055	3.09	1.70	30.3
07/02/94	15:45:52	1051	995	30	33.1	0.000877	0.43	0.03	0.0055	3.09	1.71	30.3
07/02/94	15:46:12	1051	993	30	33.0	0.000876	0.43	0.03	0.0055	3.08	1.69	30.3
07/02/94	15:46:38	1051	994	30	33.1	0.000877	0.43	0.03	0.0055	3.09	1.69	30.3
07/02/94	15:49:43	1051	997	30	33.1	0.000876	0.44	0.03	0.0055	3.10	1.68	30.3
07/02/94	16:07:26	1081	6027	81	20.7	0.000836	15.18	0.41	0.0039	75.47	-2.06	20.2
07/02/94	16:08:08	1081	6029	81	20.7	0.000836	15.19	0.41	0.0039	75.52	-1.98	20.2
07/02/94	16:08:27	1081	6031	81	20.8	0.000837	15.22	0.41	0.0039	75.65	-1.83	20.2
07/02/94	16:08:46	1081	6032	81	20.7	0.000836	15.21	0.41	0.0039	75.59	-2.04	20.2
07/02/94	16:09:05	1081	6025	81	20.8	0.000837	15.19	0.41	0.0039	75.52	-2.12	20.2
07/02/94	16:09:20	1083	6031	81	20.7	0.000836	15.21	0.41	0.0039	75.56	-2.15	20.2
07/02/94	16:09:43	1083	6036	81	20.8	0.000837	15.25	0.41	0.0039	75.77	-1.89	20.3
07/02/94	16:11:05	1083	6029	81	20.8	0.000837	15.21	0.41	0.0039	75.59	-2.03	20.3
07/02/94	16:11:32	1083	6034	81	20.8	0.000837	15.24	0.41	0.0039	75.72	-1.87	20.3
07/02/94	16:11:48	1083	6033	81	20.8	0.000837	15.23	0.41	0.0039	75.68	-2.04	20.3
07/02/94	16:12:02	1083	6034	81	20.8	0.000837	15.24	0.41	0.0039	75.71	-1.99	20.3
07/02/94	16:12:17	1084	6035	81	20.8	0.000837	15.24	0.41	0.0039	75.74	-2.00	20.3
07/02/94	16:13:25	1084	6035	81	20.8	0.000837	15.24	0.41	0.0039	75.75	-1.94	20.3
07/02/94	16:13:53	1084	6040	81	20.8	0.000837	15.27	0.41	0.0039	75.85	-1.88	20.3
07/02/94	16:14:07	1084	6025	81	20.8	0.000837	15.19	0.41	0.0039	75.52	-2.01	20.3
07/02/94	16:14:21	1084	6016	81	20.8	0.000837	15.15	0.41	0.0039	75.31	-2.01	20.3
07/02/94	16:14:35	1084	6017	81	20.9	0.000837	15.15	0.41	0.0039	75.33	-2.07	20.3
07/02/94	16:15:53	1087	6016	81	20.8	0.000837	15.15	0.41	0.0039	75.31	-2.17	20.3
07/02/94	16:16:23	1087	6018	81	20.8	0.000837	15.16	0.41	0.0039	75.36	-1.96	20.3
07/02/94	16:16:39	1087	6019	81	20.8	0.000837	15.16	0.41	0.0039	75.39	-1.97	20.3
07/02/94	16:16:53	1087	6019	81	20.8	0.000837	15.16	0.41	0.0039	75.38	-2.09	20.3
07/02/94	16:17:11	1087	6016	81	20.8	0.000837	15.15	0.41	0.0039	75.31	-2.05	20.3
30% Ring												
23/02/94	09:02:07	4031	3989	57	27.8	0.000858	6.83	0.20	0.0041	36.42	-1.92	23.5
23/02/94	09:02:26	4031	3991	57	27.8	0.000858	6.83	0.20	0.0041	36.46	-1.64	23.5
23/02/94	09:03:37	4031	3990	57	27.8	0.000858	6.83	0.20	0.0041	36.44	-1.79	23.5
23/02/94	09:05:11	4031	3992	57	27.8	0.000858	6.84	0.20	0.0041	36.47	-1.76	23.6
23/02/94	09:05:43	4031	3991	57	27.8	0.000858	6.83	0.20	0.0041	36.47	-1.81	23.5
23/02/94	09:06:13	4031	3991	57	27.7	0.000858	6.83	0.20	0.0041	36.45	-1.86	23.5
23/02/94	09:09:13	4035	3996	57	27.8	0.000858	6.85	0.20	0.0041	36.53	-1.85	23.6
23/02/94	09:09:51	4035	3996	57	27.9	0.000859	6.86	0.20	0.0041	36.58	-1.89	23.6
23/02/94	09:11:10	4035	3997	57	27.9	0.000859	6.86	0.20	0.0041	36.60	-1.84	23.6
23/02/94	09:11:24	4035	3997	57	27.8	0.000858	6.85	0.20	0.0041	36.55	-1.81	23.6
23/02/94	09:11:36	4035	3998	57	27.8	0.000858	6.86	0.20	0.0041	36.56	-1.82	23.6
23/02/94	09:11:48	4035	3995	57	27.9	0.000859	6.85	0.20	0.0041	36.55	-1.85	23.6
23/02/94	09:13:24	4036	3999	57	27.9	0.000859	6.87	0.20	0.0041	36.62	-1.81	23.7
23/02/94	09:13:50	4036	3999	57	27.9	0.000859	6.87	0.20	0.0041	36.62	-1.84	23.6
23/02/94	09:15:57	4036	4001	57	28.0	0.000859	6.87	0.20	0.0041	36.64	-1.91	23.7
23/02/94	09:16:18	4036	4002	57	28.0	0.000859	6.88	0.20	0.0041	36.66	-1.97	23.7
23/02/94	09:16:41	4036	4000	57	28.0	0.000859	6.87	0.20	0.0041	36.63	-1.97	23.7
23/02/94	09:17:00	4036	3999	57	28.0	0.000859	6.87	0.20	0.0041	36.62	-1.92	23.7
23/02/94	09:18:48	4037	4002	57	28.0	0.000859	6.88	0.20	0.0041	36.66	-1.90	23.8
23/02/94	09:19:10	4037	4005	57	28.0	0.000859	6.89	0.20	0.0041	36.72	-1.91	23.7
23/02/94	09:19:25	4037	4002	57	28.0	0.000859	6.88	0.20	0.0041	36.67	-1.91	23.7
23/02/94	09:21:39	4037	4007	57	28.0	0.000859	6.90	0.20	0.0041	36.76	-2.05	23.7
23/02/94	09:21:52	4037	4008	57	28.0	0.000859	6.90	0.20	0.0041	36.76	-1.91	23.7

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
07/02/94	15:38:08	1053	0.000866	0.43	0.03	0.0056	0.60	0.51		
07/02/94	15:38:28	1053	0.000866	0.43	0.03	0.0055	0.60	0.54		
07/02/94	15:38:57	1053	0.000866	0.43	0.03	0.0056	0.60	0.51		
07/02/94	15:40:20	1052	0.000866	0.43	0.03	0.0055	0.60	0.53		
07/02/94	15:41:05	1052	0.000866	0.43	0.03	0.0055	0.60	0.52		
07/02/94	15:41:30	1052	0.000866	0.43	0.03	0.0055	0.60	0.54		
07/02/94	15:42:04	1052	0.000866	0.43	0.03	0.0055	0.60	0.53		
07/02/94	15:42:49	1052	0.000866	0.43	0.03	0.0056	0.60	0.52		
07/02/94	15:44:28	1052	0.000867	0.43	0.03	0.0055	0.60	0.52		
07/02/94	15:45:18	1051	0.000867	0.43	0.03	0.0056	0.60	0.54		
07/02/94	15:45:52	1051	0.000867	0.43	0.03	0.0055	0.60	0.54		
07/02/94	15:46:12	1051	0.000867	0.43	0.03	0.0056	0.60	0.53		
07/02/94	15:46:38	1051	0.000867	0.43	0.03	0.0056	0.60	0.53		
07/02/94	15:49:43	1051	0.000867	0.43	0.03	0.0055	0.60	0.52		
07/02/94	16:07:26	1081	0.000835	15.17	0.41	0.0039	14.74	-1.61	0.106	0.040
07/02/94	16:08:08	1081	0.000835	15.18	0.41	0.0039	14.75	-1.60	0.105	0.040
07/02/94	16:08:27	1081	0.000835	15.19	0.41	0.0039	14.75	-1.59	0.105	0.040
07/02/94	16:08:46	1081	0.000835	15.19	0.41	0.0039	14.76	-1.64	0.108	0.040
07/02/94	16:09:05	1081	0.000835	15.16	0.41	0.0039	14.73	-1.64	0.108	0.040
07/02/94	16:09:20	1083	0.000835	15.19	0.41	0.0039	14.75	-1.66	0.109	0.040
07/02/94	16:09:43	1083	0.000835	15.21	0.41	0.0039	14.78	-1.58	0.104	0.040
07/02/94	16:11:05	1083	0.000835	15.18	0.41	0.0039	14.74	-1.61	0.106	0.040
07/02/94	16:11:32	1083	0.000835	15.20	0.41	0.0039	14.77	-1.53	0.101	0.040
07/02/94	16:11:48	1083	0.000835	15.19	0.41	0.0039	14.76	-1.57	0.103	0.040
07/02/94	16:12:02	1083	0.000835	15.20	0.41	0.0039	14.77	-1.54	0.101	0.040
07/02/94	16:12:17	1084	0.000835	15.21	0.41	0.0039	14.77	-1.58	0.104	0.040
07/02/94	16:13:25	1084	0.000835	15.21	0.41	0.0039	14.77	-1.51	0.099	0.040
07/02/94	16:13:53	1084	0.000835	15.23	0.41	0.0039	14.79	-1.50	0.098	0.040
07/02/94	16:14:07	1084	0.000835	15.16	0.41	0.0039	14.73	-1.58	0.104	0.040
07/02/94	16:14:21	1084	0.000835	15.11	0.41	0.0039	14.69	-1.52	0.101	0.040
07/02/94	16:14:35	1084	0.000835	15.12	0.41	0.0039	14.69	-1.57	0.104	0.040
07/02/94	16:15:53	1087	0.000835	15.11	0.41	0.0039	14.69	-1.55	0.102	0.040
07/02/94	16:16:23	1087	0.000835	15.12	0.41	0.0039	14.70	-1.48	0.098	0.040
07/02/94	16:16:39	1087	0.000835	15.13	0.41	0.0039	14.70	-1.49	0.099	0.040
07/02/94	16:16:53	1087	0.000835	15.13	0.41	0.0039	14.70	-1.53	0.101	0.040
07/02/94	16:17:11	1087	0.000835	15.11	0.41	0.0039	14.69	-1.52	0.101	0.040
30% Ring										
23/02/94	09:02:07	4031	0.000845	6.72	0.19	0.0042	7.05	-2.27	0.337	0.090
23/02/94	09:02:26	4031	0.000845	6.73	0.19	0.0042	7.06	-2.22	0.329	0.090
23/02/94	09:03:37	4031	0.000845	6.73	0.19	0.0042	7.06	-2.24	0.334	0.090
23/02/94	09:05:11	4031	0.000845	6.73	0.19	0.0042	7.06	-2.18	0.324	0.090
23/02/94	09:05:43	4031	0.000845	6.73	0.19	0.0042	7.06	-2.15	0.319	0.090
23/02/94	09:06:13	4031	0.000845	6.73	0.19	0.0042	7.06	-2.16	0.321	0.090
23/02/94	09:09:13	4035	0.000845	6.75	0.19	0.0042	7.07	-2.13	0.316	0.090
23/02/94	09:09:51	4035	0.000845	6.75	0.19	0.0042	7.07	-2.11	0.313	0.090
23/02/94	09:11:10	4035	0.000845	6.75	0.19	0.0042	7.08	-2.14	0.317	0.089
23/02/94	09:11:24	4035	0.000845	6.75	0.19	0.0042	7.08	-2.13	0.316	0.090
23/02/94	09:11:36	4035	0.000845	6.75	0.19	0.0042	7.08	-2.17	0.322	0.089
23/02/94	09:11:48	4035	0.000845	6.74	0.19	0.0042	7.07	-2.18	0.323	0.090
23/02/94	09:13:24	4036	0.000845	6.76	0.19	0.0042	7.08	-2.19	0.324	0.089
23/02/94	09:13:50	4036	0.000845	6.76	0.19	0.0042	7.08	-2.19	0.324	0.089
23/02/94	09:15:57	4036	0.000845	6.76	0.19	0.0042	7.09	-2.17	0.320	0.089
23/02/94	09:16:18	4036	0.000845	6.77	0.19	0.0042	7.09	-2.15	0.318	0.089
23/02/94	09:16:41	4036	0.000845	6.76	0.19	0.0042	7.09	-2.15	0.318	0.089
23/02/94	09:17:00	4036	0.000845	6.76	0.19	0.0042	7.08	-2.16	0.319	0.089
23/02/94	09:18:48	4037	0.000845	6.77	0.19	0.0042	7.09	-2.11	0.312	0.089
23/02/94	09:19:10	4037	0.000845	6.78	0.19	0.0042	7.10	-2.12	0.312	0.089
23/02/94	09:19:25	4037	0.000845	6.77	0.19	0.0042	7.09	-2.17	0.321	0.089
23/02/94	09:21:39	4037	0.000845	6.78	0.19	0.0042	7.11	-2.22	0.328	0.089
23/02/94	09:21:52	4037	0.000845	6.79	0.19	0.0042	7.11	-2.16	0.318	0.089

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
23/02/94	09:22:03	4037	4010	57	28.0	0.000859	6.91	0.20	0.0041	36.80	-1.91	23.7
23/02/94	09:24:50	4034	4002	57	28.0	0.000859	6.88	0.20	0.0041	36.67	-1.89	23.7
23/02/94	09:26:37	4034	4002	57	27.9	0.000859	6.88	0.20	0.0041	36.67	-2.01	23.7
23/02/94	09:26:55	4034	4001	57	27.9	0.000859	6.88	0.20	0.0041	36.66	-1.89	23.6
23/02/94	10:13:48	4011	1055	30	27.1	0.000856	0.48	0.03	0.0055	3.38	0.62	22.4
23/02/94	10:14:16	4011	1056	30	27.0	0.000856	0.48	0.03	0.0055	3.39	0.63	22.3
23/02/94	10:14:24	4011	1057	30	27.1	0.000856	0.48	0.03	0.0055	3.40	0.57	22.3
23/02/94	10:14:33	4011	1058	30	27.1	0.000856	0.48	0.03	0.0055	3.40	0.61	22.3
23/02/94	10:14:41	4011	1057	30	27.0	0.000856	0.48	0.03	0.0055	3.39	0.68	22.3
23/02/94	10:16:44	4014	1049	30	27.0	0.000856	0.47	0.03	0.0055	3.35	0.57	22.2
23/02/94	10:17:07	4014	1052	30	26.9	0.000855	0.47	0.03	0.0055	3.36	0.75	22.1
23/02/94	10:17:17	4014	1057	30	26.9	0.000855	0.48	0.03	0.0055	3.39	0.67	22.1
23/02/94	10:17:30	4014	1052	30	26.9	0.000855	0.47	0.03	0.0055	3.37	0.57	22.1
23/02/94	10:17:40	4014	1058	30	26.9	0.000855	0.48	0.03	0.0055	3.40	0.65	22.1
23/02/94	10:17:49	4014	1056	30	26.9	0.000855	0.48	0.03	0.0055	3.38	0.50	22.1
23/02/94	10:18:59	4015	1052	30	26.8	0.000855	0.47	0.03	0.0055	3.36	0.64	22.1
23/02/94	10:19:22	4015	1051	30	26.8	0.000855	0.47	0.03	0.0055	3.36	0.55	22.0
23/02/94	10:19:38	4015	1051	30	26.9	0.000855	0.47	0.03	0.0055	3.36	0.57	22.1
23/02/94	10:19:54	4015	1051	30	26.8	0.000855	0.47	0.03	0.0055	3.36	0.62	22.1
23/02/94	10:20:05	4015	1055	30	26.8	0.000855	0.48	0.03	0.0055	3.38	0.65	22.0
23/02/94	10:20:57	4016	1057	30	26.7	0.000855	0.48	0.03	0.0055	3.39	0.61	22.0
23/02/94	10:21:16	4016	1054	30	26.8	0.000855	0.48	0.03	0.0055	3.38	0.55	22.0
23/02/94	10:21:27	4016	1056	30	26.8	0.000855	0.48	0.03	0.0055	3.39	0.49	22.0
23/02/94	10:21:41	4016	1054	30	26.7	0.000855	0.48	0.03	0.0055	3.38	0.74	22.0
23/02/94	10:21:49	4016	1052	30	26.8	0.000855	0.47	0.03	0.0055	3.37	0.54	22.0
23/02/94	10:23:02	4017	1054	30	26.7	0.000855	0.48	0.03	0.0055	3.38	0.71	21.9
23/02/94	10:23:14	4017	1051	30	26.7	0.000855	0.47	0.03	0.0055	3.36	0.74	21.9
23/02/94	10:23:32	4017	1054	30	26.8	0.000855	0.48	0.03	0.0055	3.38	0.49	22.0
23/02/94	10:23:41	4017	1056	30	26.7	0.000855	0.48	0.03	0.0055	3.39	0.68	22.0
23/02/94	10:23:51	4017	1052	30	26.7	0.000855	0.47	0.03	0.0055	3.37	0.61	22.0
23/02/94	10:30:48	4021	2006	37	26.2	0.000853	1.72	0.06	0.0048	10.58	-0.02	21.6
23/02/94	10:30:57	4021	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	0.00	21.6
23/02/94	10:31:07	4021	2001	37	26.3	0.000853	1.71	0.06	0.0048	10.54	0.01	21.7
23/02/94	10:31:16	4021	2006	37	26.3	0.000853	1.72	0.06	0.0048	10.59	0.11	21.7
23/02/94	10:31:26	4021	2002	37	26.3	0.000853	1.71	0.06	0.0048	10.55	0.01	21.7
23/02/94	10:31:36	4021	2004	37	26.3	0.000853	1.71	0.06	0.0048	10.57	-0.03	21.7
23/02/94	10:32:52	4024	2001	37	26.4	0.000854	1.71	0.06	0.0048	10.55	-0.03	21.8
23/02/94	10:33:13	4024	2002	37	26.3	0.000854	1.71	0.06	0.0048	10.56	0.05	21.7
23/02/94	10:33:21	4024	2001	37	26.3	0.000854	1.71	0.06	0.0048	10.56	0.12	21.7
23/02/94	10:33:30	4024	2002	37	26.3	0.000853	1.71	0.06	0.0048	10.55	0.08	21.7
23/02/94	10:33:39	4024	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	0.03	21.7
23/02/94	10:33:50	4024	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	0.02	21.7
23/02/94	10:34:58	4025	2003	37	26.3	0.000853	1.71	0.06	0.0048	10.56	0.03	21.7
23/02/94	10:35:17	4025	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	0.10	21.7
23/02/94	10:35:33	4025	2003	37	26.2	0.000853	1.71	0.06	0.0048	10.56	0.02	21.7
23/02/94	10:35:46	4025	2001	37	26.3	0.000853	1.71	0.06	0.0048	10.54	0.02	21.7
23/02/94	10:36:04	4025	2005	37	26.2	0.000853	1.71	0.06	0.0048	10.58	0.08	21.6
23/02/94	10:36:31	4025	2004	37	26.3	0.000853	1.71	0.06	0.0048	10.56	0.14	21.7
23/02/94	10:37:32	4025	2004	37	26.2	0.000853	1.71	0.06	0.0048	10.57	0.02	21.6
23/02/94	10:37:44	4025	2001	37	26.2	0.000853	1.71	0.06	0.0048	10.54	0.02	21.6
23/02/94	10:39:05	4026	2005	37	26.2	0.000853	1.71	0.06	0.0048	10.58	0.05	21.6
23/02/94	10:39:27	4026	2003	37	26.2	0.000853	1.71	0.06	0.0048	10.56	0.13	21.6
23/02/94	10:39:37	4026	2001	37	26.2	0.000853	1.71	0.06	0.0048	10.54	0.12	21.6
23/02/94	10:39:54	4026	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	-0.02	21.6
23/02/94	10:40:11	4026	2002	37	26.2	0.000853	1.71	0.06	0.0048	10.55	0.05	21.6
23/02/94	10:40:37	4026	2003	37	26.1	0.000853	1.71	0.06	0.0048	10.56	0.08	21.6
23/02/94	10:41:39	4027	2004	37	26.2	0.000853	1.71	0.06	0.0048	10.57	-0.01	21.6
23/02/94	10:42:08	4027	2004	37	26.2	0.000853	1.71	0.06	0.0048	10.57	0.07	21.6
23/02/94	10:42:52	4027	2004	37	26.2	0.000853	1.71	0.06	0.0048	10.57	0.06	21.6
23/02/94	10:43:22	4027	2005	37	26.1	0.000853	1.71	0.06	0.0048	10.58	0.04	21.6
23/02/94	10:44:11	4027	2003	37	26.2	0.000853	1.71	0.06	0.0048	10.56	0.02	21.6

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
23/02/94	09:22:03	4037	0.000845	6.79	0.19	0.0042	7.12	-2.22	0.327	0.089
23/02/94	09:24:50	4034	0.000845	6.77	0.19	0.0042	7.09	-2.21	0.326	0.089
23/02/94	09:26:37	4034	0.000845	6.77	0.19	0.0042	7.10	-2.24	0.331	0.089
23/02/94	09:26:55	4034	0.000845	6.76	0.19	0.0042	7.09	-2.21	0.327	0.089
23/02/94	10:13:48	4011	0.000841	0.47	0.03	0.0056	0.65	0.05		
23/02/94	10:14:16	4011	0.000841	0.47	0.03	0.0056	0.66	0.04		
23/02/94	10:14:24	4011	0.000841	0.47	0.03	0.0055	0.66	0.04		
23/02/94	10:14:33	4011	0.000841	0.47	0.03	0.0055	0.66	0.05		
23/02/94	10:14:41	4011	0.000841	0.47	0.03	0.0056	0.66	0.05		
23/02/94	10:16:44	4014	0.000841	0.46	0.03	0.0056	0.65	0.04		
23/02/94	10:17:07	4014	0.000841	0.47	0.03	0.0056	0.65	0.08		
23/02/94	10:17:17	4014	0.000841	0.47	0.03	0.0056	0.66	0.04		
23/02/94	10:17:30	4014	0.000841	0.47	0.03	0.0056	0.65	0.03		
23/02/94	10:17:40	4014	0.000841	0.47	0.03	0.0056	0.66	0.04		
23/02/94	10:17:49	4014	0.000840	0.47	0.03	0.0056	0.65	0.01		
23/02/94	10:18:59	4015	0.000840	0.46	0.03	0.0056	0.65	0.05		
23/02/94	10:19:22	4015	0.000840	0.46	0.03	0.0056	0.65	0.03		
23/02/94	10:19:38	4015	0.000841	0.46	0.03	0.0056	0.65	0.02		
23/02/94	10:19:54	4015	0.000840	0.46	0.03	0.0056	0.65	0.04		
23/02/94	10:20:05	4015	0.000840	0.47	0.03	0.0056	0.65	0.06		
23/02/94	10:20:57	4016	0.000840	0.47	0.03	0.0056	0.66	0.04		
23/02/94	10:21:16	4016	0.000840	0.47	0.03	0.0056	0.65	0.04		
23/02/94	10:21:27	4016	0.000840	0.47	0.03	0.0056	0.66	0.03		
23/02/94	10:21:41	4016	0.000840	0.47	0.03	0.0056	0.65	0.05		
23/02/94	10:21:49	4016	0.000840	0.47	0.03	0.0056	0.65	0.02		
23/02/94	10:23:02	4017	0.000840	0.47	0.03	0.0056	0.65	0.05		
23/02/94	10:23:14	4017	0.000840	0.46	0.03	0.0056	0.65	0.05		
23/02/94	10:23:32	4017	0.000840	0.47	0.03	0.0056	0.65	0.02		
23/02/94	10:23:41	4017	0.000840	0.47	0.03	0.0056	0.66	0.03		
23/02/94	10:23:51	4017	0.000840	0.47	0.03	0.0056	0.65	0.01		
23/02/94	10:30:48	4021	0.000839	1.69	0.06	0.0048	2.05	-0.45		
23/02/94	10:30:57	4021	0.000839	1.68	0.06	0.0048	2.04	-0.47		
23/02/94	10:31:07	4021	0.000839	1.68	0.06	0.0048	2.04	-0.46		
23/02/94	10:31:16	4021	0.000839	1.69	0.06	0.0048	2.05	-0.44		
23/02/94	10:31:26	4021	0.000839	1.68	0.06	0.0048	2.04	-0.47		
23/02/94	10:31:36	4021	0.000839	1.69	0.06	0.0048	2.05	-0.46		
23/02/94	10:32:52	4024	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:33:13	4024	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:33:21	4024	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:33:30	4024	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:33:39	4024	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:33:50	4024	0.000839	1.68	0.06	0.0048	2.04	-0.42		
23/02/94	10:34:58	4025	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:35:17	4025	0.000839	1.68	0.06	0.0048	2.04	-0.42		
23/02/94	10:35:33	4025	0.000839	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:35:46	4025	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:36:04	4025	0.000839	1.69	0.06	0.0048	2.05	-0.44		
23/02/94	10:36:31	4025	0.000839	1.68	0.06	0.0048	2.05	-0.42		
23/02/94	10:37:32	4025	0.000839	1.68	0.06	0.0048	2.05	-0.44		
23/02/94	10:37:44	4025	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:39:05	4026	0.000839	1.69	0.06	0.0048	2.05	-0.43		
23/02/94	10:39:27	4026	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:39:37	4026	0.000839	1.68	0.06	0.0048	2.04	-0.42		
23/02/94	10:39:54	4026	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:40:11	4026	0.000839	1.68	0.06	0.0048	2.04	-0.43		
23/02/94	10:40:37	4026	0.000839	1.68	0.06	0.0048	2.04	-0.44		
23/02/94	10:41:39	4027	0.000839	1.68	0.06	0.0048	2.05	-0.42		
23/02/94	10:42:08	4027	0.000839	1.68	0.06	0.0048	2.05	-0.43		
23/02/94	10:42:52	4027	0.000839	1.69	0.06	0.0048	2.05	-0.42		
23/02/94	10:43:22	4027	0.000839	1.69	0.06	0.0048	2.05	-0.43		
23/02/94	10:44:11	4027	0.000839	1.68	0.06	0.0048	2.04	-0.44		

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (°C)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (°C)
23/02/94	10:48:18	4023	2001	37	26.5	0.000854	1.71	0.06	0.0048	10.55	0.02	21.9
23/02/94	10:48:34	4023	2002	37	26.4	0.000854	1.71	0.06	0.0048	10.56	0.12	21.8
23/02/94	10:48:49	4023	2000	37	26.4	0.000854	1.71	0.06	0.0048	10.54	0.02	21.8
23/02/94	10:48:59	4023	2001	37	26.4	0.000854	1.71	0.06	0.0048	10.55	0.04	21.8
23/02/94	10:49:20	4023	2001	37	26.5	0.000854	1.71	0.06	0.0048	10.55	0.04	21.8
23/02/94	10:55:39	4013	1055	30	27.2	0.000856	0.48	0.03	0.0055	3.38	0.46	22.4
23/02/94	10:55:59	4013	1060	30	27.2	0.000856	0.48	0.03	0.0055	3.41	0.63	22.4
23/02/94	10:56:09	4013	1058	30	27.1	0.000856	0.48	0.03	0.0055	3.40	0.34	22.3
23/02/94	10:56:25	4013	1060	30	27.0	0.000856	0.48	0.03	0.0055	3.41	0.24	22.3
23/02/94	10:56:35	4013	1056	30	27.0	0.000856	0.48	0.03	0.0055	3.39	0.31	22.2
23/02/94	10:57:04	4013	1058	30	26.9	0.000855	0.48	0.03	0.0055	3.40	0.77	22.1
23/02/94	11:01:47	4031	4018	58	25.7	0.000852	6.88	0.20	0.0041	36.76	-1.40	21.7
23/02/94	11:02:11	4031	4017	58	25.8	0.000852	6.87	0.20	0.0041	36.74	-1.31	21.8
23/02/94	11:02:23	4031	4014	58	25.8	0.000852	6.86	0.20	0.0041	36.70	-1.42	21.7
23/02/94	11:02:51	4031	4016	58	25.9	0.000852	6.87	0.20	0.0041	36.71	-1.35	21.9
23/02/94	11:03:09	4031	4016	58	25.9	0.000852	6.87	0.20	0.0041	36.71	-1.25	21.9
23/02/94	11:03:19	4031	4016	58	26.0	0.000852	6.87	0.20	0.0041	36.70	-1.31	21.9
23/02/94	11:03:28	4031	4017	58	26.0	0.000852	6.87	0.20	0.0041	36.72	-1.30	22.0
23/02/94	11:04:42	4033	4014	58	26.0	0.000853	6.87	0.20	0.0041	36.71	-1.45	22.0
23/02/94	11:04:57	4033	4014	58	26.1	0.000853	6.87	0.20	0.0041	36.72	-1.38	22.0
23/02/94	11:05:08	4033	4011	57	26.1	0.000853	6.86	0.20	0.0041	36.67	-1.40	22.0
23/02/94	11:05:22	4033	4013	58	26.1	0.000853	6.87	0.20	0.0041	36.71	-1.26	22.0
23/02/94	11:05:32	4033	4017	58	26.1	0.000853	6.88	0.20	0.0041	36.77	-1.13	22.1
23/02/94	11:06:06	4033	4013	57	26.1	0.000853	6.87	0.20	0.0041	36.70	-1.29	22.1
23/02/94	11:06:31	4033	4016	58	26.1	0.000853	6.88	0.20	0.0041	36.74	-1.37	22.1
23/02/94	11:07:12	4033	4015	58	26.1	0.000853	6.88	0.20	0.0041	36.73	-1.28	22.1
23/02/94	11:09:12	4034	4013	57	26.2	0.000853	6.87	0.20	0.0041	36.69	-1.44	22.2
23/02/94	11:09:42	4034	4017	58	26.1	0.000853	6.88	0.20	0.0041	36.77	-1.30	22.1
23/02/94	11:10:00	4034	4015	58	26.2	0.000853	6.87	0.20	0.0041	36.72	-1.36	22.1
23/02/94	11:10:22	4034	4015	58	26.2	0.000853	6.87	0.20	0.0041	36.72	-1.42	22.2
23/02/94	11:10:39	4034	4017	58	26.2	0.000853	6.88	0.20	0.0041	36.76	-1.45	22.2
23/02/94	11:11:05	4034	4015	58	26.2	0.000853	6.88	0.20	0.0041	36.74	-1.44	22.2
23/02/94	11:11:29	4034	4016	58	26.2	0.000853	6.88	0.20	0.0041	36.75	-1.38	22.2
23/02/94	11:15:18	4035	4011	57	26.5	0.000854	6.87	0.20	0.0041	36.68	-1.43	22.5
23/02/94	11:15:45	4035	4011	57	26.6	0.000854	6.87	0.20	0.0041	36.67	-1.45	22.6
23/02/94	11:16:13	4035	4013	58	26.6	0.000854	6.88	0.20	0.0041	36.71	-1.29	22.6
23/02/94	11:16:29	4035	4011	57	26.6	0.000854	6.87	0.20	0.0041	36.69	-1.46	22.6
23/02/94	11:16:39	4035	4013	58	26.6	0.000854	6.88	0.20	0.0041	36.71	-1.44	22.6
23/02/94	11:17:37	4036	4013	57	26.6	0.000855	6.88	0.20	0.0041	36.75	-1.44	22.6
23/02/94	11:17:54	4036	4013	57	26.7	0.000855	6.88	0.20	0.0041	36.75	-1.24	22.7
23/02/94	11:18:03	4036	4011	57	26.7	0.000855	6.88	0.20	0.0041	36.73	-1.41	22.7
23/02/94	11:18:12	4036	4015	58	26.7	0.000855	6.89	0.20	0.0041	36.78	-1.38	22.7
23/02/94	11:18:23	4036	4012	57	26.7	0.000855	6.88	0.20	0.0041	36.72	-1.46	22.7
23/02/94	11:19:24	4037	4011	57	26.7	0.000855	6.88	0.20	0.0041	36.72	-1.45	22.7
23/02/94	11:19:44	4037	4018	58	26.7	0.000855	6.90	0.20	0.0041	36.84	-1.30	22.7
23/02/94	11:20:34	4037	4014	58	26.7	0.000855	6.89	0.20	0.0041	36.77	-1.39	22.7
23/02/94	11:20:44	4037	4014	58	26.7	0.000855	6.89	0.20	0.0041	36.76	-1.31	22.7
23/02/94	11:20:57	4037	4015	58	26.7	0.000855	6.89	0.20	0.0041	36.78	-1.33	22.7
23/02/94	11:28:38	4041	6054	81	26.2	0.000853	15.63	0.42	0.0038	76.99	-3.80	22.6
23/02/94	11:28:58	4041	6049	81	26.2	0.000853	15.61	0.42	0.0038	76.89	-3.93	22.7
23/02/94	11:29:10	4041	6052	81	26.2	0.000853	15.62	0.42	0.0038	76.93	-3.88	22.7
23/02/94	11:29:23	4041	6045	81	26.3	0.000853	15.59	0.42	0.0038	76.79	-4.03	22.7
23/02/94	11:29:35	4041	6051	81	26.3	0.000853	15.62	0.42	0.0038	76.91	-3.86	22.8
23/02/94	11:31:19	4043	6043	81	26.5	0.000854	15.60	0.42	0.0038	76.81	-4.10	23.0
23/02/94	11:31:33	4043	6047	81	26.5	0.000854	15.61	0.42	0.0038	76.88	-4.09	23.0
23/02/94	11:32:19	4043	6046	81	26.5	0.000854	15.61	0.42	0.0038	76.85	-3.93	23.0
23/02/94	11:33:01	4043	6049	81	26.5	0.000854	15.62	0.42	0.0038	76.94	-3.99	23.0
23/02/94	11:33:39	4043	6050	81	26.6	0.000854	15.63	0.42	0.0038	76.96	-4.09	23.0
23/02/94	11:35:33	4044	6049	81	26.5	0.000854	15.63	0.42	0.0038	76.94	-3.93	23.0
23/02/94	11:35:55	4044	6055	81	26.5	0.000854	15.65	0.42	0.0038	77.05	-4.02	23.0
23/02/94	11:36:08	4044	6054	81	26.6	0.000854	15.65	0.42	0.0038	77.03	-4.06	23.0

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
23/02/94	10:48:18	4023	0.000840	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:48:34	4023	0.000840	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:48:49	4023	0.000840	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:48:59	4023	0.000840	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:49:20	4023	0.000840	1.68	0.06	0.0048	2.04	-0.45		
23/02/94	10:55:39	4013	0.000841	0.47	0.03	0.0056	0.65	0.01		
23/02/94	10:55:59	4013	0.000841	0.47	0.03	0.0055	0.66	0.04		
23/02/94	10:56:09	4013	0.000841	0.47	0.03	0.0055	0.66	0.03		
23/02/94	10:56:25	4013	0.000841	0.47	0.03	0.0055	0.66	-0.04		
23/02/94	10:56:35	4013	0.000841	0.47	0.03	0.0056	0.66	-0.03		
23/02/94	10:57:04	4013	0.000841	0.47	0.03	0.0055	0.66	0.06		
23/02/94	11:01:47	4031	0.000839	6.77	0.19	0.0042	7.12	-2.15	0.317	0.089
23/02/94	11:02:11	4031	0.000840	6.78	0.19	0.0042	7.12	-2.16	0.318	0.089
23/02/94	11:02:23	4031	0.000839	6.76	0.19	0.0042	7.10	-2.17	0.321	0.089
23/02/94	11:02:51	4031	0.000840	6.77	0.19	0.0042	7.12	-2.14	0.316	0.089
23/02/94	11:03:09	4031	0.000840	6.77	0.19	0.0042	7.12	-2.10	0.309	0.089
23/02/94	11:03:19	4031	0.000840	6.77	0.19	0.0042	7.11	-2.15	0.318	0.089
23/02/94	11:03:28	4031	0.000840	6.78	0.19	0.0042	7.12	-2.12	0.313	0.089
23/02/94	11:04:42	4033	0.000840	6.77	0.19	0.0042	7.11	-2.15	0.317	0.089
23/02/94	11:04:57	4033	0.000840	6.77	0.19	0.0042	7.11	-2.14	0.316	0.089
23/02/94	11:05:08	4033	0.000840	6.76	0.19	0.0042	7.10	-2.16	0.319	0.089
23/02/94	11:05:22	4033	0.000840	6.77	0.19	0.0042	7.11	-2.14	0.316	0.089
23/02/94	11:05:32	4033	0.000840	6.78	0.19	0.0042	7.12	-2.15	0.317	0.089
23/02/94	11:06:06	4033	0.000840	6.76	0.19	0.0042	7.10	-2.13	0.315	0.089
23/02/94	11:06:31	4033	0.000840	6.77	0.19	0.0042	7.11	-2.11	0.311	0.089
23/02/94	11:07:12	4033	0.000841	6.78	0.19	0.0042	7.12	-2.15	0.317	0.089
23/02/94	11:09:12	4034	0.000841	6.77	0.19	0.0042	7.11	-2.11	0.312	0.089
23/02/94	11:09:42	4034	0.000841	6.79	0.19	0.0042	7.13	-2.15	0.317	0.089
23/02/94	11:10:00	4034	0.000841	6.78	0.19	0.0042	7.12	-2.18	0.322	0.089
23/02/94	11:10:22	4034	0.000841	6.78	0.19	0.0042	7.12	-2.14	0.316	0.089
23/02/94	11:10:39	4034	0.000841	6.79	0.19	0.0042	7.12	-2.20	0.324	0.089
23/02/94	11:11:05	4034	0.000841	6.78	0.19	0.0042	7.12	-2.11	0.311	0.089
23/02/94	11:11:29	4034	0.000841	6.78	0.19	0.0042	7.12	-2.11	0.311	0.089
23/02/94	11:15:18	4035	0.000842	6.77	0.19	0.0042	7.11	-2.14	0.316	0.089
23/02/94	11:15:45	4035	0.000842	6.77	0.19	0.0042	7.11	-2.11	0.312	0.089
23/02/94	11:16:13	4035	0.000842	6.78	0.19	0.0042	7.12	-2.12	0.312	0.089
23/02/94	11:16:29	4035	0.000842	6.77	0.19	0.0042	7.11	-2.16	0.318	0.089
23/02/94	11:16:39	4035	0.000842	6.78	0.19	0.0042	7.12	-2.15	0.318	0.089
23/02/94	11:17:37	4036	0.000842	6.78	0.19	0.0042	7.11	-2.13	0.314	0.089
23/02/94	11:17:54	4036	0.000842	6.78	0.19	0.0042	7.11	-2.14	0.315	0.089
23/02/94	11:18:03	4036	0.000842	6.77	0.19	0.0042	7.11	-2.15	0.317	0.089
23/02/94	11:18:12	4036	0.000842	6.79	0.19	0.0042	7.12	-2.10	0.309	0.089
23/02/94	11:18:23	4036	0.000842	6.78	0.19	0.0042	7.11	-2.12	0.313	0.089
23/02/94	11:19:24	4037	0.000842	6.77	0.19	0.0042	7.11	-2.14	0.316	0.089
23/02/94	11:19:44	4037	0.000842	6.80	0.19	0.0042	7.13	-2.13	0.314	0.089
23/02/94	11:20:34	4037	0.000842	6.78	0.19	0.0042	7.12	-2.12	0.313	0.089
23/02/94	11:20:44	4037	0.000842	6.78	0.19	0.0042	7.12	-2.12	0.312	0.089
23/02/94	11:20:57	4037	0.000842	6.79	0.19	0.0042	7.12	-2.08	0.307	0.089
23/02/94	11:28:38	4041	0.000842	15.43	0.41	0.0038	14.93	-4.20	0.272	0.040
23/02/94	11:28:58	4041	0.000842	15.41	0.41	0.0038	14.91	-4.26	0.277	0.040
23/02/94	11:29:10	4041	0.000842	15.42	0.41	0.0038	14.92	-4.25	0.275	0.040
23/02/94	11:29:23	4041	0.000842	15.39	0.41	0.0038	14.89	-4.29	0.279	0.040
23/02/94	11:29:35	4041	0.000843	15.43	0.41	0.0038	14.93	-4.17	0.270	0.040
23/02/94	11:31:19	4043	0.000843	15.39	0.41	0.0038	14.89	-4.18	0.271	0.040
23/02/94	11:31:33	4043	0.000843	15.41	0.41	0.0038	14.90	-4.17	0.270	0.040
23/02/94	11:32:19	4043	0.000843	15.41	0.41	0.0038	14.90	-4.17	0.270	0.040
23/02/94	11:33:01	4043	0.000843	15.42	0.41	0.0038	14.91	-4.19	0.272	0.040
23/02/94	11:33:39	4043	0.000843	15.43	0.41	0.0038	14.92	-4.18	0.271	0.040
23/02/94	11:35:33	4044	0.000843	15.43	0.41	0.0038	14.92	-4.12	0.267	0.040
23/02/94	11:35:55	4044	0.000843	15.45	0.41	0.0038	14.94	-4.05	0.262	0.040
23/02/94	11:36:08	4044	0.000843	15.45	0.41	0.0038	14.93	-4.10	0.265	0.040

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	G (kg/m ² -s)	dG (kg/m ² -s)	Tb1 (oC)	v _{fl} (m ³ /kg)	KE1 (kPa)	d(KE1) (kPa)	f1	DP1-corr (kPa)	DP1-diff (kPa)	Tb2 (oC)
23/02/94	11:36:22	4044	6055	81	26.6	0.000854	15.65	0.42	0.0038	77.06	-4.05	23.0
23/02/94	11:36:37	4044	6055	81	26.5	0.000854	15.65	0.42	0.0038	77.06	-4.04	23.0
23/02/94	11:36:48	4044	6055	81	26.5	0.000854	15.66	0.42	0.0038	77.07	-3.94	23.0
23/02/94	11:37:44	4045	6057	81	26.6	0.000854	15.67	0.42	0.0038	77.10	-4.00	23.1
23/02/94	11:38:06	4045	6063	81	26.6	0.000855	15.71	0.42	0.0038	77.34	-3.90	23.1
23/02/94	11:38:17	4045	6060	81	26.6	0.000855	15.70	0.42	0.0038	77.27	-4.09	23.1
23/02/94	11:38:28	4045	6063	81	26.7	0.000855	15.71	0.42	0.0038	77.31	-4.04	23.1
23/02/94	11:38:39	4045	6063	81	26.7	0.000855	15.72	0.42	0.0038	77.33	-3.96	23.1
23/02/94	11:39:43	4046	6061	81	26.6	0.000855	15.70	0.42	0.0038	77.28	-4.12	23.1
23/02/94	11:40:07	4046	6061	81	26.7	0.000855	15.71	0.42	0.0038	77.29	-4.08	23.1
23/02/94	11:40:19	4046	6062	81	26.7	0.000855	15.71	0.42	0.0038	77.30	-4.07	23.1
23/02/94	11:40:29	4046	6063	81	26.7	0.000855	15.72	0.42	0.0038	77.34	-4.09	23.1
23/02/94	11:40:44	4046	6064	81	26.6	0.000855	15.72	0.42	0.0038	77.37	-4.08	23.1
23/02/94	11:40:55	4046	6065	81	26.6	0.000854	15.71	0.42	0.0038	77.31	-4.09	23.1
23/02/94	11:42:04	4047	6060	81	26.6	0.000854	15.68	0.42	0.0038	77.18	-4.26	23.1
23/02/94	11:42:26	4047	6063	81	26.6	0.000854	15.70	0.42	0.0038	77.25	-4.32	23.1
23/02/94	11:42:38	4047	6071	81	26.7	0.000855	15.76	0.42	0.0038	77.52	-4.00	23.1
23/02/94	11:42:51	4047	6072	81	26.7	0.000855	15.76	0.42	0.0038	77.52	-3.91	23.1
23/02/94	11:43:03	4047	6066	81	26.7	0.000855	15.73	0.42	0.0038	77.39	-4.04	23.1
23/02/94	11:43:26	4047	6065	81	26.7	0.000855	15.73	0.42	0.0038	77.37	-4.06	23.1
23/02/94	11:43:45	4047	6074	82	26.6	0.000855	15.77	0.42	0.0038	77.58	-3.74	23.1
23/02/94	11:44:09	4047	6066	81	26.7	0.000855	15.73	0.42	0.0038	77.38	-4.27	23.1

Table A.4-1: Calculated pressure drop data (cont.'d)

Date	Time	RunID	v_f2 (m3/kg)	KE2 (kPa)	d(KE2) (kPa)	f2	DP2-corr (kPa)	DP2-diff (kPa)	Kobs	dKobs
23/02/94	11:36:22	4044	0.000843	15.45	0.41	0.0038	14.94	-4.07	0.264	0.040
23/02/94	11:36:37	4044	0.000843	15.45	0.41	0.0038	14.94	-4.12	0.266	0.040
23/02/94	11:36:48	4044	0.000843	15.45	0.41	0.0038	14.94	-4.09	0.265	0.040
23/02/94	11:37:44	4045	0.000843	15.46	0.42	0.0038	14.95	-4.05	0.262	0.039
23/02/94	11:38:06	4045	0.000844	15.51	0.42	0.0038	14.99	-4.10	0.265	0.039
23/02/94	11:38:17	4045	0.000844	15.50	0.42	0.0038	14.98	-4.14	0.267	0.039
23/02/94	11:38:28	4045	0.000844	15.51	0.42	0.0038	14.99	-4.06	0.262	0.039
23/02/94	11:38:39	4045	0.000844	15.52	0.42	0.0038	14.99	-4.02	0.259	0.039
23/02/94	11:39:43	4046	0.000844	15.50	0.42	0.0038	14.98	-4.05	0.261	0.039
23/02/94	11:40:07	4046	0.000844	15.50	0.42	0.0038	14.98	-4.03	0.260	0.039
23/02/94	11:40:19	4046	0.000844	15.51	0.42	0.0038	14.99	-3.96	0.255	0.039
23/02/94	11:40:29	4046	0.000844	15.51	0.42	0.0038	14.99	-4.02	0.259	0.039
23/02/94	11:40:44	4046	0.000844	15.52	0.42	0.0038	15.00	-3.98	0.256	0.039
23/02/94	11:40:55	4046	0.000843	15.51	0.42	0.0038	14.99	-4.04	0.261	0.039
23/02/94	11:42:04	4047	0.000843	15.48	0.42	0.0038	14.96	-4.10	0.265	0.039
23/02/94	11:42:26	4047	0.000843	15.49	0.42	0.0038	14.97	-4.06	0.262	0.039
23/02/94	11:42:38	4047	0.000844	15.55	0.42	0.0038	15.03	-3.98	0.256	0.039
23/02/94	11:42:51	4047	0.000844	15.56	0.42	0.0038	15.03	-3.86	0.248	0.039
23/02/94	11:43:03	4047	0.000844	15.53	0.42	0.0038	15.00	-3.99	0.257	0.039
23/02/94	11:43:26	4047	0.000844	15.52	0.42	0.0038	15.00	-3.98	0.256	0.039
23/02/94	11:43:45	4047	0.000844	15.57	0.42	0.0038	15.04	-3.93	0.252	0.039
23/02/94	11:44:09	4047	0.000844	15.53	0.42	0.0038	15.00	-4.05	0.261	0.039

Appendix B: Two-Phase (CHF) Experiments

B.1 CHF Enhancement Test Matrix

The following table describes the experimental CHF data measured for 30% rings in Freon-134a, 18% spacers in Freon-134a, and 18% spacers in Freon-22. The run ID is used to differentiate between inlet conditions (pressure, mass flux, fluid temperature) and flow-obstruction geometries (i.e., number of rings/spacers, spacing between obstructions and the outlet).

Date	Run ID	P [MPa]	G [Mg/m ² ·s]	T _{in} [°C]	No. of Obstacles	Spacing (cm)
30% rings in R-134a						
94-04-21	1x114	1.66	4.0	11	1	20, 21.5, 22.5, 25, 30, 40, 50, 69, 80, 100, 120
94-04-27	1x914			53	1	57.5, 60, 80, 120
	2x914				2	45, 50, 55, 60
	3x914				3	32.5, 35, 40
	4x914				4	27.5, 30, 35
94-04-28	1x114			11	1	20, 22.5, 25, 50
	2x114				2	15, 17.5
	3x114				3	12.5
	4x114				4	10
94-05-10	1x714			44	1	50, 60, 70, 80, 120
	2x714				2	35, 40, 50, 60, 70
	3x714				3	27.5, 30, 35, 40, 50
	4x714				4	25, 30, 35
	1x514			34	1	30, 40
	2x514				2	25, 30, 40, 60
	3x514				3	20, 25, 30, 35, 40, 50
	4x514				4	20, 25, 30, 35

Date	Run ID	P [MPa]	G [Mg/m ² ·s]	T _{in} [°C]	No. of Obstacles	Spacing (cm)
94-05-11	1x913	1.66	3.0	55	1	60, 80, 100, 120
	2x913				2	45, 50, 60, 70
	3x913				3	35, 40, 45, 50
	4x913				4	27.5, 30, 35, 40
	4x912	1.13	2.0	53	4	40
	4x922		2.0	40		20, 25, 30, 40
94-05-12	4x624		4.0	27		35, 40
18% Spacers in R-134a						
94-05-18	1x914	1.66	4.0	54	1	55, 60, 80, 120
	2x914				2	40, 45, 50, 60, 70, 80
	3x914				3	30, 35, 40, 45, 50
	4x914				4	25, 30, 35, 40
	5x914				5	25, 30
94-05-19	1x714			45	1	35, 40, 50, 60, 80, 120
	2x714				2	30, 40, 50, 60, 80
	3x714				3	25, 30, 40, 50
	4x714				4	20, 25, 30, 40
	5x714				5	20, 25, 30
94-05-20	1x514			34	1	30, 35, 40
	2x514				2	20, 25, 30, 35, 40
	3x514				3	20, 25, 30, 35, 40
	4x514				4	15, 20, 25, 30, 40
	5x514				5	15, 20, 25, 30

Date	Run ID	P [MPa]	G [Mg/m ² ·s]	T _{in} [°C]	No. of Obstacles	Spacing (cm)
94-06-02	5x914	1.66	4.0	54	5	30
	5x612		2.0	38		20, 30
18% Spacers in R-22						
94-11-24	4x124	1.89	4.0	14	4	15, 20, 25, 30
	5x124			5	12.5	
94-11-28	4x524			29	4	17.5, 19, 20, 25, 30
	4x924			48		27.5, 29, 30, 35
	4x724			38		24, 25, 30, 35
	4x324			22		17.5, 20, 25
94-11-29	4x024			12		14, 15, 20, 25, 30, 35
95-01-26	4x124			8		12.5, 15, 20
	4x125			5.0		10
	4x525		32			20, 25
95-01-31	4x125		10			25
	4x525		33	25, 30		
	4x123		3.0	6	15, 17.5, 20, 25, 30	
	4x523			38	22.5, 25, 30	
	4x323			26	20, 25, 30	
	4x425		5.0	42	25, 30	
	95-02-01		4x123	3.0	16	25
4x023			6		10, 12.5, 15, 20, 25	
4x024			4.0	7	10, 12.5, 15, 20, 25	
4x025			5.0	9	10, 12.5, 15, 20, 25	

Note: 'x' denotes the integer used to identify the flow obstruction spacing, which varied with inlet condition and number of obstructions used.

B.2 Measured and Calculated Data

It should be mentioned that although the author performed all the CHF experiments in the present study, the tabulation of resultant CHF and other calculated data (i.e., DHin, Xin, Xc, CHF, CHFRef, CHFR) were performed by Doerffer et al. (1995). The data is re-presented here only for reference and use in the present analysis.

B.2.1 Legend for Data

The following labels are defined for each of the DAS-measured variables:

RUNID:	run identification number (user-defined)
Date:	month/day/year
Time:	24hr:min:sec
P:	measured outlet pressure (MPa)
m:	measured mass flow rate (kg/s)
G:	calculated mass flux based on cross-section area ($\text{Mg/m}^2\cdot\text{s}$)
Tw:	calculated average wall temperature ($^{\circ}\text{C}$), based on the arithmetic average of the wall temperature measured upstream of each obstacle and at the test section outlet
Tin:	measured inlet fluid temperature ($^{\circ}\text{C}$)
DHin:	calculated inlet subcooling (kJ/kg), based on inlet fluid temperature and outlet pressure
Xin:	calculated inlet quality, based on inlet fluid temperature and outlet pressure
Xc:	calculated critical quality at CHF location, based on inlet fluid temperature, outlet pressure, and critical power
Power:	measured power to the test section at occurrence of CHF (kW)
CHF:	calculated critical heat flux (CHF), based on power and wall surface area (MW/m^2)
CHFRef:	calculated reference CHF, based on previous reference CHF experiments (no obstructions), correlated for the same local condition
CHFR:	ratio of calculated CHF (with flow obstructions) to CHFRef (with no flow obstructions)
SP:	spacing (cm) between flow obstructions and the test section outlet (i.e., the N obstructions were equally spaced with each other and the outlet)

B.2.2 Tabulated Data

The flow-obstruction experimental CHF data are presented in three separate spreadsheet tables to follow:

Table B.2-1: 30% rings in Freon-134a (314 points)

Table B.2-2: 18% spacers in Freon-134a (208 points)

Table B.2-3: 18% spacers in Freon-22 (233 points)

Table B.2-1: CHF Enhancement data with 30% rings in Freon-134a

RunID	Date	Time	P	m	G	Tw	Tin	DHin	Xin	Xc	Power	CHF	CHFref	CHFR	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
11114	20/04/94	17:56:14.00	1.671	200.4	3.988	70.96	9.93	74.24	-0.531	0.005	15.007	0.291	0.295	0.987	120.0
12114	20/04/94	18:03:22.00	1.666	200.8	3.995	70.97	9.89	74.10	-0.530	0.005	15.025	0.292	0.294	0.991	100.0
12114	20/04/94	18:05:16.00	1.666	200.7	3.993	70.89	9.89	74.10	-0.530	0.006	15.030	0.292	0.292	0.998	100.0
13114	20/04/94	18:10:44.00	1.663	200.7	3.992	70.81	10.00	73.83	-0.528	0.005	14.966	0.290	0.294	0.989	80.0
15114	21/04/94	13:37:04.00	1.685	200.7	3.992	72.20	10.90	73.44	-0.528	0.013	15.088	0.293	0.267	1.095	69.0
15114	21/04/94	13:39:21.00	1.679	202.0	4.019	72.18	10.84	73.27	-0.526	0.012	15.150	0.294	0.272	1.080	69.0
15114	21/04/94	13:41:23.00	1.665	201.4	4.006	72.00	10.92	72.62	-0.519	0.012	14.967	0.290	0.274	1.061	69.0
16114	21/04/94	13:52:18.00	1.654	201.4	4.007	71.14	10.88	72.24	-0.515	0.010	14.845	0.288	0.281	1.026	50.0
16114	21/04/94	13:57:52.00	1.672	200.8	3.995	71.93	10.97	72.85	-0.522	0.012	14.952	0.290	0.273	1.064	50.0
16114	21/04/94	13:59:29.00	1.675	200.1	3.982	71.83	10.84	73.15	-0.524	0.009	14.891	0.289	0.278	1.040	50.0
17114	21/04/94	14:01:55.00	1.672	200.5	3.989	71.09	10.95	72.87	-0.522	0.012	14.959	0.290	0.270	1.076	40.0
17114	21/04/94	14:02:13.00	1.668	201.4	4.007	71.18	10.90	72.76	-0.521	0.014	15.059	0.292	0.268	1.091	40.0
17114	21/04/94	14:03:16.00	1.671	201.0	3.999	71.13	10.92	72.86	-0.522	0.009	14.885	0.289	0.282	1.023	40.0
17114	21/04/94	14:03:41.00	1.666	201.8	4.014	71.21	10.93	72.65	-0.520	0.010	14.943	0.290	0.280	1.034	40.0
17114	21/04/94	14:05:20.00	1.669	200.8	3.995	71.10	10.92	72.80	-0.521	0.011	14.927	0.290	0.275	1.054	40.0
18114	21/04/94	14:08:55.00	1.691	200.8	3.995	71.80	10.90	73.68	-0.530	0.016	15.243	0.296	0.259	1.144	30.0
18114	21/04/94	14:10:28.00	1.680	200.3	3.986	71.73	10.88	73.28	-0.526	0.015	15.111	0.293	0.261	1.124	30.0
18114	21/04/94	14:11:25.00	1.668	200.0	3.979	71.45	10.88	72.79	-0.521	0.016	15.000	0.291	0.261	1.114	30.0
19114	21/04/94	14:19:06.00	1.671	200.7	3.992	72.38	11.06	72.66	-0.520	0.061	16.293	0.316	0.189	1.673	20.0
19114	21/04/94	14:21:16.00	1.675	200.5	3.990	72.42	11.12	72.76	-0.522	0.058	16.205	0.315	0.193	1.629	20.0
19114	21/04/94	14:22:08.00	1.663	200.7	3.993	72.22	11.10	72.30	-0.517	0.061	16.224	0.315	0.190	1.659	20.0
19114	21/04/94	14:23:03.00	1.663	200.0	3.980	72.17	11.12	72.27	-0.516	0.062	16.199	0.314	0.188	1.671	20.0
116114	21/04/94	16:04:17.00	1.686	199.0	3.959	72.43	10.99	73.37	-0.527	0.026	15.328	0.298	0.236	1.259	25.0
116114	21/04/94	16:05:10.00	1.680	199.9	3.977	72.33	10.95	73.18	-0.525	0.025	15.335	0.298	0.240	1.240	25.0
116114	21/04/94	16:05:51.00	1.662	200.1	3.981	72.15	10.99	72.39	-0.517	0.026	15.222	0.295	0.241	1.224	25.0
117114	21/04/94	16:09:24.00	1.691	200.1	3.981	72.89	11.08	73.42	-0.528	0.033	15.609	0.303	0.226	1.340	22.5
117114	21/04/94	16:10:33.00	1.660	199.9	3.977	72.34	11.08	72.20	-0.516	0.035	15.411	0.299	0.226	1.321	22.5
117114	21/04/94	16:11:20.00	1.654	199.7	3.973	72.33	11.12	71.91	-0.513	0.041	15.499	0.301	0.218	1.380	22.5
117114	21/04/94	16:12:38.00	1.657	199.5	3.969	72.31	11.04	72.13	-0.515	0.040	15.499	0.301	0.219	1.374	22.5
118114	21/04/94	16:14:58.00	1.669	200.4	3.987	72.53	11.03	72.65	-0.520	0.041	15.711	0.305	0.216	1.411	21.5
118114	21/04/94	16:15:35.00	1.662	200.5	3.989	72.49	11.03	72.34	-0.517	0.046	15.795	0.307	0.210	1.460	21.5
118114	21/04/94	16:16:22.00	1.665	200.3	3.986	72.65	11.10	72.36	-0.517	0.042	15.678	0.304	0.215	1.414	21.5
11914	21/04/94	17:49:36.00	1.657	202.4	4.027	67.18	52.61	10.69	-0.076	0.162	6.751	0.131	0.127	1.029	120.0
11914	27/04/94	17:50:24.00	1.660	200.8	3.994	67.58	52.63	10.78	-0.077	0.163	6.737	0.131	0.127	1.029	120.0
11914	27/04/94	17:51:20.00	1.654	201.0	3.999	67.31	52.43	10.85	-0.077	0.160	6.688	0.130	0.128	1.012	120.0
11914	27/04/94	17:52:06.00	1.651	201.9	4.017	68.28	52.39	10.79	-0.077	0.158	6.651	0.129	0.129	1.002	120.0
11914	27/04/94	17:52:54.00	1.651	201.9	4.017	67.19	52.37	10.81	-0.077	0.160	6.716	0.130	0.128	1.016	120.0
12914	27/04/94	17:56:08.00	1.656	215.7	4.290	66.39	52.56	10.71	-0.076	0.150	6.841	0.133	0.128	1.037	80.0
12914	27/04/94	17:57:29.00	1.656	208.2	4.143	68.91	52.59	10.66	-0.076	0.159	6.851	0.133	0.127	1.045	80.0
12914	27/04/94	17:58:44.00	1.656	204.4	4.066	66.61	52.65	10.57	-0.075	0.163	6.835	0.133	0.127	1.046	80.0
12914	27/04/94	17:59:28.00	1.657	203.0	4.038	68.53	52.70	10.55	-0.075	0.165	6.824	0.132	0.127	1.046	80.0
12914	27/04/94	18:00:18.00	1.656	204.3	4.065	67.99	52.81	10.32	-0.074	0.162	6.759	0.131	0.127	1.033	80.0
13914	27/04/94	18:04:19.00	1.665	206.7	4.111	65.43	52.72	10.83	-0.077	0.168	7.086	0.138	0.125	1.102	60.0
13914	27/04/94	18:05:41.00	1.662	201.1	4.000	65.50	52.85	10.51	-0.075	0.175	7.047	0.137	0.124	1.103	60.0
13914	27/04/94	18:06:24.00	1.663	202.0	4.019	65.49	52.83	10.59	-0.076	0.173	7.040	0.137	0.124	1.101	60.0
13914	27/04/94	18:07:15.00	1.660	201.7	4.013	65.50	52.81	10.50	-0.075	0.174	7.026	0.136	0.124	1.096	60.0
13914	27/04/94	18:08:09.00	1.663	201.9	4.017	65.50	52.80	10.65	-0.076	0.173	7.048	0.137	0.124	1.102	60.0
17914	27/04/94	18:39:22.00	1.659	202.3	4.024	65.11	52.59	10.78	-0.077	0.172	7.065	0.137	0.125	1.099	57.5
17914	27/04/94	18:40:01.00	1.663	203.0	4.039	65.12	52.70	10.79	-0.077	0.175	7.169	0.139	0.124	1.126	57.5
17914	27/04/94	18:40:34.00	1.663	201.6	4.011	65.15	52.74	10.74	-0.077	0.175	7.113	0.138	0.124	1.116	57.5
17914	27/04/94	18:41:07.00	1.665	204.2	4.062	65.16	52.76	10.77	-0.077	0.172	7.113	0.138	0.124	1.113	57.5
21914	27/04/94	18:54:20.00	1.686	201.7	4.012	66.11	52.76	11.62	-0.084	0.173	7.212	0.140	0.121	1.158	60.0
21914	27/04/94	18:55:43.00	1.682	200.9	3.997	66.00	52.69	11.56	-0.083	0.177	7.276	0.141	0.121	1.169	60.0
21914	27/04/94	18:57:04.00	1.679	200.3	3.985	66.01	52.61	11.55	-0.083	0.177	7.255	0.141	0.121	1.161	60.0
21914	27/04/94	18:58:09.00	1.677	199.9	3.978	66.00	52.67	11.40	-0.082	0.177	7.224	0.140	0.121	1.154	60.0
21914	27/04/94	18:59:06.00	1.677	200.8	3.994	65.99	52.87	11.09	-0.080	0.177	7.180	0.139	0.122	1.146	60.0
22914	27/04/94	19:03:19.00	1.668	199.2	3.962	65.80	52.70	10.98	-0.079	0.180	7.201	0.140	0.122	1.143	55.0
22914	27/04/94	19:04:19.00	1.666	200.0	3.979	65.78	52.61	11.06	-0.079	0.178	7.203	0.140	0.123	1.139	55.0
23914	27/04/94	19:09:54.00	1.669	199.9	3.978	65.56	52.67	11.10	-0.079	0.183	7.322	0.142	0.121	1.170	50.0
23914	27/04/94	19:10:40.00	1.671	198.3	3.944	65.69	52.74	11.04	-0.079	0.186	7.335	0.142	0.121	1.181	50.0
23914	27/04/94	19:11:52.00	1.665	198.5	3.949	65.77	52.89	10.57	-0.076	0.188	7.312	0.142	0.121	1.172	50.0
23914	27/04/94	19:12:51.00	1.660	201.1	4.000	65.73	52.67	10.73	-0.077	0.184	7.351	0.143	0.122	1.168	50.0
23914	27/04/94	19:13:33.00	1.663	203.0	4.039	65.75	52.67	10.85	-0.078	0.181	7.351	0.143	0.122	1.166	50.0
23914	27/04/94	19:14:15.00	1.663	201.6	4.011	65.75	52.65	10.88	-0.078	0.183	7.360	0.143	0.122	1.171	50.0
24914	27/04/94	19:17:54.00	1.672	202.0	4.019	66.09	52.69	11.19	-0.080	0.190	7.609	0.148	0.119	1.237	45.0
24914	27/04/94	19:18:38.00	1.672	202.0	4.018	66.16	52.78	11.05	-0.079	0.191	7.609	0.148	0.119	1.240	45.0
24914	27/04/94	19:19:24.00	1.666	202.0	4.018	66.17	52.91	10.60	-0.076	0.191	7.538	0.146	0.120	1.220	45.0

Table B.2-1: CHF Enhancement data with 30% rings in Freon-134a (cont'd)

RunID	Date	Time	P	m	G	Tw	Tin	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
24914	27/04/94	19:20:03.00	1.663	206.4	4.106	66.18	52.83	10.59	-0.076	0.184	7.504	0.146	0.121	1.200	45.0
24914	27/04/94	19:20:59.00	1.668	210.1	4.179	66.20	52.85	10.75	-0.077	0.182	7.596	0.147	0.121	1.218	45.0
31914	27/04/94	19:51:35.00	1.650	200.6	3.991	66.00	52.94	9.87	-0.070	0.206	7.770	0.151	0.119	1.265	40.0
31914	27/04/94	19:53:13.00	1.644	200.9	3.997	65.97	53.00	9.54	-0.068	0.205	7.720	0.150	0.120	1.250	40.0
31914	27/04/94	19:54:26.00	1.704	203.6	4.050	67.05	52.72	12.41	-0.090	0.190	7.892	0.153	0.113	1.356	40.0
31914	27/04/94	19:55:39.00	1.691	210.5	4.188	66.86	53.03	11.38	-0.082	0.185	7.806	0.152	0.117	1.292	40.0
31914	27/04/94	19:56:31.00	1.668	201.9	4.017	66.53	53.20	10.21	-0.073	0.201	7.723	0.150	0.118	1.272	40.0
32914	27/04/94	20:01:15.00	1.671	201.7	4.013	66.58	53.13	10.45	-0.075	0.212	8.081	0.157	0.115	1.363	35.0
32914	27/04/94	20:01:47.00	1.668	201.7	4.012	66.47	53.24	10.15	-0.073	0.214	8.073	0.157	0.115	1.359	35.0
32914	27/04/94	20:02:36.00	1.669	203.2	4.042	66.51	53.33	10.07	-0.072	0.213	8.088	0.157	0.115	1.363	35.0
34914	27/04/94	20:11:36.00	1.668	205.0	4.078	66.51	53.64	9.53	-0.068	0.219	8.235	0.160	0.114	1.400	32.5
34914	27/04/94	20:12:06.00	1.666	203.0	4.038	66.49	53.71	9.35	-0.067	0.222	8.199	0.159	0.114	1.396	32.5
34914	27/04/94	20:12:47.00	1.663	202.6	4.030	66.52	53.64	9.34	-0.067	0.221	8.158	0.158	0.115	1.381	32.5
41914	27/04/94	20:16:27.00	1.665	203.0	4.038	66.66	54.12	8.66	-0.062	0.224	8.125	0.158	0.114	1.385	35.0
41914	27/04/94	20:17:01.00	1.663	201.2	4.003	66.64	54.13	8.57	-0.061	0.228	8.154	0.158	0.113	1.396	35.0
41914	27/04/94	20:17:54.00	1.663	202.9	4.036	66.61	54.19	8.49	-0.061	0.225	8.110	0.157	0.114	1.382	35.0
42914	27/04/94	20:21:10.00	1.662	202.9	4.037	66.53	54.24	8.34	-0.060	0.231	8.252	0.160	0.113	1.416	30.0
42914	27/04/94	20:21:37.00	1.660	201.9	4.016	66.54	54.24	8.28	-0.059	0.232	8.227	0.160	0.113	1.410	30.0
42914	27/04/94	20:22:04.00	1.669	201.3	4.005	66.62	54.46	8.30	-0.059	0.233	8.214	0.159	0.112	1.428	30.0
44914	27/04/94	20:34:15.00	1.668	203.2	4.043	66.95	54.19	8.67	-0.062	0.245	8.734	0.170	0.110	1.544	27.5
44914	27/04/94	20:34:59.00	1.665	203.7	4.053	66.83	54.34	8.32	-0.059	0.244	8.652	0.168	0.110	1.520	27.5
44914	27/04/94	20:35:33.00	1.663	204.0	4.058	66.87	54.35	8.23	-0.059	0.243	8.623	0.167	0.111	1.510	27.5
44914	27/04/94	20:36:12.00	1.668	202.3	4.024	66.91	54.41	8.33	-0.060	0.245	8.624	0.167	0.110	1.525	27.5
11114	28/04/94	13:35:22.00	1.669	201.5	4.008	71.43	10.70	73.11	-0.523	0.017	15.206	0.295	0.261	1.129	50.0
11114	28/04/94	13:37:02.00	1.672	202.6	4.031	71.66	10.71	73.20	-0.524	0.011	15.158	0.294	0.277	1.062	50.0
11114	28/04/94	13:37:56.00	1.642	203.0	4.039	71.31	10.84	71.80	-0.510	0.017	15.077	0.293	0.268	1.092	50.0
11114	28/04/94	13:40:33.00	1.653	203.8	4.055	71.37	10.73	72.38	-0.516	0.009	15.018	0.291	0.290	1.004	50.0
11114	28/04/94	13:42:32.00	1.682	203.8	4.055	72.21	10.84	73.39	-0.527	0.010	15.255	0.296	0.281	1.054	50.0
12114	28/04/94	13:50:31.00	1.706	201.4	4.007	73.17	10.90	74.29	-0.537	0.023	15.617	0.303	0.242	1.252	25.0
12114	28/04/94	13:52:16.00	1.682	201.8	4.015	72.82	10.90	73.31	-0.526	0.024	15.482	0.301	0.245	1.229	25.0
12114	28/04/94	13:52:21.00	1.683	201.9	4.016	72.87	10.90	73.38	-0.527	0.024	15.479	0.300	0.246	1.223	25.0
12114	28/04/94	13:53:10.00	1.672	200.2	3.983	72.73	10.93	72.90	-0.522	0.031	15.467	0.300	0.231	1.298	25.0
12114	28/04/94	13:55:17.00	1.671	201.7	4.013	72.61	10.92	72.86	-0.522	0.027	15.446	0.300	0.242	1.240	25.0
13114	28/04/94	13:59:39.00	1.680	199.1	3.961	73.07	10.99	73.13	-0.525	0.041	15.686	0.304	0.215	1.417	22.5
13114	28/04/94	14:00:33.00	1.666	201.9	4.017	72.89	10.95	72.63	-0.519	0.036	15.690	0.305	0.226	1.350	22.5
13114	28/04/94	14:01:08.00	1.668	201.7	4.012	72.92	10.97	72.66	-0.520	0.041	15.802	0.307	0.218	1.406	22.5
13114	28/04/94	14:01:42.00	1.662	202.1	4.021	72.84	10.97	72.42	-0.517	0.039	15.729	0.305	0.223	1.372	22.5
14114	28/04/94	14:04:30.00	1.677	202.7	4.033	73.44	11.04	72.93	-0.523	0.051	16.218	0.315	0.203	1.549	20.0
14114	28/04/94	14:05:07.00	1.672	202.2	4.023	73.29	11.08	72.69	-0.521	0.056	16.271	0.316	0.196	1.607	20.0
14114	28/04/94	14:05:40.00	1.668	201.9	4.017	73.27	11.10	72.48	-0.519	0.055	16.200	0.314	0.197	1.596	20.0
21114	28/04/94	14:13:27.00	1.662	200.4	3.988	73.28	11.17	72.14	-0.515	0.063	16.226	0.315	0.187	1.681	17.5
21114	28/04/94	14:14:02.00	1.657	200.2	3.983	73.18	11.15	71.98	-0.514	0.065	16.232	0.315	0.185	1.702	17.5
21114	28/04/94	14:14:42.00	1.662	201.4	4.006	73.22	11.14	72.19	-0.516	0.062	16.277	0.316	0.189	1.672	17.5
22114	28/04/94	14:17:47.00	1.688	199.0	3.959	74.14	11.17	73.17	-0.526	0.076	16.668	0.324	0.171	1.894	15.0
22114	28/04/94	14:18:59.00	1.665	199.7	3.974	73.86	11.19	72.23	-0.516	0.081	16.690	0.324	0.166	1.948	15.0
22114	28/04/94	14:19:48.00	1.668	200.0	3.979	73.92	11.21	72.33	-0.517	0.080	16.688	0.324	0.168	1.931	15.0
22114	28/04/94	14:20:26.00	1.679	198.8	3.955	73.96	11.21	72.76	-0.522	0.085	16.825	0.327	0.162	2.018	15.0
31114	28/04/94	14:47:29.00	1.632	202.2	3.984	73.73	11.23	70.83	-0.502	0.093	16.809	0.326	0.154	2.119	12.5
31114	28/04/94	14:54:43.00	1.662	203.2	4.042	74.38	11.36	71.88	-0.513	0.082	16.929	0.329	0.164	2.002	12.5
31114	28/04/94	14:55:17.00	1.665	203.0	4.038	74.38	11.37	71.98	-0.515	0.082	16.946	0.329	0.163	2.012	12.5
31114	28/04/94	14:55:48.00	1.663	202.3	4.025	74.33	11.39	71.89	-0.514	0.084	16.924	0.328	0.162	2.030	12.5
41114	28/04/94	16:01:22.00	1.641	199.3	3.966	74.48	11.21	71.22	-0.506	0.119	17.540	0.340	0.140	2.432	10.0
41114	28/04/94	16:02:29.00	1.632	200.0	3.980	74.04	11.26	70.78	-0.502	0.118	17.500	0.340	0.140	2.427	10.0
41114	28/04/94	16:03:02.00	1.633	200.2	3.984	73.93	11.28	70.81	-0.502	0.119	17.529	0.340	0.140	2.433	10.0
41114	28/04/94	16:04:17.00	1.650	200.0	3.979	74.22	11.30	71.47	-0.509	0.122	17.706	0.344	0.139	2.473	10.0
41114	28/04/94	16:04:59.00	1.644	200.4	3.987	74.10	11.25	71.30	-0.507	0.118	17.626	0.342	0.140	2.445	10.0
11714	10/05/94	14:23:20.00	1.656	202.6	4.030	68.36	44.10	23.66	-0.169	0.103	7.711	0.150	0.144	1.036	120.0
11714	10/05/94	14:25:05.00	1.656	203.3	4.045	67.69	44.25	23.44	-0.167	0.100	7.618	0.148	0.145	1.018	120.0
11714	10/05/94	14:25:48.00	1.657	204.6	4.071	68.31	44.25	23.50	-0.168	0.097	7.582	0.147	0.146	1.011	120.0
12714	10/05/94	14:29:45.00	1.647	201.2	4.003	67.02	44.07	23.34	-0.166	0.104	7.634	0.148	0.144	1.026	80.0
12714	10/05/94	14:35:34.00	1.672	202.0	4.020	65.71	44.25	24.11	-0.173	0.096	7.578	0.147	0.149	0.989	80.0
12714	10/05/94	14:36:20.00	1.668	202.2	4.022	66.72	44.34	23.79	-0.170	0.097	7.542	0.146	0.148	0.990	80.0
12714	10/05/94	14:38:03.00	1.668	202.7	4.033	66.10	44.38	23.73	-0.170	0.097	7.571	0.147	0.147	1.002	80.0
13714	10/05/94	14:41:05.00	1.668	204.5	4.069	66.64	44.47	23.59	-0.169	0.112	8.039	0.156	0.140	1.112	60.0
13714	10/05/94	14:41:43.00	1.666	203.6	4.050	66.42	44.54	23.42	-0.167	0.115	8.029	0.156	0.140	1.115	60.0
13714	10/05/94	14:42:45.00	1.668	198.9	3.957	66.93	44.65	23.31	-0.167	0.120	7.980	0.155	0.139	1.117	60.0
13714	10/05/94	14:43:23.00	1.671	199.2	3.963	67.01	44.67	23.41	-0.168	0.123	8.084	0.157	0.137	1.142	60.0

Table B.2-1: CHF Enhancement data with 30% rings in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	T _w	T _{in}	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
14714	10/05/94	14:44:55.00	1.653	198.8	3.956	65.88	44.58	22.81	-0.163	0.109	7.575	0.147	0.143	1.026	70.0
14714	10/05/94	14:46:01.00	1.700	204.6	4.070	66.70	44.21	25.26	-0.182	0.091	7.742	0.150	0.152	0.989	70.0
14714	10/05/94	14:47:28.00	1.668	201.1	4.000	66.38	44.31	23.84	-0.171	0.100	7.618	0.148	0.145	1.017	70.0
14714	10/05/94	14:47:53.00	1.668	203.0	4.039	65.98	44.32	23.81	-0.170	0.099	7.634	0.148	0.145	1.022	70.0
15714	10/05/94	14:50:52.00	1.666	196.9	3.918	68.71	44.53	23.45	-0.168	0.139	8.458	0.164	0.133	1.234	50.0
15714	10/05/94	14:51:29.00	1.663	200.5	3.988	67.17	44.71	23.05	-0.165	0.136	8.436	0.164	0.134	1.224	50.0
15714	10/05/94	14:52:10.00	1.663	201.7	4.014	68.36	44.87	22.80	-0.163	0.136	8.445	0.164	0.134	1.227	50.0
15714	10/05/94	14:52:52.00	1.666	197.1	3.921	68.91	44.89	22.89	-0.164	0.143	8.448	0.164	0.132	1.242	50.0
21714	10/05/94	15:04:38.00	1.615	202.2	4.022	65.14	44.10	21.99	-0.155	0.108	7.551	0.147	0.141	1.036	70.0
21714	10/05/94	15:05:47.00	1.675	202.5	4.029	66.20	43.92	24.73	-0.177	0.097	7.745	0.150	0.147	1.020	70.0
21714	10/05/94	15:06:10.00	1.671	205.6	4.091	66.21	44.01	24.41	-0.175	0.095	7.740	0.150	0.147	1.024	70.0
21714	10/05/94	15:09:33.00	1.666	204.3	4.065	66.16	44.25	23.86	-0.171	0.100	7.745	0.150	0.145	1.039	70.0
22714	10/05/94	15:14:35.00	1.674	204.5	4.068	66.43	44.09	24.42	-0.175	0.106	8.023	0.156	0.142	1.095	60.0
22714	10/05/94	15:14:41.00	1.674	205.2	4.081	66.58	44.10	24.39	-0.175	0.108	8.098	0.157	0.141	1.111	60.0
22714	10/05/94	15:15:54.00	1.662	203.6	4.050	66.51	44.34	23.54	-0.168	0.116	8.100	0.157	0.140	1.127	60.0
23714	10/05/94	15:19:26.00	1.677	203.5	4.048	66.98	44.56	23.82	-0.171	0.128	8.479	0.165	0.135	1.222	50.0
23714	10/05/94	15:20:02.00	1.671	199.7	3.974	67.42	44.65	23.44	-0.168	0.135	8.453	0.164	0.133	1.229	50.0
23714	10/05/94	15:20:42.00	1.669	204.0	4.059	67.46	44.76	23.21	-0.166	0.130	8.448	0.164	0.135	1.219	50.0
24714	10/05/94	15:27:11.00	1.683	198.7	3.952	67.14	45.04	23.34	-0.168	0.155	8.920	0.173	0.126	1.371	40.0
24714	10/05/94	15:29:35.00	1.666	204.4	4.067	66.82	45.37	22.17	-0.159	0.152	8.872	0.172	0.129	1.338	40.0
24714	10/05/94	15:31:50.00	1.666	201.4	4.006	66.81	45.35	22.19	-0.159	0.154	8.797	0.171	0.129	1.328	40.0
25714	10/05/94	15:39:14.00	1.666	199.3	3.964	67.25	45.59	21.83	-0.156	0.170	9.086	0.176	0.125	1.413	35.0
25714	10/05/94	15:40:15.00	1.666	200.3	3.985	67.29	45.66	21.72	-0.155	0.170	9.119	0.177	0.125	1.420	35.0
25714	10/05/94	15:42:07.00	1.665	198.6	3.951	67.33	45.79	21.46	-0.153	0.174	9.103	0.177	0.124	1.424	35.0
31714	10/05/94	16:01:13.00	1.666	208.2	4.143	67.15	44.73	23.14	-0.165	0.130	8.593	0.167	0.134	1.243	50.0
31714	10/05/94	16:01:51.00	1.662	205.1	4.081	67.16	44.67	23.04	-0.165	0.135	8.593	0.167	0.134	1.249	50.0
31714	10/05/94	16:02:27.00	1.660	203.4	4.047	68.34	44.65	23.01	-0.164	0.133	8.483	0.165	0.134	1.226	50.0
32714	10/05/94	16:05:55.00	1.672	206.4	4.107	67.32	44.60	23.58	-0.169	0.141	8.945	0.174	0.131	1.329	40.0
32714	10/05/94	16:07:24.00	1.669	202.7	4.033	67.46	45.00	22.95	-0.163	0.153	8.955	0.174	0.128	1.353	40.0
33714	10/05/94	16:11:05.00	1.671	202.6	4.031	67.51	45.28	22.49	-0.161	0.168	9.317	0.181	0.124	1.454	35.0
33714	10/05/94	16:11:55.00	1.663	200.1	3.980	67.33	45.42	21.96	-0.157	0.172	9.206	0.179	0.125	1.433	35.0
33714	10/05/94	16:12:38.00	1.663	205.1	4.080	67.36	45.52	21.82	-0.156	0.167	9.260	0.180	0.125	1.434	35.0
33714	10/05/94	16:13:20.00	1.666	202.1	4.020	67.36	45.57	21.86	-0.156	0.171	9.243	0.179	0.124	1.443	35.0
34714	10/05/94	16:17:10.00	1.668	198.2	3.944	67.60	45.81	21.56	-0.154	0.192	9.537	0.186	0.120	1.554	30.0
34714	10/05/94	16:17:51.00	1.668	203.2	4.042	67.66	45.92	21.39	-0.153	0.186	9.619	0.187	0.121	1.546	30.0
34714	10/05/94	16:18:34.00	1.671	198.7	3.953	67.72	45.99	21.40	-0.153	0.196	9.681	0.188	0.118	1.586	30.0
36714	10/05/94	16:34:12.00	1.648	201.8	4.014	67.67	46.51	19.70	-0.140	0.212	9.986	0.194	0.118	1.641	27.5
36714	10/05/94	16:34:47.00	1.650	199.7	3.973	67.76	46.51	19.76	-0.141	0.215	9.984	0.194	0.118	1.648	27.5
36714	10/05/94	16:35:28.00	1.663	203.7	4.052	68.01	46.49	20.34	-0.145	0.207	10.034	0.195	0.117	1.662	27.5
41714	10/05/94	16:46:26.00	1.672	199.2	3.964	67.44	45.31	22.49	-0.161	0.171	9.248	0.179	0.124	1.452	35.0
41714	10/05/94	16:47:42.00	1.669	204.5	4.069	67.45	45.57	21.98	-0.157	0.165	9.222	0.179	0.125	1.431	35.0
41714	10/05/94	16:49:26.00	1.660	199.6	3.971	67.30	45.75	21.34	-0.152	0.176	9.167	0.178	0.124	1.432	35.0
43714	10/05/94	17:54:30.00	1.674	199.6	3.970	67.61	45.70	21.97	-0.157	0.183	9.486	0.184	0.121	1.526	30.0
43714	10/05/94	17:55:28.00	1.669	208.1	4.141	67.58	46.14	21.12	-0.151	0.171	9.365	0.182	0.123	1.472	30.0
43714	10/05/94	17:56:19.00	1.668	204.2	4.063	67.61	46.36	20.72	-0.148	0.180	9.371	0.182	0.122	1.492	30.0
43714	10/05/94	17:57:01.00	1.669	207.2	4.122	67.59	46.49	20.59	-0.147	0.176	9.347	0.181	0.122	1.481	30.0
43714	10/05/94	17:58:06.00	1.669	202.1	4.021	67.62	46.65	20.33	-0.146	0.184	9.298	0.180	0.121	1.490	30.0
43714	10/05/94	18:00:32.00	1.657	204.4	4.067	67.37	45.00	22.36	-0.159	0.174	9.549	0.185	0.124	1.490	30.0
43714	10/05/94	18:01:17.00	1.653	202.6	4.030	67.45	44.80	22.48	-0.160	0.174	9.505	0.184	0.125	1.477	30.0
44714	10/05/94	18:04:46.00	1.666	201.5	4.009	68.09	44.73	23.14	-0.165	0.192	10.070	0.195	0.120	1.631	25.0
44714	10/05/94	18:05:33.00	1.665	205.4	4.086	68.18	44.87	22.86	-0.163	0.190	10.157	0.197	0.120	1.642	25.0
44714	10/05/94	18:07:16.00	1.668	202.1	4.021	68.17	45.15	22.56	-0.161	0.198	10.163	0.197	0.118	1.668	25.0
15514	10/05/94	19:08:53.00	1.668	200.4	3.987	67.83	33.93	39.44	-0.282	0.069	9.839	0.191	0.180	1.064	40.0
15514	10/05/94	19:09:29.00	1.665	200.9	3.997	67.86	34.02	39.18	-0.280	0.069	9.826	0.191	0.179	1.064	40.0
15514	10/05/94	19:09:58.00	1.665	200.1	3.981	67.98	34.07	39.10	-0.279	0.072	9.834	0.191	0.177	1.081	40.0
16514	10/05/94	19:14:59.00	1.668	199.2	3.962	68.64	34.31	38.87	-0.278	0.096	10.412	0.202	0.151	1.338	30.0
16514	10/05/94	19:15:25.00	1.662	194.6	3.872	68.70	34.37	38.54	-0.275	0.107	10.404	0.202	0.144	1.398	30.0
16514	10/05/94	19:15:52.00	1.663	196.0	3.899	68.65	34.48	38.44	-0.275	0.107	10.462	0.203	0.143	1.417	30.0
21514	10/05/94	19:30:16.00	1.665	195.5	3.889	68.51	33.78	39.54	-0.283	0.062	9.438	0.183	0.186	0.983	60.0
22514	10/05/94	19:33:12.00	1.669	199.5	3.969	68.10	33.76	39.75	-0.284	0.072	9.946	0.193	0.176	1.098	40.0
22514	10/05/94	19:33:47.00	1.665	202.2	4.023	68.06	33.93	39.32	-0.281	0.070	9.931	0.193	0.178	1.081	40.0
22514	10/05/94	19:34:47.00	1.660	203.6	4.050	67.98	34.02	39.00	-0.278	0.067	9.846	0.191	0.182	1.048	40.0
23514	10/05/94	19:37:05.00	1.671	197.3	3.925	68.54	34.20	39.15	-0.280	0.103	10.567	0.205	0.145	1.414	30.0
23514	10/05/94	19:37:43.00	1.668	200.8	3.995	68.47	34.29	38.89	-0.278	0.097	10.545	0.205	0.148	1.380	30.0
23514	10/05/94	19:38:04.00	1.666	201.6	4.011	68.50	34.37	38.72	-0.277	0.096	10.526	0.204	0.149	1.374	30.0
23514	10/05/94	19:38:39.00	1.665	201.6	4.011	68.48	34.48	38.50	-0.275	0.097	10.507	0.204	0.148	1.380	30.0
24514	10/05/94	19:40:40.00	1.669	199.2	3.963	68.73	34.53	38.60	-0.276	0.119	11.008	0.214	0.139	1.539	25.0

Table B.2-1: CHF Enhancement data with 30% rings in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	T _w	T _{in}	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
24514	10/05/94	19:41:25.00	1.669	194.5	3.869	68.76	34.68	38.38	-0.275	0.132	11.043	0.214	0.135	1.583	25.0
24514	10/05/94	19:42:08.00	1.662	202.0	4.018	68.76	34.70	38.05	-0.272	0.121	11.096	0.215	0.138	1.557	25.0
24514	10/05/94	19:42:39.00	1.662	199.8	3.976	68.74	34.70	38.05	-0.272	0.124	11.078	0.215	0.138	1.562	25.0
24514	10/05/94	19:43:02.00	1.663	198.6	3.952	68.74	34.73	38.05	-0.272	0.125	11.038	0.214	0.137	1.539	25.0
31514	10/05/94	19:54:21.00	1.663	195.5	3.889	67.78	33.34	40.13	-0.287	0.061	9.522	0.185	0.167	1.108	50.0
32514	10/05/94	20:04:58.00	1.666	202.5	4.029	67.92	33.21	40.44	-0.289	0.064	10.014	0.194	0.185	1.049	40.0
32514	10/05/94	20:05:44.00	1.660	203.5	4.048	67.88	33.49	39.79	-0.284	0.065	9.952	0.193	0.185	1.046	40.0
32514	10/05/94	20:06:10.00	1.662	205.5	4.089	67.97	33.60	39.69	-0.283	0.066	10.044	0.195	0.184	1.061	40.0
33514	10/05/94	20:10:33.00	1.657	198.4	3.946	68.17	34.20	38.60	-0.275	0.091	10.196	0.198	0.156	1.265	35.0
33514	10/05/94	20:11:05.00	1.659	197.4	3.927	68.19	34.26	38.58	-0.275	0.095	10.240	0.199	0.153	1.295	35.0
33514	10/05/94	20:11:41.00	1.659	204.3	4.065	68.14	34.28	38.55	-0.275	0.082	10.236	0.199	0.163	1.222	35.0
34514	10/05/94	20:15:49.00	1.668	200.7	3.993	68.47	34.20	39.03	-0.279	0.100	10.647	0.207	0.146	1.419	30.0
34514	10/05/94	20:16:14.00	1.659	199.5	3.969	68.29	34.22	38.64	-0.276	0.106	10.663	0.207	0.144	1.436	30.0
34514	10/05/94	20:16:48.00	1.662	199.4	3.966	68.36	34.33	38.59	-0.276	0.105	10.624	0.206	0.144	1.429	30.0
34514	10/05/94	20:17:47.00	1.660	200.1	3.980	68.34	34.39	38.45	-0.275	0.104	10.615	0.206	0.144	1.426	30.0
35514	10/05/94	20:19:50.00	1.668	205.6	4.091	68.85	34.51	38.57	-0.276	0.111	11.108	0.216	0.141	1.532	25.0
35514	10/05/94	20:20:17.00	1.666	194.6	3.871	68.81	34.55	38.45	-0.275	0.133	11.097	0.215	0.135	1.591	25.0
35514	10/05/94	20:20:48.00	1.662	198.0	3.940	68.71	34.64	38.13	-0.272	0.128	11.111	0.216	0.137	1.579	25.0
36514	10/05/94	20:24:31.00	1.662	201.6	4.011	69.24	34.88	37.77	-0.270	0.149	11.829	0.230	0.130	1.764	20.0
36514	10/05/94	20:25:09.00	1.660	209.2	4.162	69.24	35.06	37.44	-0.267	0.138	11.883	0.231	0.132	1.748	20.0
36514	10/05/94	20:25:42.00	1.662	207.5	4.127	69.29	35.25	37.23	-0.266	0.143	11.881	0.231	0.131	1.762	20.0
36514	10/05/94	20:26:17.00	1.663	203.6	4.050	69.33	35.41	37.04	-0.265	0.152	11.858	0.230	0.129	1.782	20.0
41514	10/05/94	20:42:12.00	1.663	195.7	3.892	68.28	33.85	39.37	-0.281	0.101	10.465	0.203	0.147	1.385	35.0
41514	10/05/94	20:42:55.00	1.653	201.0	3.998	68.12	34.06	38.64	-0.275	0.093	10.392	0.202	0.153	1.320	35.0
41514	10/05/94	20:44:07.00	1.654	202.0	4.018	68.16	34.24	38.42	-0.274	0.091	10.327	0.200	0.155	1.294	35.0
41514	10/05/94	20:44:46.00	1.654	200.2	3.982	68.11	34.29	38.34	-0.273	0.095	10.328	0.200	0.152	1.319	35.0
42514	10/05/94	20:48:45.00	1.669	195.9	3.897	68.39	34.26	39.01	-0.279	0.104	10.496	0.204	0.145	1.400	30.0
42514	10/05/94	20:49:24.00	1.657	196.6	3.912	68.17	34.28	38.49	-0.275	0.109	10.573	0.205	0.144	1.429	30.0
42514	10/05/94	20:50:02.00	1.656	197.8	3.935	68.19	34.37	38.29	-0.273	0.109	10.588	0.206	0.144	1.432	30.0
43514	10/05/94	20:53:04.00	1.647	205.8	4.095	68.43	34.48	37.76	-0.269	0.113	11.050	0.214	0.140	1.531	25.0
43514	10/05/94	20:53:32.00	1.645	201.4	4.006	68.45	34.51	37.64	-0.268	0.119	10.943	0.212	0.140	1.522	25.0
43514	10/05/94	20:54:05.00	1.660	206.9	4.116	68.67	34.61	38.12	-0.272	0.109	11.052	0.214	0.141	1.520	25.0
43514	10/05/94	20:54:36.00	1.663	200.9	3.997	68.76	34.66	38.16	-0.273	0.123	11.123	0.216	0.138	1.568	25.0
43514	10/05/94	20:55:08.00	1.662	195.7	3.894	68.79	34.73	37.99	-0.271	0.131	11.027	0.214	0.136	1.572	25.0
44514	10/05/94	20:58:40.00	1.666	199.2	3.963	69.16	34.97	37.82	-0.270	0.153	11.792	0.229	0.129	1.773	20.0
44514	10/05/94	20:59:40.00	1.666	195.2	3.882	69.17	35.25	37.41	-0.268	0.162	11.722	0.228	0.127	1.790	20.0
44514	10/05/94	21:00:28.00	1.663	199.7	3.973	69.14	35.43	37.01	-0.264	0.156	11.765	0.228	0.128	1.778	20.0
11913	11/05/94	14:01:32.00	1.647	146.2	2.909	66.88	55.82	5.26	-0.037	0.229	5.468	0.106	0.100	1.057	120.0
11913	11/05/94	14:02:19.00	1.647	148.5	2.955	65.31	55.75	5.38	-0.038	0.223	5.450	0.106	0.101	1.047	120.0
11913	11/05/94	14:03:35.00	1.648	150.0	2.985	67.90	54.81	6.90	-0.049	0.215	5.573	0.108	0.103	1.054	120.0
11913	11/05/94	14:05:09.00	1.651	151.3	3.010	66.01	54.83	7.00	-0.050	0.214	5.596	0.109	0.103	1.059	120.0
11913	11/05/94	14:05:48.00	1.653	147.3	2.930	69.44	54.67	7.31	-0.052	0.218	5.574	0.108	0.104	1.038	120.0
12913	11/05/94	14:08:01.00	1.653	152.6	3.036	67.57	54.74	7.20	-0.051	0.214	5.692	0.110	0.102	1.088	100.0
12913	11/05/94	14:08:52.00	1.651	148.9	2.963	66.95	54.68	7.22	-0.051	0.220	5.682	0.110	0.102	1.080	100.0
12913	11/05/94	14:09:47.00	1.651	152.0	3.023	67.19	54.65	7.28	-0.052	0.214	5.678	0.110	0.102	1.081	100.0
13913	11/05/94	14:11:54.00	1.657	150.0	2.984	67.75	55.14	6.75	-0.048	0.222	5.672	0.110	0.102	1.083	80.0
13913	11/05/94	14:12:35.00	1.654	148.3	2.950	67.21	55.01	6.83	-0.049	0.225	5.691	0.110	0.101	1.089	80.0
13913	11/05/94	14:13:30.00	1.650	151.9	3.021	66.69	54.74	7.08	-0.050	0.217	5.692	0.110	0.101	1.092	80.0
14913	11/05/94	14:16:09.00	1.657	150.3	2.989	69.34	54.90	7.13	-0.051	0.231	5.941	0.115	0.099	1.169	60.0
14913	11/05/94	14:16:46.00	1.656	147.9	2.942	67.81	54.83	7.18	-0.051	0.237	5.971	0.116	0.098	1.180	60.0
14913	11/05/94	14:17:38.00	1.656	153.7	3.058	66.35	54.85	7.15	-0.051	0.223	5.908	0.115	0.099	1.164	60.0
21913	11/05/94	14:28:15.00	1.666	149.9	2.982	68.08	55.11	7.18	-0.051	0.225	5.794	0.112	0.102	1.108	70.0
21913	11/05/94	14:29:18.00	1.662	149.0	2.964	67.63	54.94	7.25	-0.052	0.227	5.813	0.113	0.101	1.115	70.0
21913	11/05/94	14:29:41.00	1.662	151.9	3.021	71.01	54.87	7.37	-0.053	0.221	5.823	0.113	0.101	1.121	70.0
22913	11/05/94	14:31:24.00	1.666	148.3	2.951	66.68	55.03	7.29	-0.052	0.233	5.908	0.115	0.100	1.142	60.0
22913	11/05/94	14:31:57.00	1.666	151.9	3.023	66.52	55.11	7.18	-0.051	0.228	5.942	0.115	0.099	1.163	60.0
22913	11/05/94	14:32:39.00	1.668	152.7	3.038	68.32	55.12	7.21	-0.052	0.228	5.973	0.116	0.099	1.174	60.0
23913	11/05/94	14:34:29.00	1.651	145.3	2.890	65.37	55.40	6.11	-0.044	0.255	6.091	0.118	0.093	1.268	50.0
23913	11/05/94	14:35:01.00	1.653	147.8	2.940	66.32	55.42	6.14	-0.044	0.254	6.166	0.120	0.093	1.289	50.0
23913	11/05/94	14:36:12.00	1.656	147.6	2.937	67.30	55.55	6.06	-0.043	0.255	6.175	0.120	0.093	1.289	50.0
24913	11/05/94	14:38:05.00	1.654	146.8	2.920	65.07	55.67	5.80	-0.041	0.261	6.234	0.121	0.091	1.325	45.0
24913	11/05/94	14:38:42.00	1.656	149.5	2.975	64.99	55.60	5.98	-0.043	0.257	6.273	0.122	0.092	1.328	45.0
24913	11/05/94	14:39:40.00	1.663	150.4	2.993	66.58	55.80	5.97	-0.043	0.257	6.303	0.122	0.092	1.327	45.0
24913	11/05/94	14:40:34.00	1.654	148.8	2.960	65.34	55.53	6.03	-0.043	0.257	6.254	0.121	0.092	1.322	45.0
31913	11/05/94	14:46:40.00	1.642	149.7	2.977	64.49	54.90	6.51	-0.046	0.246	6.148	0.119	0.093	1.287	50.0
31913	11/05/94	14:47:11.00	1.641	149.6	2.977	64.85	54.63	6.88	-0.049	0.244	6.178	0.120	0.093	1.292	50.0
31913	11/05/94	14:48:09.00	1.662	149.6	2.976	64.86	54.56	7.85	-0.056	0.241	6.221	0.121	0.097	1.248	50.0

Table B.2-1: CHF Enhancement data with 30% rings in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DHin	Xin	Xc	Power	CHF	CHFref	CHFR	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
31913	11/05/94	14:48:40.00	1.662	152.6	3.036	64.90	54.52	7.91	-0.057	0.233	6.177	0.120	0.097	1.234	50.0
31913	11/05/94	14:49:09.00	1.662	148.9	2.962	64.75	54.63	7.74	-0.055	0.243	6.222	0.121	0.097	1.251	50.0
32913	11/05/94	14:51:13.00	1.663	151.2	3.008	64.88	54.54	7.94	-0.057	0.244	6.364	0.124	0.095	1.299	45.0
32913	11/05/94	14:51:43.00	1.665	148.2	2.948	64.93	54.67	7.81	-0.056	0.253	6.394	0.124	0.095	1.311	45.0
32913	11/05/94	14:52:20.00	1.665	148.6	2.957	64.90	54.63	7.86	-0.056	0.250	6.357	0.123	0.095	1.295	45.0
33913	11/05/94	14:55:05.00	1.665	152.2	3.029	65.12	54.39	8.23	-0.059	0.258	6.752	0.131	0.091	1.439	40.0
33913	11/05/94	14:55:45.00	1.665	149.0	2.964	65.29	54.39	8.23	-0.059	0.266	6.768	0.131	0.091	1.447	40.0
33913	11/05/94	14:56:18.00	1.666	152.4	3.033	65.16	54.37	8.32	-0.060	0.259	6.793	0.132	0.091	1.451	40.0
34913	11/05/94	14:58:48.00	1.671	148.9	2.963	65.74	54.81	7.82	-0.056	0.278	6.953	0.135	0.089	1.525	35.0
34913	11/05/94	14:59:27.00	1.657	149.1	2.966	65.44	54.98	7.01	-0.050	0.282	6.937	0.135	0.085	1.575	35.0
34913	11/05/94	15:00:01.00	1.659	148.8	2.960	65.42	55.18	6.76	-0.048	0.286	6.965	0.135	0.085	1.594	35.0
41913	11/05/94	15:10:36.00	1.662	150.8	3.001	65.16	54.90	7.31	-0.052	0.266	6.720	0.130	0.089	1.459	40.0
41913	11/05/94	15:11:19.00	1.663	148.9	2.962	65.17	54.94	7.32	-0.052	0.271	6.736	0.131	0.089	1.465	40.0
41913	11/05/94	15:11:49.00	1.662	149.8	2.980	65.16	55.01	7.14	-0.051	0.266	6.645	0.129	0.090	1.434	40.0
42913	11/05/94	15:13:47.00	1.671	146.7	2.919	65.45	55.18	7.25	-0.052	0.287	6.947	0.135	0.087	1.545	35.0
42913	11/05/94	15:14:17.00	1.657	147.8	2.940	65.23	55.27	6.55	-0.047	0.290	6.976	0.135	0.084	1.616	35.0
42913	11/05/94	15:14:44.00	1.657	147.5	2.934	65.25	55.20	6.67	-0.048	0.290	6.979	0.135	0.084	1.614	35.0
43913	11/05/94	15:18:30.00	1.663	147.7	2.938	65.56	55.64	6.23	-0.044	0.304	7.194	0.140	0.082	1.711	30.0
43913	11/05/94	15:18:55.00	1.665	146.1	2.907	65.56	55.73	6.14	-0.044	0.308	7.185	0.139	0.081	1.715	30.0
43913	11/05/94	15:19:35.00	1.665	147.9	2.942	65.53	55.66	6.26	-0.045	0.299	7.103	0.138	0.083	1.661	30.0
43913	11/05/94	15:20:54.00	1.662	145.6	2.897	65.53	55.84	5.85	-0.042	0.312	7.210	0.140	0.080	1.755	30.0
45913	11/05/94	15:30:37.00	1.650	151.6	3.017	65.54	55.25	6.28	-0.045	0.311	7.578	0.147	0.076	1.925	27.5
45913	11/05/94	15:31:53.00	1.668	151.7	3.017	65.91	55.38	6.81	-0.049	0.309	7.588	0.147	0.080	1.842	27.5
45913	11/05/94	15:32:23.00	1.656	153.5	3.055	65.69	55.45	6.21	-0.044	0.309	7.601	0.148	0.078	1.902	27.5
45913	11/05/94	15:33:02.00	1.659	148.4	2.953	65.67	55.44	6.36	-0.045	0.319	7.571	0.147	0.077	1.907	27.5
41912	11/05/94	16:20:33.00	1.660	106.3	2.115	63.82	53.02	10.19	-0.073	0.264	5.016	0.097	0.072	1.345	40.0
41912	11/05/94	16:21:16.00	1.662	103.9	2.067	63.72	53.07	10.16	-0.073	0.273	5.022	0.097	0.085	1.142	40.0
41912	11/05/94	16:21:47.00	1.662	103.0	2.049	63.82	53.05	10.19	-0.073	0.276	5.030	0.098	0.085	1.153	40.0
41922	11/05/94	19:31:37.00	1.136	100.1	1.991	54.04	39.10	7.72	-0.049	0.320	5.843	0.113	0.112	1.009	40.0
41922	11/05/94	19:32:45.00	1.121	95.9	1.907	54.07	39.10	6.94	-0.044	0.340	5.848	0.114	0.110	1.036	40.0
41922	11/05/94	19:34:11.00	1.120	100.0	1.989	54.33	39.01	7.00	-0.044	0.330	5.936	0.115	0.111	1.041	40.0
42922	11/05/94	19:37:33.00	1.123	103.6	2.062	55.45	39.50	6.41	-0.040	0.347	6.379	0.124	0.099	1.246	30.0
42922	11/05/94	19:38:50.00	1.121	100.1	1.991	55.14	39.76	5.95	-0.037	0.361	6.341	0.123	0.104	1.182	30.0
42922	11/05/94	19:41:16.00	1.120	103.1	2.052	54.37	40.25	5.12	-0.032	0.356	6.365	0.124	0.099	1.249	30.0
43922	11/05/94	19:45:29.00	1.129	98.5	1.959	54.08	40.77	4.82	-0.030	0.387	6.520	0.127	0.101	1.248	25.0
43922	11/05/94	19:47:02.00	1.124	97.2	1.934	55.20	40.90	4.39	-0.028	0.397	6.552	0.127	0.101	1.261	25.0
44922	11/05/94	19:53:12.00	1.133	105.6	2.100	54.31	41.46	4.00	-0.025	0.382	6.810	0.132	0.083	1.600	20.0
44922	11/05/94	19:54:03.00	1.124	97.7	1.943	54.40	41.63	3.29	-0.021	0.419	6.811	0.132	0.097	1.358	20.0
44922	11/05/94	19:56:02.00	1.126	96.5	1.919	57.77	41.70	3.25	-0.020	0.429	6.877	0.133	0.097	1.379	20.0
41624	12/05/94	13:28:09.00	1.138	201.5	4.009	54.42	25.95	27.31	-0.173	0.103	8.801	0.171	0.156	1.094	40.0
41624	12/05/94	13:28:31.00	1.130	197.9	3.937	54.47	26.02	26.82	-0.169	0.110	8.770	0.170	0.154	1.104	40.0
41624	12/05/94	13:29:09.00	1.130	201.0	3.999	55.32	26.21	26.55	-0.168	0.109	8.797	0.171	0.153	1.112	40.0
41624	12/05/94	13:30:00.00	1.132	203.4	4.046	54.86	26.39	26.36	-0.166	0.107	8.804	0.171	0.153	1.114	40.0
43624	12/05/94	13:38:32.00	1.129	204.5	4.068	55.95	27.84	24.08	-0.152	0.145	9.610	0.187	0.143	1.301	35.0
43624	12/05/94	13:39:10.00	1.127	204.1	4.061	56.92	27.86	23.97	-0.151	0.147	9.657	0.187	0.143	1.313	35.0
43624	12/05/94	13:39:51.00	1.129	200.3	3.984	57.70	28.10	23.70	-0.149	0.154	9.640	0.187	0.143	1.309	35.0

Table B.2-2: CHF Enhancement data with 18% spacers in Freon-134a

RunID	Date	Time	P	m	G	Tw	Tin	DHin	Xin	Xc	Power	CHF	CHFref	CHFR	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
11914	18/05/94	20:44:54.00	1.662	201.0	3.998	66.87	53.32	9.77	-0.070	0.160	6.475	0.126	0.127	0.986	120.0
11914	18/05/94	20:45:24.00	1.663	200.3	3.986	66.75	53.31	9.86	-0.070	0.160	6.463	0.125	0.127	0.984	120.0
11914	18/05/94	20:46:03.00	1.663	196.2	3.903	66.74	53.31	9.86	-0.070	0.165	6.469	0.126	0.127	0.992	120.0
12914	18/05/94	20:48:33.00	1.663	202.0	4.019	66.96	53.56	9.46	-0.068	0.177	6.911	0.134	0.123	1.087	80.0
12914	18/05/94	20:49:29.00	1.665	200.1	3.982	72.54	53.64	9.40	-0.067	0.180	6.916	0.134	0.123	1.094	80.0
12914	18/05/94	20:50:01.00	1.663	203.7	4.052	67.68	53.62	9.37	-0.067	0.175	6.895	0.134	0.124	1.083	80.0
13914	18/05/94	20:51:29.00	1.666	199.3	3.966	66.41	53.82	9.18	-0.066	0.183	6.931	0.135	0.122	1.104	60.0
13914	18/05/94	20:52:09.00	1.663	199.2	3.963	67.13	53.79	9.11	-0.065	0.185	6.967	0.135	0.122	1.110	60.0
13914	18/05/94	20:52:38.00	1.665	201.8	4.014	67.45	53.82	9.12	-0.065	0.182	6.965	0.135	0.122	1.107	60.0
15914	18/05/94	20:56:06.00	1.665	199.9	3.978	67.20	54.16	8.60	-0.061	0.190	7.021	0.136	0.121	1.130	55.0
15914	18/05/94	20:56:33.00	1.665	199.6	3.972	66.48	54.16	8.60	-0.061	0.187	6.943	0.135	0.121	1.113	55.0
15914	18/05/94	20:57:01.00	1.665	199.0	3.958	65.92	54.19	8.54	-0.061	0.191	7.005	0.136	0.120	1.129	55.0
21914	18/05/94	21:02:31.00	1.656	198.1	3.941	67.83	53.90	8.63	-0.062	0.185	6.849	0.133	0.123	1.082	80.0
21914	18/05/94	21:03:05.00	1.651	200.2	3.984	67.66	53.90	8.45	-0.060	0.183	6.829	0.133	0.124	1.073	80.0
21914	18/05/94	21:03:36.00	1.653	202.7	4.032	67.98	53.86	8.57	-0.061	0.180	6.869	0.133	0.124	1.079	80.0
22914	18/05/94	21:05:14.00	1.654	200.6	3.991	68.67	53.95	8.49	-0.060	0.185	6.909	0.134	0.123	1.093	70.0
22914	18/05/94	21:05:45.00	1.653	196.8	3.915	67.91	53.95	8.42	-0.060	0.187	6.811	0.132	0.123	1.075	70.0
22914	18/05/94	21:06:15.00	1.654	199.1	3.961	67.52	53.93	8.51	-0.061	0.186	6.891	0.134	0.123	1.090	70.0
23914	18/05/94	21:08:02.00	1.654	202.6	4.030	67.17	53.93	8.51	-0.061	0.181	6.870	0.133	0.123	1.081	60.0
23914	18/05/94	21:08:39.00	1.654	200.0	3.979	66.43	53.93	8.51	-0.061	0.186	6.915	0.134	0.123	1.094	60.0
23914	18/05/94	21:09:12.00	1.654	200.8	3.994	66.20	53.93	8.51	-0.061	0.185	6.932	0.135	0.123	1.097	60.0
24914	18/05/94	21:10:58.00	1.659	199.2	3.963	66.55	53.92	8.73	-0.062	0.194	7.164	0.139	0.120	1.155	50.0
24914	18/05/94	21:11:34.00	1.657	199.5	3.969	65.99	53.93	8.64	-0.062	0.195	7.167	0.139	0.121	1.154	50.0
24914	18/05/94	21:12:00.00	1.659	201.5	4.008	67.68	54.05	8.53	-0.061	0.192	7.149	0.139	0.121	1.150	50.0
25914	18/05/94	21:13:14.00	1.663	199.2	3.963	66.11	54.14	8.57	-0.061	0.196	7.180	0.139	0.119	1.167	45.0
25914	18/05/94	21:13:36.00	1.660	198.7	3.953	66.00	54.18	8.39	-0.060	0.198	7.188	0.140	0.119	1.168	45.0
25914	18/05/94	21:14:03.00	1.659	200.3	3.985	65.99	54.18	8.32	-0.059	0.196	7.171	0.139	0.120	1.160	45.0
26914	18/05/94	21:16:01.00	1.668	200.9	3.997	66.21	54.21	8.63	-0.062	0.200	7.363	0.143	0.118	1.212	40.0
26914	18/05/94	21:16:25.00	1.666	195.6	3.892	66.64	54.32	8.40	-0.060	0.211	7.415	0.144	0.116	1.239	40.0
26914	18/05/94	21:16:48.00	1.665	198.9	3.958	66.46	54.40	8.22	-0.059	0.208	7.438	0.144	0.117	1.236	40.0
31914	18/05/94	21:22:47.00	1.654	199.5	3.970	65.29	54.19	8.11	-0.058	0.196	7.099	0.138	0.121	1.142	50.0
31914	18/05/94	21:23:20.00	1.650	200.1	3.981	65.84	54.16	7.98	-0.057	0.195	7.070	0.137	0.121	1.131	50.0
31914	18/05/94	21:23:58.00	1.645	202.8	4.034	66.02	54.01	8.03	-0.057	0.194	7.164	0.139	0.122	1.144	50.0
32914	18/05/94	21:25:41.00	1.650	203.6	4.050	65.67	53.95	8.30	-0.059	0.193	7.216	0.140	0.121	1.156	45.0
32914	18/05/94	21:26:06.00	1.647	204.5	4.069	65.59	54.01	8.09	-0.058	0.194	7.225	0.140	0.121	1.157	45.0
32914	18/05/94	21:26:48.00	1.647	204.7	4.073	65.86	54.08	7.98	-0.057	0.196	7.284	0.141	0.121	1.171	45.0
33914	18/05/94	21:28:20.00	1.666	204.2	4.061	66.02	54.08	8.77	-0.063	0.198	7.456	0.145	0.118	1.223	40.0
33914	18/05/94	21:28:45.00	1.666	204.2	4.063	65.93	54.14	8.69	-0.062	0.198	7.435	0.144	0.118	1.219	40.0
33914	18/05/94	21:29:16.00	1.665	199.3	3.965	66.07	54.21	8.51	-0.061	0.207	7.458	0.145	0.117	1.236	40.0
34914	18/05/94	21:31:05.00	1.663	200.6	3.991	66.08	54.51	7.99	-0.057	0.215	7.626	0.148	0.116	1.277	35.0
34914	18/05/94	21:31:30.00	1.659	203.1	4.040	66.09	54.56	7.72	-0.055	0.211	7.572	0.147	0.117	1.256	35.0
34914	18/05/94	21:31:58.00	1.662	203.2	4.042	66.21	54.64	7.73	-0.055	0.211	7.580	0.147	0.117	1.262	35.0
35914	18/05/94	21:33:47.00	1.663	200.7	3.993	66.33	54.90	7.38	-0.053	0.229	7.904	0.153	0.113	1.353	30.0
35914	18/05/94	21:34:10.00	1.656	203.8	4.055	66.15	54.97	6.96	-0.050	0.226	7.864	0.153	0.115	1.329	30.0
35914	18/05/94	21:34:35.00	1.659	203.3	4.045	66.18	55.03	7.00	-0.050	0.228	7.905	0.153	0.114	1.344	30.0
41914	18/05/94	21:41:08.00	1.650	202.3	4.024	65.58	54.30	7.75	-0.055	0.203	7.345	0.143	0.119	1.193	40.0
41914	18/05/94	21:41:35.00	1.650	205.6	4.089	65.64	54.30	7.75	-0.055	0.201	7.385	0.143	0.120	1.198	40.0
41914	18/05/94	21:42:04.00	1.650	202.4	4.027	65.65	54.40	7.61	-0.054	0.205	7.375	0.143	0.119	1.202	40.0
42914	18/05/94	21:44:01.00	1.668	206.0	4.098	66.05	54.53	8.14	-0.058	0.205	7.580	0.147	0.117	1.260	35.0
42914	18/05/94	21:44:24.00	1.666	204.8	4.075	66.09	54.68	7.85	-0.056	0.209	7.592	0.147	0.116	1.267	35.0
42914	18/05/94	21:44:54.00	1.665	210.4	4.186	66.13	54.66	7.82	-0.056	0.201	7.568	0.147	0.118	1.250	35.0
43913	18/05/94	21:48:00.00	1.663	204.6	4.071	66.28	54.95	7.30	-0.052	0.218	7.728	0.150	0.115	1.303	30.0
43913	18/05/94	21:48:35.00	1.654	206.7	4.112	66.13	55.03	6.81	-0.049	0.220	7.774	0.151	0.116	1.303	30.0
43913	18/05/94	21:49:08.00	1.656	206.6	4.109	66.06	55.12	6.73	-0.048	0.220	7.750	0.150	0.116	1.301	30.0
44914	18/05/94	21:51:06.00	1.669	209.8	4.174	66.74	55.40	6.85	-0.049	0.230	8.178	0.159	0.112	1.417	25.0
44914	18/05/94	21:52:16.00	1.665	207.3	4.123	66.60	55.69	6.20	-0.044	0.238	8.181	0.159	0.111	1.425	25.0
51914	18/05/94	22:00:37.00	1.653	208.8	4.155	66.20	53.99	8.37	-0.060	0.216	8.075	0.157	0.116	1.347	30.0
51914	18/05/94	22:01:32.00	1.639	209.3	4.164	65.81	54.45	7.09	-0.050	0.218	7.911	0.154	0.117	1.313	30.0

Table B.2-2: CHF Enhancement data with 18% spacers in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	T _w	T _{in}	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
51914	18/05/94	22:01:58.00	1.639	206.1	4.101	65.73	54.77	6.60	-0.047	0.223	7.822	0.152	0.117	1.301	30.0
51914	18/05/94	22:02:52.00	1.668	205.1	4.080	66.19	55.16	7.16	-0.051	0.219	7.751	0.150	0.114	1.317	30.0
51914	18/05/94	22:03:25.00	1.666	204.2	4.062	66.19	55.32	6.84	-0.049	0.222	7.727	0.150	0.114	1.316	30.0
51914	18/05/94	22:03:47.00	1.668	198.0	3.939	66.22	55.38	6.81	-0.049	0.231	7.739	0.150	0.112	1.339	30.0
52914	18/05/94	22:07:00.00	1.657	200.5	3.988	66.26	55.93	5.52	-0.039	0.244	7.962	0.155	0.112	1.383	25.0
52914	18/05/94	22:07:33.00	1.650	199.8	3.976	66.11	56.05	5.03	-0.036	0.249	7.988	0.155	0.112	1.383	25.0
52914	18/05/94	22:07:58.00	1.651	200.2	3.983	66.09	56.17	4.89	-0.035	0.248	7.937	0.154	0.112	1.374	25.0
11714	19/05/94	12:51:14.00	1.665	204.5	4.069	69.25	44.75	23.04	-0.165	0.101	7.616	0.148	0.144	1.024	120.0
11714	19/05/94	12:51:57.00	1.663	198.7	3.952	67.05	44.79	22.92	-0.164	0.108	7.563	0.147	0.143	1.025	120.0
11714	19/05/94	12:52:22.00	1.663	201.3	4.005	66.27	44.83	22.87	-0.163	0.105	7.558	0.147	0.144	1.020	120.0
12714	19/05/94	12:53:35.00	1.656	201.0	3.998	66.17	44.81	22.59	-0.161	0.102	7.412	0.144	0.145	0.991	80.0
12714	19/05/94	12:54:45.00	1.656	200.9	3.997	66.45	44.81	22.59	-0.161	0.104	7.455	0.145	0.145	1.000	80.0
12714	19/05/94	12:55:21.00	1.654	199.8	3.975	66.78	44.79	22.56	-0.161	0.105	7.463	0.145	0.144	1.004	80.0
13714	19/05/94	12:57:21.00	1.659	200.0	3.979	66.60	44.81	22.71	-0.162	0.116	7.802	0.151	0.140	1.080	60.0
13714	19/05/94	12:57:25.00	1.659	201.8	4.016	69.50	44.77	22.77	-0.163	0.112	7.751	0.150	0.141	1.063	60.0
13714	19/05/94	12:57:51.00	1.659	199.3	3.965	67.06	44.85	22.66	-0.162	0.117	7.795	0.151	0.140	1.080	60.0
14714	19/05/94	13:00:41.00	1.657	199.1	3.960	66.91	45.01	22.34	-0.159	0.131	8.089	0.157	0.136	1.154	50.0
14714	19/05/94	13:01:21.00	1.657	201.7	4.013	66.94	45.07	22.26	-0.159	0.124	8.007	0.155	0.137	1.131	50.0
14714	19/05/94	13:01:58.00	1.659	198.3	3.946	66.79	45.14	22.21	-0.158	0.130	8.007	0.155	0.136	1.139	50.0
15714	19/05/94	13:03:57.00	1.662	196.0	3.900	66.48	44.99	22.55	-0.161	0.139	8.242	0.160	0.134	1.197	40.0
15714	19/05/94	13:04:22.00	1.662	199.4	3.967	66.54	44.94	22.64	-0.162	0.133	8.238	0.160	0.135	1.185	40.0
15714	19/05/94	13:04:53.00	1.662	197.5	3.929	67.52	44.97	22.58	-0.161	0.136	8.213	0.159	0.134	1.185	40.0
17714	19/05/94	13:09:35.00	1.663	201.4	4.007	67.04	45.12	22.42	-0.160	0.138	8.405	0.163	0.133	1.226	35.0
17714	19/05/94	13:09:59.00	1.663	198.1	3.941	66.82	45.07	22.50	-0.161	0.141	8.364	0.162	0.133	1.223	35.0
17714	19/05/94	13:10:23.00	1.663	198.6	3.951	66.70	45.14	22.39	-0.160	0.142	8.391	0.163	0.132	1.230	35.0
21714	19/05/94	13:14:48.00	1.666	203.6	4.050	68.29	43.96	24.31	-0.174	0.096	7.691	0.149	0.147	1.015	80.0
21714	19/05/94	13:15:17.00	1.666	200.1	3.981	70.09	44.03	24.20	-0.173	0.099	7.625	0.148	0.147	1.007	80.0
21714	19/05/94	13:15:52.00	1.666	203.1	4.040	70.35	44.27	23.83	-0.170	0.098	7.619	0.148	0.146	1.014	80.0
22714	19/05/94	13:18:49.00	1.668	198.6	3.951	66.65	44.23	23.95	-0.171	0.108	7.760	0.151	0.143	1.054	60.0
22714	19/05/94	13:19:32.00	1.654	201.2	4.003	66.12	44.35	23.23	-0.166	0.108	7.718	0.150	0.143	1.047	60.0
22714	19/05/94	13:20:10.00	1.654	203.2	4.042	66.09	44.33	23.26	-0.166	0.106	7.740	0.150	0.143	1.049	60.0
23714	19/05/94	13:22:35.00	1.668	202.0	4.019	66.74	44.51	23.53	-0.168	0.116	8.018	0.156	0.140	1.114	50.0
23714	19/05/94	13:22:55.00	1.668	202.5	4.028	66.62	44.53	23.50	-0.168	0.116	8.030	0.156	0.140	1.116	50.0
23714	19/05/94	13:23:24.00	1.668	198.9	3.956	67.89	44.59	23.42	-0.168	0.123	8.071	0.157	0.138	1.137	50.0
24714	19/05/94	13:25:21.00	1.656	200.5	3.989	66.59	44.88	22.48	-0.160	0.132	8.207	0.159	0.136	1.175	40.0
24714	19/05/94	13:25:52.00	1.656	202.6	4.030	66.47	44.92	22.42	-0.160	0.127	8.159	0.158	0.136	1.161	40.0
24714	19/05/94	13:26:17.00	1.659	201.4	4.006	67.10	44.96	22.49	-0.160	0.129	8.178	0.159	0.136	1.168	40.0
25714	19/05/94	13:31:31.00	1.665	202.8	4.035	66.59	45.16	22.42	-0.160	0.143	8.598	0.167	0.131	1.269	30.0
25714	19/05/94	13:32:11.00	1.666	202.3	4.025	66.64	45.27	22.32	-0.160	0.147	8.682	0.169	0.130	1.294	30.0
25714	19/05/94	13:32:37.00	1.665	195.4	3.888	66.60	45.34	22.14	-0.158	0.158	8.636	0.168	0.128	1.306	30.0
31714	19/05/94	13:38:18.00	1.619	201.2	4.003	70.25	44.83	21.08	-0.149	0.132	8.000	0.155	0.136	1.145	50.0
31714	19/05/94	13:39:38.00	1.669	201.5	4.009	66.27	44.59	23.48	-0.168	0.118	8.062	0.156	0.139	1.128	50.0
31714	19/05/94	13:40:32.00	1.662	202.7	4.032	66.13	44.64	23.09	-0.165	0.117	8.009	0.155	0.139	1.116	50.0
31714	19/05/94	13:41:02.00	1.665	202.1	4.021	66.16	44.68	23.15	-0.166	0.118	8.017	0.156	0.139	1.119	50.0
32714	19/05/94	13:44:13.00	1.660	203.5	4.049	66.51	44.85	22.72	-0.162	0.127	8.245	0.160	0.136	1.176	40.0
32714	19/05/94	13:44:33.00	1.660	202.4	4.028	66.42	44.85	22.72	-0.162	0.131	8.304	0.161	0.135	1.192	40.0
32714	19/05/94	13:45:08.00	1.662	208.8	4.153	66.42	44.97	22.58	-0.161	0.123	8.319	0.161	0.136	1.186	40.0
33714	19/05/94	13:48:08.00	1.653	202.8	4.034	66.49	45.01	22.16	-0.158	0.146	8.651	0.168	0.131	1.278	30.0
33714	19/05/94	13:48:41.00	1.653	201.2	4.003	66.38	45.07	22.07	-0.157	0.148	8.607	0.167	0.131	1.272	30.0
33714	19/05/94	13:49:15.00	1.656	210.5	4.188	66.45	45.23	21.94	-0.156	0.136	8.637	0.168	0.132	1.266	30.0
34714	19/05/94	13:51:21.00	1.657	199.9	3.976	67.01	45.75	21.22	-0.151	0.171	9.024	0.175	0.126	1.395	25.0
34714	19/05/94	13:51:50.00	1.659	201.4	4.007	66.94	45.77	21.25	-0.152	0.168	9.030	0.175	0.126	1.393	25.0
34714	19/05/94	13:52:31.00	1.657	198.2	3.944	66.93	45.96	20.91	-0.149	0.176	9.034	0.175	0.125	1.407	25.0
41714	19/05/94	14:17:43.00	1.612	206.6	4.111	65.33	45.51	19.72	-0.139	0.137	8.078	0.157	0.133	1.182	40.0
41714	19/05/94	14:19:00.00	1.669	209.5	4.168	66.95	45.23	22.49	-0.161	0.121	8.244	0.160	0.137	1.172	40.0
41714	19/05/94	14:19:27.00	1.665	206.3	4.103	66.55	45.29	22.23	-0.159	0.125	8.181	0.159	0.136	1.167	40.0
42714	19/05/94	14:22:27.00	1.672	205.0	4.079	68.47	45.34	22.45	-0.161	0.143	8.709	0.169	0.130	1.297	30.0
42714	19/05/94	14:22:55.00	1.665	205.7	4.092	67.65	45.38	22.09	-0.158	0.145	8.708	0.169	0.130	1.295	30.0

Table B.2-2: CHF Enhancement data with 18% spacers in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHF _R	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
42714	19/05/94	14:23:38.00	1.663	208.0	4.137	67.07	45.55	21.77	-0.156	0.144	8.704	0.169	0.131	1.294	30.0
43714	19/05/94	14:26:23.00	1.660	204.8	4.075	67.19	45.90	21.11	-0.151	0.164	9.031	0.175	0.126	1.389	25.0
43714	19/05/94	14:26:54.00	1.659	206.6	4.111	67.13	45.99	20.91	-0.149	0.162	9.025	0.175	0.126	1.385	25.0
43714	19/05/94	14:27:55.00	1.659	209.6	4.170	67.15	46.10	20.74	-0.148	0.158	8.973	0.174	0.127	1.370	25.0
44714	19/05/94	14:32:46.00	1.665	203.2	4.042	67.46	46.38	20.56	-0.147	0.188	9.510	0.185	0.121	1.528	20.0
44714	19/05/94	14:33:40.00	1.656	201.2	4.003	68.12	46.62	19.83	-0.141	0.195	9.498	0.184	0.120	1.530	20.0
44714	19/05/94	14:34:29.00	1.662	209.6	4.171	70.23	46.73	19.90	-0.142	0.186	9.632	0.187	0.121	1.547	20.0
51714	19/05/94	14:48:34.00	1.674	210.2	4.183	67.43	43.44	25.40	-0.182	0.127	9.056	0.176	0.134	1.309	30.0
51714	19/05/94	14:49:46.00	1.669	207.4	4.126	67.43	44.60	23.45	-0.168	0.134	8.740	0.170	0.133	1.276	30.0
51714	19/05/94	14:50:19.00	1.666	202.3	4.024	67.36	45.05	22.65	-0.162	0.143	8.631	0.168	0.131	1.276	30.0
51714	19/05/94	14:51:31.00	1.666	204.7	4.073	68.52	45.57	21.86	-0.156	0.145	8.624	0.167	0.130	1.283	30.0
51714	19/05/94	14:52:34.00	1.668	207.5	4.129	67.88	45.84	21.50	-0.154	0.143	8.600	0.167	0.131	1.278	30.0
52714	19/05/94	14:55:16.00	1.651	202.9	4.036	68.56	46.20	20.29	-0.145	0.170	8.964	0.174	0.126	1.383	25.0
52714	19/05/94	14:55:43.00	1.653	208.0	4.138	68.54	46.23	20.30	-0.145	0.165	9.044	0.176	0.126	1.393	25.0
52714	19/05/94	14:56:38.00	1.654	202.1	4.021	68.95	46.40	20.11	-0.143	0.174	8.989	0.174	0.125	1.396	25.0
53714	19/05/94	15:02:57.00	1.662	198.3	3.945	68.87	47.18	19.23	-0.137	0.201	9.395	0.182	0.119	1.536	20.0
53714	19/05/94	15:03:53.00	1.665	203.3	4.045	68.90	47.25	19.24	-0.138	0.194	9.422	0.183	0.120	1.530	20.0
53714	19/05/94	15:04:29.00	1.665	205.4	4.087	67.76	47.31	19.15	-0.137	0.191	9.412	0.183	0.120	1.522	20.0
14514	20/05/94	10:01:03.00	1.659	205.2	4.083	67.96	33.79	39.27	-0.280	0.062	9.832	0.191	0.189	1.007	40.0
14514	20/05/94	10:02:00.00	1.659	203.1	4.040	68.16	33.83	39.22	-0.280	0.067	9.869	0.192	0.182	1.050	40.0
15514	20/05/94	10:04:12.00	1.659	205.3	4.084	68.58	33.87	39.16	-0.280	0.063	9.855	0.191	0.187	1.021	50.0
16514	20/05/94	10:21:56.00	1.650	200.9	3.996	67.95	33.42	39.45	-0.281	0.070	9.896	0.192	0.180	1.070	35.0
16514	20/05/94	10:22:44.00	1.648	201.2	4.003	68.01	33.52	39.26	-0.279	0.073	9.974	0.194	0.175	1.104	35.0
16514	20/05/94	10:23:39.00	1.648	200.2	3.983	68.02	33.63	39.09	-0.278	0.073	9.877	0.192	0.176	1.089	35.0
17514	20/05/94	10:24:52.00	1.659	201.8	4.015	68.23	33.70	39.41	-0.281	0.077	10.143	0.197	0.170	1.159	30.0
17514	20/05/94	10:25:46.00	1.654	203.7	4.052	68.18	33.77	39.12	-0.279	0.076	10.147	0.197	0.171	1.155	30.0
17514	20/05/94	10:26:27.00	1.656	205.2	4.082	68.22	33.83	39.09	-0.279	0.074	10.137	0.197	0.173	1.135	30.0
24514	20/05/94	10:47:19.00	1.666	202.8	4.034	68.30	33.79	39.58	-0.283	0.062	9.777	0.190	0.189	1.005	40.0
24514	20/05/94	10:48:24.00	1.668	204.6	4.070	68.32	33.89	39.50	-0.283	0.060	9.788	0.190	0.192	0.991	40.0
24514	20/05/94	10:52:14.00	1.663	202.2	4.023	68.29	34.03	39.10	-0.279	0.064	9.705	0.188	0.187	1.009	40.0
25514	20/05/94	10:53:28.00	1.665	200.9	3.996	68.45	34.03	39.16	-0.280	0.072	9.876	0.192	0.177	1.085	35.0
25514	20/05/94	10:54:01.00	1.663	200.2	3.984	68.36	34.07	39.04	-0.279	0.075	9.912	0.192	0.173	1.111	35.0
25514	20/05/94	10:54:31.00	1.662	204.7	4.073	68.37	34.09	38.95	-0.278	0.067	9.884	0.192	0.182	1.051	35.0
26514	20/05/94	11:00:48.00	1.660	206.6	4.111	68.17	34.16	38.78	-0.277	0.071	10.076	0.196	0.176	1.114	30.0
26514	20/05/94	11:01:49.00	1.660	207.1	4.121	68.21	34.22	38.70	-0.276	0.070	10.045	0.195	0.177	1.100	30.0
26514	20/05/94	11:02:47.00	1.659	205.7	4.092	68.22	34.24	38.61	-0.276	0.073	10.059	0.195	0.173	1.128	30.0
27514	20/05/94	11:06:19.00	1.665	202.4	4.026	68.42	34.35	38.69	-0.277	0.088	10.336	0.201	0.157	1.280	25.0
27514	20/05/94	11:07:22.00	1.659	208.5	4.148	68.31	34.40	38.36	-0.274	0.078	10.292	0.200	0.165	1.214	25.0
27514	20/05/94	11:08:40.00	1.660	209.9	4.175	68.35	34.46	38.34	-0.274	0.077	10.319	0.200	0.165	1.214	25.0
27514	20/05/94	11:09:23.00	1.657	205.0	4.079	68.33	34.44	38.25	-0.273	0.088	10.359	0.201	0.156	1.291	25.0
28514	20/05/94	11:11:38.00	1.659	199.8	3.975	68.95	34.48	38.25	-0.273	0.109	10.684	0.207	0.143	1.450	20.0
28514	20/05/94	11:12:09.00	1.659	194.6	3.870	68.91	34.57	38.11	-0.272	0.120	10.683	0.207	0.140	1.479	20.0
28514	20/05/94	11:12:50.00	1.657	197.9	3.936	68.91	34.66	37.91	-0.271	0.114	10.676	0.207	0.141	1.465	20.0
32514	20/05/94	11:31:57.00	1.666	201.8	4.014	68.34	33.96	39.33	-0.281	0.062	9.673	0.188	0.189	0.994	40.0
32514	20/05/94	11:32:23.00	1.665	201.4	4.007	68.31	34.02	39.19	-0.280	0.062	9.636	0.187	0.189	0.992	40.0
33514	20/05/94	11:35:05.00	1.663	202.3	4.024	68.10	34.15	38.93	-0.278	0.069	9.826	0.191	0.180	1.061	35.0
33514	20/05/94	11:36:30.00	1.662	202.6	4.031	68.03	34.22	38.76	-0.277	0.071	9.865	0.191	0.177	1.080	35.0
33514	20/05/94	11:37:57.00	1.662	204.4	4.067	68.12	34.27	38.68	-0.276	0.067	9.822	0.191	0.182	1.047	35.0
33514	20/05/94	11:39:06.00	1.665	199.3	3.965	68.40	34.27	38.80	-0.277	0.076	9.848	0.191	0.172	1.111	35.0
34514	20/05/94	11:41:06.00	1.657	204.0	4.059	68.19	34.24	38.55	-0.275	0.074	9.992	0.194	0.173	1.123	30.0
34514	20/05/94	11:43:37.00	1.659	199.0	3.960	68.30	34.33	38.47	-0.275	0.083	9.967	0.193	0.165	1.174	30.0
34514	20/05/94	11:44:08.00	1.660	201.4	4.006	68.31	34.31	38.56	-0.275	0.078	9.973	0.194	0.169	1.145	30.0
35514	20/05/94	11:46:53.00	1.660	203.3	4.044	68.38	34.39	38.45	-0.275	0.084	10.221	0.198	0.161	1.234	25.0
35514	20/05/94	11:47:27.00	1.663	202.7	4.033	68.55	34.46	38.46	-0.275	0.087	10.257	0.199	0.159	1.256	25.0
35514	20/05/94	11:48:35.00	1.663	201.1	4.001	68.53	34.52	38.38	-0.274	0.090	10.257	0.199	0.156	1.278	25.0
36514	20/05/94	11:50:24.00	1.660	199.1	3.962	68.96	34.61	38.12	-0.272	0.108	10.602	0.206	0.143	1.436	20.0
36514	20/05/94	11:51:14.00	1.663	196.7	3.913	68.99	34.70	38.10	-0.272	0.114	10.645	0.207	0.141	1.462	20.0
36514	20/05/94	11:52:10.00	1.665	198.4	3.948	69.03	34.79	38.03	-0.272	0.112	10.648	0.207	0.142	1.456	20.0

Table B.2-2: CHF Enhancement data with 18% spacers in Freon-134a (cont.'d)

RunID	Date	Time	P	m	G	T _w	T _{in}	ΔH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
41514	20/05/94	12:01:42.00	1.641	202.1	4.020	67.79	33.63	38.78	-0.276	0.064	9.645	0.187	0.188	0.996	40.0
42514	20/05/94	12:06:34.00	1.665	199.6	3.971	68.42	34.20	38.91	-0.278	0.077	9.906	0.192	0.171	1.123	30.0
42514	20/05/94	12:07:13.00	1.662	207.8	4.134	68.35	34.27	38.68	-0.276	0.065	9.925	0.193	0.184	1.046	30.0
42514	20/05/94	12:08:42.00	1.660	203.1	4.041	68.37	34.44	38.37	-0.274	0.075	9.934	0.193	0.172	1.121	30.0
43514	20/05/94	12:11:14.00	1.659	201.9	4.017	68.30	34.46	38.28	-0.273	0.086	10.175	0.197	0.159	1.239	25.0
43514	20/05/94	12:12:00.00	1.651	203.2	4.042	68.07	34.53	37.86	-0.270	0.088	10.197	0.198	0.157	1.259	25.0
43514	20/05/94	12:12:53.00	1.653	200.6	3.990	67.99	34.63	37.79	-0.269	0.093	10.191	0.198	0.154	1.289	25.0
44514	20/05/94	12:15:20.00	1.663	200.3	3.985	68.84	34.63	38.22	-0.273	0.106	10.624	0.206	0.144	1.435	20.0
44514	20/05/94	12:16:10.00	1.666	195.5	3.890	68.91	34.72	38.20	-0.273	0.117	10.672	0.207	0.140	1.475	20.0
45514	20/05/94	12:19:02.00	1.669	195.2	3.883	69.38	34.83	38.16	-0.273	0.143	11.341	0.220	0.132	1.669	15.0
45514	20/05/94	12:21:02.00	1.650	204.9	4.077	69.06	35.24	36.75	-0.262	0.137	11.488	0.223	0.133	1.672	15.0
45514	20/05/94	12:21:47.00	1.653	203.1	4.040	69.13	35.39	36.65	-0.261	0.144	11.554	0.224	0.132	1.701	15.0
51514	20/05/94	12:34:00.00	1.669	202.3	4.025	70.05	33.59	40.00	-0.286	0.075	10.226	0.198	0.172	1.157	30.0
51514	20/05/94	12:34:52.00	1.666	207.0	4.119	69.92	34.09	39.14	-0.280	0.075	10.281	0.200	0.170	1.175	30.0
51514	20/05/94	12:36:15.00	1.665	204.7	4.071	69.85	34.46	38.52	-0.275	0.082	10.224	0.198	0.163	1.217	30.0
52514	20/05/94	12:38:13.00	1.665	200.4	3.987	69.15	34.52	38.44	-0.275	0.098	10.465	0.203	0.148	1.376	25.0
52514	20/05/94	12:38:49.00	1.665	200.0	3.978	69.80	34.59	38.33	-0.274	0.095	10.336	0.201	0.151	1.328	25.0
52514	20/05/94	12:39:44.00	1.660	210.7	4.192	69.81	34.72	37.95	-0.271	0.081	10.391	0.202	0.159	1.270	25.0
52514	20/05/94	12:40:35.00	1.666	203.9	4.057	70.98	34.81	38.06	-0.272	0.089	10.310	0.200	0.155	1.295	25.0
52514	20/05/94	12:41:29.00	1.666	205.5	4.088	70.90	34.81	38.06	-0.272	0.084	10.245	0.199	0.159	1.249	25.0
53514	20/05/94	12:43:28.00	1.657	195.6	3.892	68.87	34.76	37.78	-0.270	0.115	10.537	0.205	0.137	1.495	20.0
53514	20/05/94	12:44:19.00	1.654	200.1	3.981	68.84	34.81	37.57	-0.268	0.111	10.630	0.206	0.142	1.450	20.0
53514	20/05/94	12:44:49.00	1.653	198.4	3.947	68.75	34.81	37.51	-0.267	0.116	10.670	0.207	0.141	1.469	20.0
53514	20/05/94	12:45:26.00	1.656	200.0	3.978	68.82	34.92	37.47	-0.267	0.113	10.670	0.207	0.141	1.465	20.0
54514	20/05/94	12:47:50.00	1.663	193.6	3.852	69.23	35.09	37.52	-0.268	0.149	11.297	0.219	0.131	1.672	15.0
54514	20/05/94	12:48:24.00	1.665	194.5	3.869	69.21	35.24	37.37	-0.267	0.148	11.289	0.219	0.131	1.671	15.0
54514	20/05/94	12:49:04.00	1.668	196.7	3.913	69.27	35.44	37.18	-0.266	0.146	11.319	0.220	0.131	1.675	15.0
51914	02/06/94	10:57:46.00	1.663	201.7	4.012	66.60	53.64	9.34	-0.067	0.210	7.811	0.152	0.117	1.300	30.0
51914	02/06/94	10:59:34.00	1.672	201.9	4.018	66.82	55.32	7.08	-0.051	0.222	7.704	0.150	0.113	1.325	30.0
51914	02/06/94	11:00:40.00	1.662	202.7	4.032	66.55	55.77	5.96	-0.043	0.227	7.662	0.149	0.114	1.308	30.0
51914	02/06/94	11:01:19.00	1.662	202.4	4.027	66.44	55.90	5.76	-0.041	0.228	7.630	0.148	0.114	1.303	30.0
51612	02/06/94	19:20:40.00	1.656	108.2	2.152	68.36	37.87	33.06	-0.236	0.129	5.536	0.107	0.107	1.004	30.0
53612	02/06/94	19:29:23.00	1.665	97.1	1.931	65.19	38.09	33.10	-0.237	0.193	5.830	0.113	0.114	0.992	20.0
53612	02/06/94	19:30:14.00	1.660	99.4	1.978	65.51	38.13	32.86	-0.235	0.187	5.868	0.114	0.115	0.987	20.0

Table B.2-3: CHF Enhancement data with 18% spacers in Freon-22

RunID	Date	Time	P	m	G	Tw	Tin	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
41124	24/11/94	16:01:21.00	1.897	200.6	3.991	60.17	13.28	46.26	-0.297	0.097	12.292	0.239	0.189	1.260	30.0
41124	24/11/94	16:02:10.00	1.889	200.1	3.981	60.11	13.27	46.02	-0.295	0.099	12.296	0.239	0.185	1.288	30.0
41124	24/11/94	16:03:02.00	1.889	201.4	4.006	60.18	13.30	46.01	-0.295	0.097	12.316	0.239	0.189	1.263	30.0
42124	24/11/94	16:16:31.00	1.904	200.8	3.996	60.39	13.32	46.47	-0.299	0.108	12.704	0.247	0.185	1.333	25.0
42124	24/11/94	16:17:15.00	1.901	201.0	3.998	60.40	13.35	46.33	-0.298	0.107	12.666	0.246	0.185	1.328	25.0
42124	24/11/94	16:17:59.00	1.901	201.2	4.002	60.45	13.37	46.30	-0.298	0.108	12.677	0.246	0.185	1.327	25.0
43124	24/11/94	16:29:21.00	1.880	200.5	3.989	60.64	13.45	45.51	-0.292	0.125	13.033	0.253	0.171	1.477	20.0
43124	24/11/94	16:32:56.00	1.878	200.7	3.993	60.33	13.58	45.29	-0.290	0.126	13.040	0.253	0.171	1.481	20.0
43124	24/11/94	16:33:30.00	1.877	200.7	3.993	60.36	13.57	45.26	-0.290	0.125	12.999	0.252	0.171	1.474	20.0
43124	24/11/94	16:34:11.00	1.874	200.3	3.985	60.40	13.58	45.16	-0.289	0.127	13.025	0.253	0.169	1.498	20.0
44124	24/11/94	16:45:24.00	1.906	201.2	4.002	61.74	14.00	45.72	-0.294	0.162	14.257	0.277	0.163	1.702	15.0
44124	24/11/94	16:46:09.00	1.907	201.1	4.000	61.78	14.05	45.70	-0.294	0.165	14.331	0.278	0.162	1.721	15.0
51124	24/11/94	17:03:34.00	1.904	200.1	3.981	62.20	14.41	45.20	-0.291	0.197	15.182	0.295	0.148	1.987	12.5
51124	24/11/94	17:06:23.00	1.897	200.1	3.982	62.14	14.51	44.80	-0.288	0.198	15.119	0.293	0.147	1.994	12.5
51124	24/11/94	17:07:38.00	1.900	200.0	3.980	62.16	14.56	44.86	-0.289	0.199	15.173	0.295	0.147	2.005	12.5
41524	28/11/94	16:17:03.00	1.841	205.8	4.095	58.85	28.50	25.85	-0.164	0.179	11.104	0.216	0.156	1.379	30.0
41524	28/11/94	16:19:19.00	1.888	207.1	4.119	59.65	28.68	27.19	-0.174	0.171	11.145	0.216	0.170	1.273	30.0
41524	28/11/94	16:20:18.00	1.883	206.7	4.113	59.51	28.75	26.95	-0.173	0.171	11.086	0.215	0.168	1.278	30.0
41524	28/11/94	16:22:47.00	1.891	202.6	4.030	59.86	28.98	26.91	-0.173	0.179	11.091	0.215	0.158	1.366	30.0
42524	28/11/94	16:28:11.00	1.901	201.8	4.014	59.86	29.12	27.06	-0.174	0.187	11.313	0.220	0.155	1.417	25.0
42524	28/11/94	16:29:48.00	1.900	201.6	4.011	59.81	29.22	26.89	-0.173	0.189	11.351	0.220	0.154	1.435	25.0
42524	28/11/94	16:30:27.00	1.898	201.6	4.011	59.84	29.25	26.82	-0.172	0.189	11.335	0.220	0.153	1.435	25.0
42524	28/11/94	16:30:57.00	1.898	200.7	3.993	59.81	29.27	26.79	-0.172	0.190	11.307	0.219	0.151	1.454	25.0
43524	28/11/94	16:39:33.00	1.909	200.1	3.981	60.57	28.26	28.41	-0.183	0.211	12.253	0.238	0.145	1.639	20.0
43524	28/11/94	16:41:43.00	1.900	201.6	4.011	60.38	28.28	28.09	-0.181	0.208	12.168	0.236	0.148	1.594	20.0
43524	28/11/94	16:42:47.00	1.901	202.1	4.021	60.37	28.30	28.10	-0.181	0.210	12.263	0.238	0.149	1.597	20.0
54524	28/11/94	16:56:54.00	1.909	202.0	4.019	60.72	28.68	27.86	-0.180	0.218	12.469	0.242	0.148	1.639	17.5
54524	28/11/94	16:58:16.00	1.903	201.8	4.015	60.78	28.58	27.81	-0.179	0.221	12.530	0.243	0.146	1.670	17.5
54524	28/11/94	16:58:50.00	1.904	201.3	4.004	60.85	28.59	27.86	-0.179	0.219	12.467	0.242	0.145	1.670	17.5
47524	28/11/94	17:14:10.00	1.894	202.5	4.029	60.39	28.07	28.14	-0.181	0.211	12.364	0.240	0.148	1.620	19.0
47524	28/11/94	17:14:36.00	1.891	201.8	4.015	60.46	28.13	27.95	-0.179	0.216	12.432	0.241	0.145	1.665	19.0
47524	28/11/94	17:15:23.00	1.892	202.4	4.026	60.55	28.22	27.91	-0.179	0.215	12.412	0.241	0.147	1.641	19.0
47524	28/11/94	17:15:54.00	1.892	202.4	4.027	60.49	28.24	27.89	-0.179	0.214	12.395	0.241	0.147	1.637	19.0
41924	28/11/94	18:34:10.00	1.904	202.3	4.024	63.40	47.57	2.54	-0.016	0.270	9.001	0.175	0.135	1.294	35.0
41924	28/11/94	18:35:09.00	1.901	202.2	4.024	63.19	47.76	2.16	-0.014	0.274	9.045	0.176	0.134	1.313	35.0
41924	28/11/94	18:36:08.00	1.901	201.5	4.008	63.61	47.97	1.91	-0.012	0.276	9.025	0.175	0.131	1.332	35.0
42924	28/11/94	18:42:43.00	1.903	201.7	4.012	58.51	47.85	2.13	-0.014	0.281	9.222	0.179	0.131	1.365	30.0
42924	28/11/94	18:43:24.00	1.900	201.2	4.004	58.45	47.87	2.00	-0.013	0.283	9.247	0.179	0.129	1.387	30.0
42924	28/11/94	18:43:59.00	1.901	200.6	3.990	58.29	47.97	1.96	-0.013	0.283	9.232	0.179	0.128	1.401	30.0
54294	28/11/94	19:01:29.00	1.900	200.0	3.979	58.47	48.08	1.70	-0.011	0.293	9.444	0.183	0.125	1.471	27.5
54294	28/11/94	19:02:37.00	1.889	200.6	3.991	58.27	48.35	0.99	-0.006	0.294	9.398	0.182	0.124	1.469	27.5
54294	28/11/94	19:03:42.00	1.888	200.6	3.990	58.23	48.42	0.84	-0.005	0.295	9.379	0.182	0.124	1.470	27.5
45924	28/11/94	19:10:29.00	1.868	202.1	4.020	57.54	47.30	1.75	-0.011	0.282	9.283	0.180	0.127	1.420	29.0
45924	28/11/94	19:12:08.00	1.868	201.5	4.009	57.62	47.23	1.82	-0.012	0.284	9.323	0.181	0.125	1.443	29.0
45924	28/11/94	19:13:00.00	1.877	202.1	4.020	57.79	47.21	2.12	-0.014	0.281	9.284	0.180	0.129	1.402	29.0
41724	28/11/94	19:22:17.00	1.878	202.3	4.024	58.47	38.33	14.32	-0.092	0.222	9.897	0.192	0.143	1.348	35.0
41724	28/11/94	19:23:51.00	1.898	203.1	4.041	58.81	38.32	14.98	-0.096	0.218	9.939	0.193	0.148	1.299	35.0
41724	28/11/94	19:24:29.00	1.884	202.8	4.034	58.68	38.33	14.51	-0.093	0.221	9.939	0.193	0.145	1.333	35.0
42724	28/11/94	19:28:15.00	1.884	201.8	4.015	58.55	38.12	14.79	-0.095	0.225	10.073	0.196	0.142	1.381	30.0
42724	28/11/94	19:28:50.00	1.884	201.5	4.009	58.57	38.14	14.78	-0.095	0.227	10.116	0.196	0.140	1.398	30.0
42724	28/11/94	19:29:47.00	1.888	201.3	4.005	58.59	38.17	14.83	-0.095	0.228	10.144	0.197	0.140	1.404	30.0
43724	28/11/94	19:33:12.00	1.903	199.9	3.976	59.01	38.36	15.08	-0.097	0.242	10.521	0.204	0.136	1.504	25.0
43724	28/11/94	19:34:07.00	1.894	202.1	4.021	58.88	38.36	14.79	-0.095	0.241	10.568	0.205	0.140	1.468	25.0
43724	28/11/94	19:34:50.00	1.886	201.8	4.015	58.85	38.44	14.42	-0.092	0.243	10.556	0.205	0.137	1.491	25.0
46724	28/11/94	20:00:49.00	1.889	201.2	4.003	59.11	38.40	14.58	-0.094	0.249	10.733	0.208	0.135	1.541	24.0

Table B.2-3: CHF Enhancement data with 18% spacers in Freon-22 (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHF _R	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kJ/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
46724	28/11/94	20:01:28.00	1.889	201.5	4.009	59.13	38.47	14.47	-0.093	0.249	10.727	0.208	0.136	1.533	24.0
46724	28/11/94	20:02:29.00	1.884	201.0	3.998	59.17	38.63	14.12	-0.091	0.249	10.644	0.207	0.134	1.543	24.0
46724	28/11/94	20:05:15.00	1.889	201.0	3.999	59.18	38.81	14.04	-0.090	0.250	10.660	0.207	0.134	1.539	24.0
41324	28/11/94	20:20:45.00	1.875	201.3	4.004	59.58	22.60	34.35	-0.220	0.153	11.709	0.227	0.161	1.412	25.0
41324	28/11/94	20:21:48.00	1.919	203.0	4.038	60.33	22.36	36.08	-0.233	0.143	11.809	0.229	0.177	1.296	25.0
41324	28/11/94	20:22:29.00	1.912	202.7	4.033	60.34	22.28	35.98	-0.232	0.145	11.862	0.230	0.174	1.326	25.0
41324	28/11/94	20:23:05.00	1.898	202.1	4.021	60.15	22.21	35.58	-0.229	0.145	11.753	0.228	0.170	1.343	25.0
42324	28/11/94	20:26:26.00	1.904	199.7	3.974	60.45	22.09	35.94	-0.231	0.163	12.250	0.238	0.158	1.501	20.0
42324	28/11/94	20:27:13.00	1.904	203.1	4.040	60.60	22.17	35.82	-0.231	0.163	12.416	0.241	0.166	1.449	20.0
42324	28/11/94	20:27:51.00	1.906	202.8	4.034	60.62	22.30	35.75	-0.230	0.164	12.420	0.241	0.166	1.456	20.0
43324	28/11/94	20:31:56.00	1.903	199.2	3.963	62.01	22.47	35.41	-0.228	0.183	12.726	0.247	0.150	1.643	17.5
43324	28/11/94	20:33:15.00	1.895	202.2	4.022	62.47	22.57	35.04	-0.225	0.184	12.864	0.250	0.156	1.603	17.5
43324	28/11/94	20:34:26.00	1.891	202.0	4.019	61.74	22.75	34.68	-0.223	0.186	12.846	0.249	0.154	1.619	17.5
41024	29/11/94	10:32:44.00	1.900	202.1	4.021	63.38	11.97	47.85	-0.308	0.093	12.599	0.245	0.196	1.250	35.0
41024	29/11/94	10:33:44.00	1.901	202.1	4.020	62.80	11.99	47.90	-0.308	0.092	12.570	0.244	0.197	1.241	35.0
41024	29/11/94	10:35:11.00	1.904	201.9	4.017	64.13	11.99	47.99	-0.309	0.093	12.611	0.245	0.196	1.247	35.0
42024	29/11/94	10:40:47.00	1.897	201.4	4.006	67.93	11.98	47.76	-0.307	0.098	12.700	0.246	0.190	1.297	30.0
42024	29/11/94	10:41:30.00	1.898	201.1	4.001	68.08	11.98	47.79	-0.307	0.099	12.700	0.247	0.190	1.299	30.0
43024	29/11/94	10:45:20.00	1.903	201.5	4.008	65.40	12.06	47.85	-0.308	0.109	13.057	0.253	0.186	1.365	25.0
43024	29/11/94	10:46:29.00	1.900	201.2	4.003	64.82	12.13	47.67	-0.307	0.112	13.097	0.254	0.183	1.390	25.0
43024	29/11/94	10:47:06.00	1.904	202.1	4.021	67.21	12.15	47.79	-0.308	0.110	13.120	0.255	0.187	1.362	25.0
44024	29/11/94	10:50:39.00	1.897	200.9	3.998	61.99	12.19	47.51	-0.305	0.126	13.476	0.262	0.175	1.494	20.0
44024	29/11/94	10:51:27.00	1.901	200.9	3.997	62.04	12.24	47.59	-0.306	0.124	13.443	0.261	0.176	1.479	20.0
44024	29/11/94	10:52:24.00	1.903	201.6	4.012	61.97	12.29	47.57	-0.306	0.123	13.452	0.261	0.179	1.458	20.0
45024	29/11/94	10:59:15.00	1.915	201.6	4.010	62.39	12.37	47.87	-0.309	0.141	14.071	0.273	0.173	1.578	15.0
45024	29/11/94	11:00:08.00	1.892	201.7	4.012	62.08	12.45	47.03	-0.302	0.146	14.069	0.273	0.167	1.632	15.0
45024	29/11/94	11:01:04.00	1.897	201.1	4.001	62.11	12.56	47.06	-0.302	0.149	14.124	0.274	0.166	1.655	15.0
47024	29/11/94	11:17:16.00	1.880	200.6	3.992	62.35	12.64	46.42	-0.297	0.168	14.584	0.283	0.155	1.829	14.0
47024	29/11/94	11:17:59.00	1.872	201.1	4.001	62.25	12.71	46.11	-0.295	0.166	14.482	0.281	0.155	1.808	14.0
47024	29/11/94	11:19:47.00	1.915	203.0	4.038	62.78	12.84	47.34	-0.305	0.151	14.356	0.279	0.173	1.615	14.0
47024	29/11/94	11:20:28.00	1.907	202.6	4.031	62.72	12.80	47.14	-0.304	0.153	14.363	0.279	0.170	1.644	14.0
47024	29/11/94	11:21:09.00	1.900	202.3	4.026	62.68	12.79	46.89	-0.302	0.156	14.384	0.279	0.167	1.676	14.0
41124	26/01/95	19:01:22.00	1.895	201.2	4.002	61.96	7.37	52.83	-0.339	0.113	14.149	0.275	0.182	1.512	20.0
41124	26/01/95	19:02:17.00	1.884	200.8	3.995	61.59	7.53	52.27	-0.335	0.114	14.073	0.273	0.178	1.536	20.0
41124	26/01/95	19:03:00.00	1.871	200.9	3.997	61.33	7.60	51.74	-0.331	0.113	13.956	0.271	0.176	1.540	20.0
41124	26/01/95	19:03:53.00	1.880	200.8	3.996	61.47	7.70	51.97	-0.333	0.113	13.990	0.272	0.178	1.530	20.0
42124	26/01/95	19:08:07.00	1.878	200.9	3.998	61.83	7.71	51.88	-0.332	0.134	14.615	0.284	0.168	1.686	15.0
42124	26/01/95	19:09:28.00	1.877	201.9	4.017	61.80	7.87	51.62	-0.331	0.135	14.681	0.285	0.170	1.681	15.0
42124	26/01/95	19:10:28.00	1.862	201.6	4.011	61.58	7.96	51.04	-0.326	0.134	14.534	0.282	0.166	1.696	15.0
42124	26/01/95	19:11:40.00	1.880	201.7	4.013	61.71	7.99	51.57	-0.330	0.134	14.634	0.284	0.170	1.672	15.0
43124	26/01/95	19:15:52.00	1.900	200.5	3.988	62.47	8.01	52.23	-0.336	0.155	15.313	0.297	0.162	1.832	12.5
43124	26/01/95	19:16:30.00	1.880	199.8	3.975	62.19	8.04	51.54	-0.330	0.163	15.390	0.299	0.154	1.933	12.5
43124	26/01/95	19:17:52.00	1.859	209.4	4.166	62.16	8.27	50.60	-0.323	0.150	15.526	0.301	0.177	1.700	12.5
43124	26/01/95	19:18:42.00	1.877	201.5	4.009	62.29	8.34	51.10	-0.327	0.167	15.563	0.302	0.157	1.930	12.5
43125	26/01/95	19:37:56.00	1.839	251.5	5.004	63.15	8.93	49.19	-0.313	0.122	17.201	0.334	0.196	1.702	12.5
43125	26/01/95	19:39:02.00	1.825	251.3	4.999	62.68	9.69	47.90	-0.304	0.128	17.119	0.332	0.193	1.724	12.5
43125	26/01/95	19:41:41.00	1.875	252.7	5.028	63.67	9.98	49.17	-0.315	0.121	17.222	0.334	0.200	1.672	12.5
43125	26/01/95	19:42:46.00	1.869	251.8	5.009	63.78	10.02	48.89	-0.313	0.126	17.260	0.335	0.196	1.708	12.5
43125	26/01/95	19:43:38.00	1.862	252.1	5.015	63.78	10.09	48.60	-0.310	0.127	17.248	0.335	0.196	1.706	12.5
42125	26/01/95	19:46:49.00	1.821	255.5	5.083	62.39	9.86	47.53	-0.301	0.108	16.506	0.320	0.208	1.539	15.0
42125	26/01/95	19:48:10.00	1.889	255.7	5.086	63.64	9.88	49.77	-0.319	0.102	16.784	0.326	0.215	1.512	15.0
42125	26/01/95	19:49:35.00	1.865	254.7	5.067	63.33	9.95	48.89	-0.312	0.107	16.704	0.324	0.210	1.543	15.0
42125	26/01/95	19:51:19.00	1.874	255.5	5.082	63.61	9.93	49.19	-0.315	0.102	16.639	0.323	0.214	1.507	15.0
41125	26/01/95	19:53:33.00	1.881	253.2	5.037	63.19	9.87	49.51	-0.317	0.085	15.909	0.309	0.219	1.410	20.0
41125	26/01/95	19:54:56.00	1.865	253.0	5.033	67.97	9.69	49.19	-0.314	0.091	16.058	0.312	0.214	1.454	20.0

Table B.2-3: CHF Enhancement data with 18% spacers in Freon-22 (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DH _{in}	X _{in}	X _c	Power	CHF	CHF _{ref}	CHFR	SP
-	-	-	MPa	g/s	Mg/m ² s	C	C	kl/kg	-	-	kW	MW/m ²	MW/m ²	-	cm
41125	26/01/95	20:00:33.00	1.871	247.8	4.931	65.41	8.81	50.33	-0.322	0.089	15.919	0.309	0.205	1.506	20.0
41525	26/01/95	20:18:42.00	1.912	250.2	4.977	61.36	31.86	23.66	-0.153	0.194	13.432	0.261	0.169	1.543	20.0
41525	26/01/95	20:19:48.00	1.859	251.6	5.006	60.83	32.48	21.09	-0.135	0.206	13.447	0.261	0.172	1.520	20.0
41525	26/01/95	20:20:29.00	1.847	251.7	5.008	60.80	32.74	20.41	-0.130	0.212	13.519	0.262	0.171	1.536	20.0
44525	26/01/95	20:39:11.00	1.889	252.3	5.020	60.84	32.28	22.40	-0.144	0.179	12.702	0.247	0.179	1.377	25.0
44525	26/01/95	20:39:52.00	1.874	251.7	5.007	60.29	32.51	21.62	-0.138	0.185	12.728	0.247	0.177	1.399	25.0
44525	26/01/95	20:40:30.00	1.868	250.1	4.975	60.14	32.74	21.15	-0.135	0.190	12.737	0.247	0.172	1.435	25.0
44125	31/01/95	11:24:24.00	1.904	251.9	5.011	63.60	8.69	51.60	-0.332	0.064	15.519	0.301	0.232	1.297	25.0
44125	31/01/95	11:25:54.00	1.891	252.0	5.013	63.36	8.89	50.97	-0.327	0.065	15.387	0.299	0.231	1.292	25.0
44125	31/01/95	11:26:29.00	1.884	252.1	5.015	63.29	8.91	50.73	-0.325	0.067	15.429	0.299	0.229	1.308	25.0
44125	31/01/95	11:27:23.00	1.875	252.3	5.020	63.07	8.98	50.36	-0.322	0.066	15.327	0.297	0.229	1.297	25.0
43525	31/01/95	11:38:56.00	1.875	254.1	5.054	60.54	31.12	23.49	-0.150	0.170	12.718	0.247	0.186	1.330	25.0
43525	31/01/95	11:40:32.00	1.866	253.3	5.040	60.42	31.28	22.99	-0.147	0.175	12.772	0.248	0.183	1.356	25.0
43525	31/01/95	11:41:40.00	1.900	255.2	5.078	60.91	31.24	24.16	-0.155	0.167	12.775	0.248	0.189	1.315	25.0
43525	31/01/95	11:43:43.00	1.898	251.8	5.009	60.75	33.53	21.14	-0.136	0.185	12.580	0.244	0.176	1.390	25.0
43525	31/01/95	11:44:21.00	1.892	251.9	5.011	60.76	33.70	20.74	-0.133	0.187	12.539	0.243	0.176	1.384	25.0
44525	31/01/95	11:50:29.00	1.854	255.4	5.081	59.91	33.05	20.31	-0.130	0.171	12.025	0.233	0.188	1.240	30.0
44525	31/01/95	11:52:14.00	1.898	253.2	5.037	60.54	33.14	21.64	-0.139	0.161	11.823	0.229	0.186	1.234	30.0
44525	31/01/95	11:53:07.00	1.888	253.4	5.041	60.52	33.22	21.18	-0.136	0.164	11.861	0.230	0.186	1.240	30.0
41123	31/01/95	13:16:33.00	1.889	150.6	2.995	60.04	5.62	54.59	-0.350	0.119	11.006	0.214	0.178	1.200	30.0
41123	31/01/95	13:18:48.00	1.871	150.9	3.003	59.32	5.65	53.95	-0.345	0.116	10.880	0.211	0.177	1.191	30.0
41123	31/01/95	13:19:12.00	1.868	151.1	3.006	59.29	5.68	53.85	-0.344	0.119	10.956	0.213	0.175	1.212	30.0
41123	31/01/95	13:20:28.00	1.856	150.8	3.001	59.12	5.70	53.43	-0.341	0.122	10.951	0.213	0.173	1.227	30.0
42123	31/01/95	13:24:14.00	1.904	150.9	3.001	59.81	5.73	55.00	-0.354	0.123	11.170	0.217	0.177	1.226	25.0
42123	31/01/95	13:24:48.00	1.897	151.3	3.010	59.77	5.72	54.76	-0.352	0.124	11.196	0.217	0.176	1.238	25.0
42123	31/01/95	13:26:19.00	1.884	150.8	3.000	59.52	5.75	54.31	-0.348	0.125	11.124	0.216	0.175	1.234	25.0
43123	31/01/95	13:27:53.00	1.875	150.3	2.990	59.42	5.70	54.04	-0.346	0.127	11.100	0.215	0.174	1.239	20.0
43123	31/01/95	13:28:36.00	1.869	150.0	2.984	59.40	5.70	53.85	-0.344	0.132	11.182	0.217	0.172	1.265	20.0
43123	31/01/95	13:30:28.00	1.895	153.7	3.057	59.92	5.75	54.65	-0.351	0.121	11.304	0.219	0.174	1.260	20.0
43123	31/01/95	13:31:23.00	1.895	153.8	3.060	59.84	5.76	54.62	-0.351	0.122	11.331	0.220	0.174	1.267	20.0
44123	31/01/95	13:34:41.00	1.910	149.0	2.964	60.33	5.81	55.05	-0.355	0.163	11.973	0.232	0.159	1.457	15.0
44123	31/01/95	13:35:31.00	1.894	151.5	3.014	60.25	5.77	54.53	-0.350	0.163	12.108	0.235	0.159	1.479	15.0
44123	31/01/95	13:36:19.00	1.894	152.0	3.023	60.17	5.82	54.50	-0.350	0.164	12.170	0.236	0.158	1.494	15.0
44123	31/01/95	13:38:28.00	1.878	151.1	3.007	59.95	5.90	53.90	-0.345	0.173	12.228	0.237	0.156	1.520	15.0
44123	31/01/95	13:39:30.00	1.869	153.0	3.043	59.76	5.94	53.57	-0.343	0.167	12.186	0.237	0.157	1.508	15.0
45123	31/01/95	13:44:24.00	1.906	152.9	3.041	60.09	6.03	54.69	-0.352	0.150	11.912	0.231	0.163	1.419	17.5
45123	31/01/95	13:45:18.00	1.886	151.5	3.013	60.04	5.97	54.09	-0.347	0.158	11.933	0.232	0.161	1.439	17.5
45123	31/01/95	13:46:04.00	1.886	151.9	3.022	60.04	5.94	54.10	-0.347	0.157	11.932	0.232	0.161	1.437	17.5
46123	31/01/95	13:50:43.00	1.897	150.9	3.003	63.33	5.92	54.49	-0.350	0.210	13.165	0.256	0.142	1.803	12.5
45523	31/01/95	14:21:04.00	1.869	152.5	3.033	58.19	37.92	14.31	-0.091	0.294	9.197	0.179	0.122	1.467	22.5
45523	31/01/95	14:21:57.00	1.865	151.8	3.020	57.95	38.07	14.00	-0.089	0.299	9.222	0.179	0.122	1.470	22.5
45523	31/01/95	14:23:52.00	1.892	153.0	3.043	58.25	38.07	14.85	-0.095	0.292	9.235	0.179	0.117	1.534	22.5
45523	31/01/95	14:24:54.00	1.881	152.2	3.029	58.07	38.19	14.51	-0.093	0.293	9.160	0.178	0.120	1.487	22.5
46523	31/01/95	14:26:39.00	1.862	152.8	3.041	57.77	38.13	13.79	-0.088	0.285	8.929	0.173	0.125	1.385	25.0
46523	31/01/95	14:27:34.00	1.915	154.3	3.070	58.77	37.34	16.61	-0.107	0.276	9.166	0.178	0.115	1.549	25.0
46523	31/01/95	14:28:37.00	1.897	153.4	3.052	58.61	37.52	15.72	-0.101	0.281	9.110	0.177	0.119	1.488	25.0
46523	31/01/95	14:29:41.00	1.886	153.1	3.046	58.32	37.53	15.50	-0.099	0.281	9.074	0.176	0.121	1.450	25.0
47523	31/01/95	14:32:22.00	1.848	154.6	3.075	57.20	37.15	14.66	-0.093	0.264	8.683	0.169	0.131	1.289	30.0
47523	31/01/95	14:33:44.00	1.903	154.4	3.071	58.03	37.04	16.58	-0.107	0.255	8.676	0.168	0.125	1.349	30.0
47523	31/01/95	14:34:28.00	1.897	153.9	3.061	57.95	37.23	16.16	-0.104	0.257	8.643	0.168	0.126	1.335	30.0
47523	31/01/95	14:35:19.00	1.892	153.9	3.063	57.87	37.36	15.86	-0.102	0.259	8.660	0.168	0.126	1.335	30.0
41323	31/01/95	14:44:01.00	1.897	151.7	3.017	58.14	26.12	30.52	-0.196	0.200	9.353	0.182	0.145	1.253	30.0
41323	31/01/95	14:44:37.00	1.892	151.3	3.009	58.07	26.17	30.25	-0.194	0.200	9.282	0.180	0.146	1.235	30.0
41323	31/01/95	14:45:18.00	1.883	151.4	3.011	58.09	26.23	29.89	-0.192	0.201	9.270	0.180	0.146	1.229	30.0
42323	31/01/95	14:47:54.00	1.886	150.8	3.001	58.02	26.47	29.71	-0.191	0.222	9.692	0.188	0.140	1.347	25.0

Table B.2-3: CHF Enhancement data with 18% spacers in Freon-22 (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DHin	Xin	Xc	Power	CHF	CHFref	CHFR	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
42323	31/01/95	14:48:42.00	1.878	150.4	2.991	58.02	26.32	29.65	-0.190	0.223	9.701	0.188	0.140	1.342	25.0
42323	31/01/95	14:49:38.00	1.907	154.6	3.076	58.57	26.04	30.97	-0.199	0.209	9.792	0.190	0.139	1.366	25.0
43323	31/01/95	14:51:53.00	1.903	150.5	2.994	58.88	26.34	30.44	-0.196	0.247	10.351	0.201	0.128	1.566	20.0
43323	31/01/95	14:54:18.00	1.888	150.7	2.998	58.72	26.64	29.51	-0.189	0.252	10.354	0.201	0.130	1.544	20.0
43323	31/01/95	14:56:23.00	1.869	149.3	2.971	58.38	26.82	28.70	-0.184	0.258	10.303	0.200	0.132	1.512	20.0
42425	31/01/95	15:40:54.00	1.909	250.5	4.984	60.17	39.86	13.11	-0.084	0.228	12.157	0.236	0.161	1.466	25.0
42425	31/01/95	15:42:03.00	1.910	251.2	4.998	60.27	41.26	11.31	-0.073	0.233	11.923	0.231	0.161	1.436	25.0
42425	31/01/95	15:43:13.00	1.904	250.3	4.979	60.27	41.95	10.09	-0.065	0.237	11.737	0.228	0.159	1.434	25.0
42425	31/01/95	15:44:06.00	1.906	249.7	4.968	60.32	42.31	9.65	-0.062	0.241	11.768	0.228	0.157	1.458	25.0
43425	31/01/95	15:45:58.00	1.872	250.6	4.986	59.78	42.52	8.28	-0.053	0.236	11.313	0.220	0.162	1.351	30.0
43425	31/01/95	15:47:06.00	1.859	250.1	4.976	59.37	42.49	7.93	-0.051	0.235	11.179	0.217	0.163	1.334	30.0
43425	31/01/95	15:48:41.00	1.880	251.0	4.993	59.71	42.35	8.82	-0.057	0.232	11.300	0.219	0.164	1.341	30.0
43425	31/01/95	15:49:41.00	1.868	250.9	4.992	59.58	42.30	8.43	-0.054	0.233	11.272	0.219	0.164	1.335	30.0
43425	31/01/95	15:51:15.00	1.856	250.5	4.984	59.29	42.37	7.97	-0.051	0.235	11.234	0.218	0.163	1.335	30.0
41123	01/02/95	10:15:23.00	1.915	151.9	3.022	61.01	16.10	43.31	-0.279	0.110	9.165	0.235	0.183	1.289	25.0
41123	01/02/95	10:17:06.00	1.904	151.5	3.015	60.46	16.59	42.41	-0.273	0.108	8.977	0.230	0.183	1.258	25.0
41123	01/02/95	10:18:06.00	1.897	151.1	3.007	60.40	16.72	41.98	-0.270	0.110	8.935	0.229	0.182	1.260	25.0
41123	01/02/95	10:27:22.00	1.906	152.6	3.037	60.93	15.51	43.73	-0.282	0.105	9.162	0.235	0.184	1.280	25.0
41123	01/02/95	10:28:03.00	1.903	152.4	3.032	60.81	15.95	43.13	-0.278	0.102	8.993	0.231	0.185	1.247	25.0
41123	01/02/95	10:28:33.00	1.903	152.2	3.027	60.75	16.23	42.80	-0.275	0.106	9.026	0.232	0.183	1.264	25.0
41023	01/02/95	10:42:19.00	1.859	154.1	3.066	61.15	5.94	53.20	-0.340	0.087	10.295	0.264	0.184	1.439	20.0
41023	01/02/95	10:45:39.00	1.906	154.4	3.072	62.14	5.98	54.69	-0.352	0.084	10.453	0.268	0.193	1.390	20.0
41023	01/02/95	10:46:57.00	1.891	154.2	3.067	62.00	5.97	54.23	-0.348	0.086	10.433	0.268	0.190	1.413	20.0
42023	01/02/95	10:49:43.00	1.881	151.8	3.020	61.90	5.93	53.97	-0.346	0.105	10.674	0.274	0.182	1.503	15.0
42023	01/02/95	10:50:22.00	1.884	152.2	3.028	61.86	5.97	54.06	-0.347	0.102	10.651	0.273	0.183	1.490	15.0
42023	01/02/95	10:52:05.00	1.909	152.2	3.029	62.46	5.94	54.85	-0.353	0.102	10.759	0.276	0.186	1.485	15.0
43023	01/02/95	10:55:32.00	1.886	150.8	2.999	62.15	5.95	54.10	-0.347	0.112	10.787	0.277	0.181	1.532	12.5
43023	01/02/95	10:57:41.00	1.897	153.2	3.047	62.50	5.95	54.42	-0.350	0.112	11.007	0.283	0.179	1.579	12.5
43023	01/02/95	10:58:46.00	1.888	152.7	3.039	62.32	6.01	54.11	-0.347	0.112	10.933	0.281	0.179	1.571	12.5
44023	01/02/95	11:02:15.00	1.875	154.6	3.075	62.70	5.98	53.73	-0.344	0.125	11.326	0.291	0.170	1.707	10.0
44023	01/02/95	11:03:28.00	1.901	154.9	3.082	63.15	6.04	54.49	-0.351	0.126	11.477	0.295	0.171	1.720	10.0
44023	01/02/95	11:04:32.00	1.892	154.3	3.070	63.02	6.07	54.15	-0.348	0.129	11.466	0.294	0.170	1.731	10.0
46023	01/02/95	11:15:15.00	1.900	153.1	3.047	61.50	5.30	55.29	-0.356	0.081	10.391	0.267	0.195	1.365	25.0
46023	01/02/95	11:15:55.00	1.889	153.0	3.044	61.42	5.42	54.79	-0.352	0.084	10.397	0.267	0.192	1.392	25.0
46023	01/02/95	11:17:29.00	1.904	152.8	3.040	62.01	5.67	55.04	-0.354	0.084	10.406	0.267	0.195	1.372	25.0
41024	01/02/95	11:23:13.00	1.912	204.2	4.062	64.45	7.06	53.72	-0.346	0.044	12.376	0.318	0.247	1.286	25.0
41024	01/02/95	11:24:22.00	1.894	203.4	4.046	64.23	7.15	53.01	-0.341	0.050	12.350	0.317	0.234	1.356	25.0
41024	01/02/95	11:25:22.00	1.884	203.4	4.047	64.07	7.22	52.67	-0.338	0.051	12.325	0.316	0.230	1.374	25.0
42024	01/02/95	11:28:00.00	1.875	206.1	4.100	64.16	7.30	52.30	-0.335	0.059	12.683	0.326	0.226	1.441	20.0
42024	01/02/95	11:28:29.00	1.871	206.2	4.102	64.08	7.29	52.11	-0.333	0.059	12.635	0.324	0.225	1.438	20.0
42024	01/02/95	11:29:17.00	1.860	205.9	4.097	63.95	7.35	51.68	-0.330	0.060	12.565	0.323	0.221	1.457	20.0
42024	01/02/95	11:30:17.00	1.894	206.6	4.109	64.45	7.42	52.73	-0.339	0.055	12.670	0.325	0.236	1.380	20.0
43024	01/02/95	11:32:51.00	1.889	204.7	4.072	64.72	7.45	52.54	-0.337	0.069	12.947	0.332	0.217	1.531	15.0
43024	34731	11:33:41.00	1.889	204.8	4.075	64.67	7.49	52.52	-0.337	0.068	12.924	0.332	0.218	1.519	15.0
43024	34731	11:34:58.00	1.895	208.3	4.144	65.05	7.54	52.65	-0.338	0.068	13.162	0.338	0.228	1.479	15.0
44024	34731	11:37:40.00	1.897	207.4	4.126	64.91	7.64	52.55	-0.338	0.076	13.344	0.343	0.220	1.556	12.5
44024	34731	11:38:19.00	1.884	206.8	4.114	64.78	7.64	52.15	-0.334	0.077	13.257	0.340	0.215	1.583	12.5
44024	34731	11:38:55.00	1.880	206.7	4.111	64.70	7.67	51.98	-0.333	0.078	13.248	0.340	0.213	1.598	12.5
45024	34731	11:41:23.00	1.904	204.0	4.058	65.58	7.69	52.74	-0.340	0.093	13.695	0.352	0.202	1.744	10.0
45024	34731	11:42:08.00	1.898	206.4	4.107	65.60	7.72	52.52	-0.338	0.092	13.792	0.354	0.207	1.712	10.0
45024	34731	11:42:53.00	1.892	206.1	4.100	65.55	7.78	52.27	-0.336	0.093	13.757	0.353	0.204	1.732	10.0
41025	34731	14:00:10.00	1.919	256.4	5.101	66.71	8.46	52.36	-0.338	0.024	14.380	0.369	0.299	1.235	25.0
41025	34731	14:00:53.00	1.906	256.5	5.103	66.56	8.61	51.72	-0.333	0.029	14.431	0.370	0.286	1.296	25.0
41025	34731	14:06:26.00	1.865	256.8	5.110	65.45	8.38	50.64	-0.324	0.030	14.218	0.365	0.277	1.316	25.0
42025	34731	14:10:15.00	1.924	255.0	5.074	67.02	8.63	52.37	-0.338	0.037	14.814	0.380	0.272	1.398	20.0

Table B.2-3: CHF Enhancement data with 18% spacers in Freon-22 (cont.'d)

RunID	Date	Time	P	m	G	Tw	Tin	DHin	Xin	Xc	Power	CHF	CHFref	CHFR	SP
-	-	-	MPa	g/s	Mg/m2s	C	C	kJ/kg	-	-	kW	MW/m2	MW/m2	-	cm
42025	34731	14:11:08.00	1.915	255.4	5.082	67.25	8.77	51.88	-0.335	0.036	14.676	0.377	0.273	1.378	20.0
42025	34731	14:12:01.00	1.895	256.9	5.111	67.03	8.89	51.13	-0.329	0.040	14.734	0.378	0.268	1.410	20.0
43025	34731	14:14:19.00	1.912	256.1	5.095	67.27	9.04	51.49	-0.332	0.053	15.295	0.393	0.253	1.551	15.0
43025	34731	14:17:00.00	1.884	254.0	5.053	66.68	8.96	50.69	-0.325	0.057	15.145	0.389	0.241	1.610	15.0
43025	34731	14:18:30.00	1.869	255.5	5.084	66.46	9.09	50.02	-0.320	0.060	15.159	0.389	0.241	1.613	15.0
43025	34731	14:20:40.00	1.912	256.0	5.092	67.19	9.06	51.44	-0.332	0.055	15.342	0.394	0.251	1.570	15.0
44025	34731	14:23:19.00	1.903	254.4	5.060	67.60	9.20	50.97	-0.328	0.065	15.549	0.399	0.237	1.685	12.5
44025	34731	14:24:24.00	1.884	261.1	5.194	67.52	9.39	50.20	-0.322	0.064	15.691	0.403	0.252	1.599	12.5
44025	34731	14:25:33.00	1.880	258.0	5.133	67.39	9.44	49.96	-0.320	0.067	15.604	0.401	0.241	1.659	12.5
45025	34731	14:27:40.00	1.884	256.1	5.095	67.48	9.39	50.17	-0.322	0.077	15.932	0.409	0.231	1.773	10.0
45025	34731	14:28:25.00	1.874	255.2	5.076	67.57	9.44	49.80	-0.319	0.080	15.885	0.408	0.226	1.803	10.0
45025	34731	14:29:03.00	1.865	255.5	5.083	67.42	9.52	49.41	-0.316	0.079	15.791	0.405	0.226	1.790	10.0
45025	34731	14:29:51.00	1.892	255.7	5.087	67.85	9.56	50.22	-0.323	0.078	15.931	0.409	0.230	1.777	10.0

B.3 CHF Analysis

B.3.1 Analysis Procedures

Although the analysis procedures used to derive the non-measured (calculated) data in Tables B.2-1 through B.2-3 are well described in Doerffer et al. (1995), a few relations are introduced for use in the error analysis to follow.

- Inlet subcooling: a positive number, indicating the degree to which the inlet fluid is subcooled (i.e., below saturation temperature):

$$H_{\text{sub}} = H_f(P) - H_f(T_{\text{in}}) \quad (\text{B.1})$$

where $H_f(T_{\text{in}})$ is the saturated liquid enthalpy (J/kg) based on temperature (T_{in}), and $H_f(P)$ is the saturated liquid enthalpy based on outlet pressure (P). The fluid enthalpy is assumed to be independent of pressure, and the effect of pressure-drop (across the test-section) to be small.

- Inlet quality:

$$X_{\text{in}} = \frac{-H_{\text{sub}}}{H_{\text{fg}}(P)} = \frac{-H_{\text{sub}}}{H_g(P) - H_f(P)} \quad (\text{B.2})$$

$H_{\text{fg}}(P)$ is the enthalpy of vaporization and $H_g(P)$ the saturated vapour enthalpy, which are both functions of outlet pressure.

- Critical quality: similar to inlet quality,

$$X_c = \frac{H_{\text{out}} - H_f(P)}{H_{\text{fg}}(P)} \quad (\text{B.3})$$

From an energy balance:

$$Q = \dot{m} [H_f(T_{\text{out}}) - H_f(T_{\text{in}})] \quad (\text{B.4})$$

$$H_f(T_{\text{out}}) = H_f(T_{\text{in}}) + \frac{Q}{\dot{m}} \quad (\text{B.5})$$

Therefore,

$$X_c = \frac{H_f(T_{in}) + \frac{Q_c}{\dot{m}} - H_f(P)}{H_{fg}(P)} = X_{in} + \frac{Q_c}{\dot{m}} \quad (B.6)$$

- Critical Heat Flux (CHF):

$$q_c = \frac{Q_c}{\pi d L} \quad (B.7)$$

- CHF enhancement ratio: the ratio of CHF with and without a flow obstruction, based on constant (local) quality:

$$R_{CHF} = \left. \frac{q_{c,obs}}{q_{c,ref}} \right|_{X_c=const} \quad (B.8)$$

or constant inlet temperature and heated length:

$$R_{CHF} = \left. \frac{q_{c,obs}}{q_{c,ref}} \right|_{T_{in}, L_h=const} \quad (B.9)$$

B.3.2 Error Analysis

The following error analysis is used to estimate the uncertainty in all measured and calculated parameters from the previous CHF analysis procedures. The results can be considered as an RMS error or single standard deviation (σ) in each variable, combining both systematic and random sources of error.

- Inlet subcooling:

$$\Delta H_{sub} = \sqrt{\left(\frac{\partial H_{sub}}{\partial H_f(P)} \Delta H_f(P) \right)^2 + \left(\frac{\partial H_{sub}}{\partial H_f(T_{in})} \Delta H_f(T_{in}) \right)^2} \quad (B.10)$$

$$\frac{\partial H_{\text{sub}}}{\partial H_f(P)} = \frac{\partial H_{\text{sub}}}{\partial H_f(T_{\text{in}})} = 1 \quad (\text{B.11})$$

$$\Delta H_f(P) = \sqrt{\left(\frac{\Delta f(P)}{f(P)} H_f(P) \right)^2 + \left(\frac{\partial H_f}{\partial P} \Delta P \right)^2} \quad (\text{B.12})$$

$$\Delta H_f(T) = \sqrt{\left(\frac{\Delta f(T)}{f(T)} H_f(T) \right)^2 + \left(\frac{\partial H_f}{\partial T} \Delta T \right)^2} \quad (\text{B.13})$$

Assume: $\frac{\Delta f(P)}{f(P)} = \frac{\Delta f(T)}{f(T)} = 0.2 \%$

- Outlet Pressure:

calibration range:	0–3.45 MPa	
pressure calibrator:	$\pm 0.01\%$ (F.S.)	$= \pm 0.345 \text{ kPa}$
max. calibration error:	1.834 kPa	

$$\Delta P = \sqrt{(0.345)^2 + (1.834)^2} = 1.866 \text{ kPa} = 0.001866 \text{ MPa} \quad (\text{B.14})$$

- Inlet Quality:

$$\Delta X_{\text{in}} = \sqrt{\left(\frac{\partial X_{\text{in}}}{\partial H_{\text{sub}}} \Delta H_{\text{sub}} \right)^2 + \left(\frac{\partial X_{\text{in}}}{\partial H_{\text{fg}}} \Delta H_{\text{fg}} \right)^2} \quad (\text{B.15})$$

$$\frac{\partial X_{\text{in}}}{\partial H_{\text{sub}}} = \frac{-1}{H_{\text{fg}}} \quad \frac{\partial X_{\text{in}}}{\partial H_{\text{fg}}} = \frac{-H_{\text{sub}}}{H_{\text{fg}}^2} \quad (\text{B.16})$$

$$\Delta H_{\text{fg}}(P) = \sqrt{\left(\frac{\Delta f(P)}{f(P)} H_f(P) \right)^2 + \left(\frac{\partial H_{\text{fg}}}{\partial P} \Delta P \right)^2} \quad (\text{B.17})$$

Table B.3.2-1: Uncertainty in inlet subcooling and inlet quality, 30% rings in Freon-134a.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	H_{sub} (J/kg)	ΔH_{sub} (J/kg)	X_{in}	ΔX_{in}	
							(%)
1.13	2.0	40	6046	385	-0.0378	0.0024	6.4
1.13	4.0	27	26475	360	-0.1654	0.0023	1.4
1.66	3.0	55	7268	447	-0.0517	0.0032	6.2
1.66	4.0	11	76528	368	-0.5446	0.0029	0.5
1.66	4.0	34	41263	404	-0.2936	0.0029	1.0
1.66	4.0	45	23727	425	-0.1689	0.0030	1.8
1.66	4.0	53	10602	443	-0.0755	0.0032	4.2

- Critical quality:

$$\Delta X_c = \sqrt{\left(\frac{\partial X_c}{\partial H_f(T_{in})} \Delta H_f(T_{in})\right)^2 + \left(\frac{\partial X_c}{\partial Q} \Delta Q\right)^2 + \left(\frac{\partial X_c}{\partial \dot{m}} \Delta \dot{m}\right)^2 + \left(\frac{\partial X_c}{\partial H_f(P)} \Delta H_f(P)\right)^2 + \left(\frac{\partial X_c}{\partial H_{fg}(P)} \Delta H_{fg}(P)\right)^2} \quad (\text{B.18})$$

See Section A.3.2 for details on $\Delta \dot{m}$, and below for ΔQ .

- Power loss: as outlined in Section 3.2.3, the heat losses from the test-section are small in comparison to the uncertainty in measured heat loss (i.e., contain errors in both power and latent heat). As such, the uncertainty in predicted heat loss is used, instead of heat loss, to specify the uncertainty in power (Q).

From the graph of ΔQ_{loss} versus Q for all single-phase flow data, shown in Figure B.3.2-1, the following uncertainty in power is obtained:

$$\Delta Q = \Delta Q_{loss} = 120 + \frac{60}{13000} (Q - 5000) \quad (\text{W}) \quad (\text{B.19})$$

The dead-band at zero power (120 W) is a result of uncertainties in the measurement of latent heat exchange (i.e, a combination of error in flow measurement and inlet/outlet

fluid temperature measurement). It should be mentioned that Doerffer et al. (1995) corrected the measured power for heat loss (i.e., the values of CHF in Tables B.2-1 through B.2-3 include these corrections), but no mention is made of the uncertainties associated with these heat loss predictions. As heat losses are small (1-4% of measured power), the corrected values are used, and the uncertainties assumed to be that of measured power (ΔQ).

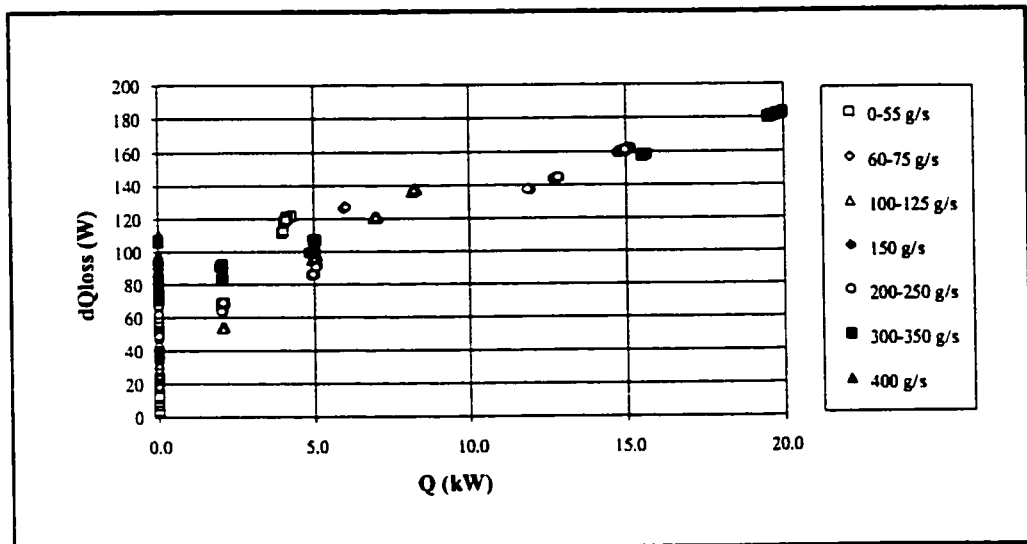


Figure B.3.2-1: Uncertainty in heat loss versus measured power (MR-7A, single-phase tests in Freon-134a, all data).

Table B.3.2-2: Uncertainty in critical power and critical quality, 30% rings in Freon-134a.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	$X_{c,min}$		$X_{c,max}$		ΔQ_c (W)	ΔX_c
			X_c	Q_c (kW)	X_c	Q_c (kW)		
1.13	2.0	40	0.32	5.82	0.43	6.85	130	0.012
1.13	4.0	27	0.10	8.76	0.15	9.64	140	0.006
1.66	3.0	55	0.21	5.46	0.32	7.63	130	0.009
1.66	4.0	11	0.01	14.8	0.12	17.7	180	0.009
1.66	4.0	34	0.06	9.43	0.16	11.9	150	0.008
1.66	4.0	45	0.09	7.52	0.22	10.2	140	0.007
1.66	4.0	53	0.15	6.65	0.25	8.76	140	0.007

- Critical heat flux as a measured quantity:

$$\Delta q_c = \sqrt{\left(\frac{\partial q_c}{\partial Q} \Delta Q\right)^2 + \left(\frac{\partial q_c}{\partial d} \Delta d\right)^2 + \left(\frac{\partial q_c}{\partial L} \Delta L\right)^2} \quad (B.20)$$

$$\frac{\partial q_c}{\partial Q} = \frac{1}{\pi d L}$$

$$\frac{\partial q_c}{\partial d} = \frac{Q}{\pi d^2 L} \quad \begin{array}{l} d = 0.008 \pm 0.00005 \\ L = 2.05 \pm 0.0005 \end{array} \quad (B.21)$$

$$\frac{\partial q_c}{\partial L} = \frac{Q}{\pi d L^2}$$

- Critical heat flux as a calculated quantity: a reference value of CHF is required to define the non-dimensional CHF enhancement ratio (R_{CHF}), as described in Section B.3.1. Doerffer et al. (1995) used the following empirical correlation to describe a series of reference-tube CHF data, covering the complete range of CHF enhancement experiments:

$$\Delta \hat{q}_c = a P^b G^c + d P^e G^f X_c^g \quad (B.22)$$

One can determine the uncertainty in the correlation, as per the measured quantities:

$$\Delta \hat{q}_c = \sqrt{\left(\frac{\partial \hat{q}_c}{\partial P} \Delta P\right)^2 + \left(\frac{\partial \hat{q}_c}{\partial G} \Delta G\right)^2 + \left(\frac{\partial \hat{q}_c}{\partial X_c} \Delta X_c\right)^2} \quad (\text{B.23})$$

where

$$\begin{aligned} \frac{\partial \hat{q}_c}{\partial P} &= abP^{(b-1)}G^c + deP^{(e-1)}G^fX_c^g \\ \frac{\partial \hat{q}_c}{\partial G} &= acP^bG^{(c-1)} + dfP^eG^{(f-1)}X_c^g \\ \frac{\partial \hat{q}_c}{\partial X_c} &= dgP^eG^fX_c^{(g-1)} \end{aligned} \quad (\text{B.24})$$

Applying the appropriate correlation for Freon-134a, the following uncertainties were obtained.

Table B.3.2-3: Uncertainty in measured and calculated CHF, 30% rings in Freon-134a.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	Δq_c (kW/m ²)	$X_{c,min}$		$X_{c,max}$	
				q_c (MW/m ²)	$\Delta \hat{q}_c$ (kW/m ²)	q_c (MW/m ²)	$\Delta \hat{q}_c$ (kW/m ²)
1.13	2.0	40	2.5	0.113	3.1	0.133	4.9
1.13	4.0	27	2.7	0.170	2.1	0.187	1.5
1.66	3.0	55	2.5	0.106	3.1	0.148	2.0
1.66	4.0	11	3.5	0.288	34.6 [†]	0.344	3.0
1.66	4.0	34	2.9	0.183	8.9	0.231	1.9
1.66	4.0	45	2.7	0.146	7.3	0.197	1.4
1.66	4.0	53	2.7	0.129	1.7	0.170	1.2

† Large $\Delta \hat{q}_c$ at low X_c is due to large values of $\frac{\partial \hat{q}_c}{\partial X_c}$.

Table B.3.2-4: Percent uncertainty in measured and calculated CHF, 30% rings in Freon-134a.

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	$X_{c,min}$		$X_{c,max}$	
			Δq_c (%)	$\Delta \hat{q}_c$ (%)	Δq_c (%)	$\Delta \hat{q}_c$ (%)
1.13	2.0	40	2.2	2.7	1.9	3.7
1.13	4.0	27	1.6	1.2	1.4	0.8
1.66	3.0	55	2.4	2.9	1.7	1.4
1.66	4.0	11	1.2	12.0	1.0	0.9
1.66	4.0	34	1.6	4.9	1.3	0.8
1.66	4.0	45	1.8	5.0	1.4	0.7
1.66	4.0	53	2.1	1.3	1.6	0.7

- CHF enhancement ratio:

$$\Delta R_{CHF} = \sqrt{\left(\frac{\partial R_{CHF}}{\partial q_{c,obs}} \Delta q_{c,obs} \right)^2 + \left(\frac{\partial R_{CHF}}{\partial q_{c,ref}} \Delta q_{c,ref} \right)^2} \quad (B.25)$$

where

$$\frac{\partial R_{CHF}}{\partial q_{c,obs}} = \frac{1}{q_{c,ref}} = R_{CHF} \cdot \frac{1}{q_{c,obs}} \quad (B.26)$$

$$\frac{\partial R_{CHF}}{\partial q_{c,ref}} = \frac{q_{c,obs}}{q_{c,ref}^2} = R_{CHF} \cdot \frac{1}{q_{c,ref}} \quad (B.27)$$

therefore

$$\frac{\Delta R_{CHF}}{R_{CHF}} = \sqrt{\left(\frac{\Delta q_{c,obs}}{q_{c,obs}} \right)^2 + \left(\frac{\Delta q_{c,ref}}{q_{c,ref}} \right)^2} \quad (B.28)$$

The correlations are used to compute the reference-CHF values ($q_{c,ref}$) for use in the CHF enhancement ratio, based on both constant (local) quality and constant inlet temperature. The RMS errors computed from each correlation (against reference-CHF experimental data in Freon-134a), over the specific quality range of the CHF enhancement measurements, are presented in Table B.3.2-5.

Table B.3.2-5: RMS errors in reference-tube CHF correlations (Freon-134a).

P (MPa)	G (Mg/m ² ·s)	T_{in} (°C)	X_c	$\Delta \hat{q}_{c,RMS}$ (%)	
				local	inlet
1.13	2.0	40	0.32–0.43	5.4	3.0
1.13	4.0	27	0.10–0.15	8.1	5.6
1.66	3.0	55	0.21–0.32	12.1	5.4
1.66	4.0	11	0.01–0.12	2.7	0.8
1.66	4.0	34	0.06–0.16	4.0	3.0
1.66	4.0	45	0.09–0.22	4.1	3.2
1.66	4.0	53	0.15–0.25	4.2	3.6

The maximum of both $\Delta \hat{q}_c$ and $\Delta \hat{q}_{c,RMS}$ is used to estimate the RMS error in the reference-CHF used for the enhancement ratio ($\Delta q_{c,ref}$). These are summarized in Table 3.2-6.

Table B.3.2-6: Uncertainty in CHF enhancement ratios, 30% rings in Freon-134a.

P (MPa)	G (Mg/m ² . s)	T _{in} (°C)	$\Delta q_{c,obs}$ [†] (%)	$\Delta q_{c,ref}$ [†] (%)		ΔR_{CHF} (%)	
				local	inlet	local	inlet
1.13	2.0	40	2.2	5.4	3.0	5.8	3.7
1.13	4.0	27	1.6	8.1	5.6	8.3	5.8
1.66	3.0	55	2.4	12.1	5.4	12.3	5.9
1.66	4.0	11	1.2	12.0	12.0	12.1	12.1
1.66	4.0	34	1.6	4.9	4.9	5.2	5.2
1.66	4.0	45	1.8	5.0	5.0	5.3	5.3
1.66	4.0	53	2.1	4.2	3.6	4.7	4.2

† Maximum values of $\Delta q_{c,obs}$ and $\Delta q_{c,ref}$ are used as an upper bound for RMS error.

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C.1 Reference Tube CHF Network Model

The following section contains a complete listing of all data files for the reference tube CHF model.

C.1.1 Network Component List (`ref-exp.nwk`)

Iter-1	Iterator
Jct-0	SigJctx10
ExpIn	TPAInput
trans1	iTrans
Sect-1	TPAPipe
trans2	iTrans
Jct-1	AOBank
Jct-2	AOBank
q-min	SigRatio
q-max	SigRatio

C.1.2 Network Component Links (`ref-exp.lnk`)

Iter-1	0	Jct-0	0
Jct-0	0	Sect-1	1
Jct-0	1	q-min	0
Jct-0	2	q-max	0
ExpIn	0	trans1	0
trans1	0	Sect-1	0
Sect-1	0	trans2	0
Sect-1	1	Iter-1	0
Sect-1	3	q-min	3
Sect-1	4	q-max	3
trans1	1	Jct-1	0
trans2	1	Jct-2	0
Jct-1	0	q-min	1
Jct-1	1	q-max	1
Jct-2	0	q-min	2
Jct-2	1	q-max	2
q-min	0	Iter-1	1
q-max	0	Iter-1	2

C.1.3 Network Input Variable List (ref-exp.ivl)

Iter-1	Element	Sp
ExpIn	Element	p
ExpIn	Element	W
ExpIn	Element	T
ExpIn	Element	WLF

C.1.4 Network Trend Variable List (ref-exp.tvl)

Iter-1	Element	iniOut	: initial output signal	: <Float>	: <config>
Iter-1	Element	Sp	: controller set point	: <Float>	: <input>
Iter-1	Element	minOut	: minimum output signal	: <Float>	: <exec>
Iter-1	Element	maxOut	: maximum output signal	: <Float>	: <exec>
Iter-1	Stream	Output 0	: value	: <Float>	: <exec>
Jct-0	Stream	Output 0	: value	: <Float>	: <exec>
Jct-0	Stream	Output 1	: value	: <Float>	: <exec>
Jct-0	Stream	Output 2	: value	: <Float>	: <exec>
Jct-0	Stream	Output 3	: value	: <Float>	: <exec>
Jct-0	Stream	Output 4	: value	: <Float>	: <exec>
Jct-0	Stream	Output 5	: value	: <Float>	: <exec>
Jct-0	Stream	Output 6	: value	: <Float>	: <exec>
Jct-0	Stream	Output 7	: value	: <Float>	: <exec>
Jct-0	Stream	Output 8	: value	: <Float>	: <exec>
Jct-0	Stream	Output 9	: value	: <Float>	: <exec>
ExpIn	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
ExpIn	Element	Mode	: inlet specification	: <Mode>	: <build>
ExpIn	Element	p	: thermodynamic pressure [Pa]	: <Float>	: <input>
ExpIn	Element	W	: total flow rate [kg/s]	: <Float>	: <input>
ExpIn	Element	T	: fluid temperature [oC]	: <Float>	: <input>
ExpIn	Element	WLF	: liquid film flow rate [kg/s]	: <Float>	: <input>
ExpIn	Stream	Output 0	: total flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: pressure [Pa]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: enthalpy [J/kg]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: temperature [oC]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: total liquid flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: vapour flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: liquid film flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Element	Stream	: Type of Stream connection	: <Mode>	: <build>
trans1	Element	p	: pressure [Pa]	: <Float>	: <exec>
trans1	Element	W	: total flow rate [kg/s]	: <Float>	: <exec>
trans1	Element	i	: enthalpy [J/kg]	: <Float>	: <exec>
trans1	Element	T	: temperature [oC]	: <Float>	: <exec>
trans1	Stream	Output 0	: total flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0	: pressure [Pa]	: <Float>	: <exec>
trans1	Stream	Output 0	: enthalpy [J/kg]	: <Float>	: <exec>
trans1	Stream	Output 0	: temperature [oC]	: <Float>	: <exec>
trans1	Stream	Output 0	: total liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0	: vapour flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0	: liquid film flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 1	: value	: <Float>	: <exec>
Sect-1	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-1	Element	d	: pipe diameter [m]	: <Float>	: <config>
Sect-1	Element	L	: pipe length [m]	: <Float>	: <config>
Sect-1	Element	Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-1	Element	Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-1	Element	G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-1	Element	dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-1	Element	NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-1	Element	Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-1	Element	q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-1	Element	NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-1	Element	EDTtype	: entrainment/deposition model option	: <Mode>	: <build>
Sect-1	Element	Node_Type	: annular node type option	: <Mode>	: <build>
Sect-1	Element	G1E_frac	: entrainment fraction at CHAF (0-1)	: <Float>	: <config>
Sect-1	Element	L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-1	Element	x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-1	Element	NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-1	Stream	Output 0	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: pressure [Pa]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: temperature [oC]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 1	: value	: <Float>	: <exec>
Sect-1	Stream	Output 2	: value	: <Float>	: <exec>
Sect-1	Stream	Output 3	: value	: <Float>	: <exec>
Sect-1	Stream	Output 4	: value	: <Float>	: <exec>
trans2	Element	Stream	: Type of Stream connection	: <Mode>	: <build>
trans2	Element	p	: pressure [Pa]	: <Float>	: <exec>
trans2	Element	W	: total flow rate [kg/s]	: <Float>	: <exec>

trans2	Element		i	: enthalpy [J/kg]	: <Float>	: <exec>
trans2	Element		T	: temperature [oC]	: <Float>	: <exec>
trans2	Stream	Output	0 W	: total flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0 p	: pressure [Pa]	: <Float>	: <exec>
trans2	Stream	Output	0 i	: enthalpy [J/kg]	: <Float>	: <exec>
trans2	Stream	Output	0 T	: temperature [oC]	: <Float>	: <exec>
trans2	Stream	Output	0 Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0 Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0 Wlf	: liquid film flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0 Wle	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	1 value	: Analog Stream value	: <Float>	: <exec>
Jct-1	Stream	Output	0 value	: Analog Stream value	: <Float>	: <exec>
Jct-1	Stream	Output	1 value	: Analog Stream value	: <Float>	: <exec>
Jct-2	Stream	Output	0 value	: Analog Stream value	: <Float>	: <exec>
Jct-2	Stream	Output	1 value	: Analog Stream value	: <Float>	: <exec>
q-min	Stream	Output	0 value	: Analog Stream value	: <Float>	: <exec>
q-max	Stream	Output	0 value	: Analog Stream value	: <Float>	: <exec>

C.2 Enhancement Tube CHF Network Model

The following section contains a complete listing of all data files for the 1-4 obstacle CHF enhancement tube model.

C.2.1 Network Component List (*obs-exp.nwk*)

Iter-1	Iterator
Jct-0	SigJctx10
ExpIn	TPAInput
trans1	iTrans
Sect-1	TPAOPipe
Sect-2	TPAOPipe
Sect-3	TPAOPipe
Sect-4	TPAOPipe
Sect-5	TPAOPipe
trans2	iTrans
Jct-1	AOBank
High	HighSigx10
Low	LowSigx10
Jct-2	AOBank
q-min	SigRatio
q-max	SigRatio
Err-1	SigError
Err-2	SigError
Err-3	SigError
Err-4	SigError
Err-5	SigError
High-e	HighSigx10

C.2.2 Network Component Links (*obs-exp.lnk*)

Iter-1	0	Jct-0	0
Jct-0	0	q-min	0
Jct-0	1	q-max	0
Jct-0	2	Sect-1	1
Jct-0	3	Sect-2	1
Jct-0	4	Sect-3	1
Jct-0	5	Sect-4	1
Jct-0	6	Sect-5	1
ExpIn	0	trans1	0
trans1	0	Sect-1	0
Sect-1	0	Sect-2	0
Sect-2	0	Sect-3	0
Sect-3	0	Sect-4	0
Sect-4	0	Sect-5	0
Sect-5	0	trans2	0
trans1	1	Jct-1	0
Sect-1	1	Err-1	1
Sect-1	3	High	0
Sect-1	4	Low	0
Sect-2	1	Err-2	1

Sect-2	3	High	1
Sect-2	4	Low	1
Sect-3	1	Err-3	1
Sect-3	3	High	2
Sect-3	4	Low	2
Sect-4	1	Err-4	1
Sect-4	3	High	3
Sect-4	4	Low	3
Sect-5	1	Err-5	1
Sect-5	3	High	4
Sect-5	4	Low	4
trans2	1	Jct-2	0
Jct-1	0	q-min	1
Jct-1	1	q-max	1
High	0	q-min	3
Low	0	q-max	3
Jct-2	0	q-min	2
Jct-2	1	q-max	2
q-min	0	Iter-1	1
q-max	0	Iter-1	2
Err-1	0	High-e	0
Err-2	0	High-e	1
Err-3	0	High-e	2
Err-4	0	High-e	3
Err-5	0	High-e	4
High-e	0	Iter-1	0

C.2.3 Network Input Variable List (obs-exp.iv1)

Iter-1	Element	Sp
ExpIn	Element	p
ExpIn	Element	W
ExpIn	Element	T
ExpIn	Element	WlF
Err-1	Stream	Input 0 value
Err-2	Stream	Input 0 value
Err-3	Stream	Input 0 value
Err-4	Stream	Input 0 value
Err-5	Stream	Input 0 value

C.2.4 Network Trend Variable List (obs-exp.tv1)

Iter-1	Element	iniOut	: initial output signal	: <Float>	: <config>
Iter-1	Element	Sp	: controller set point	: <Float>	: <input>
Iter-1	Element	minOut	: minimum output signal	: <Float>	: <exec>
Iter-1	Element	maxOut	: maximum output signal	: <Float>	: <exec>
Iter-1	Stream	Output 0	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 0	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 1	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 2	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 3	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 4	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 5	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 6	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 7	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 8	value : Analog Stream value	: <Float>	: <exec>
Jct-0	Stream	Output 9	value : Analog Stream value	: <Float>	: <exec>
ExpIn	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
ExpIn	Element	Mode	: inlet specification	: <Mode>	: <build>
ExpIn	Element	p	: thermodynamic pressure [Pa]	: <Float>	: <input>
ExpIn	Element	W	: total flow rate [kg/s]	: <Float>	: <input>

ExpIn	Element	T	: fluid temperature [oC]	: <Float>	: <input>
ExpIn	Element	WLF	: liquid film flow rate [kg/s]	: <Float>	: <input>
ExpIn	Stream	Output 0 W	: total flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0 p	: pressure [Pa]	: <Float>	: <exec>
ExpIn	Stream	Output 0 i	: enthalpy [J/kg]	: <Float>	: <exec>
ExpIn	Stream	Output 0 T	: temperature [oC]	: <Float>	: <exec>
ExpIn	Stream	Output 0 Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0 Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0 WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
ExpIn	Stream	Output 0 WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Element	Stream	: Type of Stream connection	: <Mode>	: <build>
trans1	Element	p	: pressure [Pa]	: <Float>	: <exec>
trans1	Element	W	: total flow rate [kg/s]	: <Float>	: <exec>
trans1	Element	i	: enthalpy [J/kg]	: <Float>	: <exec>
trans1	Element	T	: temperature [oC]	: <Float>	: <exec>
trans1	Stream	Output 0 W	: total flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0 p	: pressure [Pa]	: <Float>	: <exec>
trans1	Stream	Output 0 i	: enthalpy [J/kg]	: <Float>	: <exec>
trans1	Stream	Output 0 T	: temperature [oC]	: <Float>	: <exec>
trans1	Stream	Output 0 Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0 Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0 WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 0 WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans1	Stream	Output 1 value	: Analog Stream value	: <Float>	: <exec>
Sect-1	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-1	Element	d	: pipe diameter [m]	: <Float>	: <config>
Sect-1	Element	L	: pipe length [m]	: <Float>	: <config>
Sect-1	Element	Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-1	Element	Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-1	Element	G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-1	Element	dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-1	Element	NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-1	Element	Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-1	Element	q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-1	Element	NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-1	Element	EDType	: entrainment/deposition model option	: <Mode>	: <build>
Sect-1	Element	Node_Type	: annular node type option	: <Mode>	: <build>
Sect-1	Element	GLE frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
Sect-1	Element	L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-1	Element	x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-1	Element	K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
Sect-1	Element	K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Sect-1	Element	CG	: deposition enhancement constant	: <Float>	: <config>
Sect-1	Element	a	: deposition enhancement decay rate	: <Float>	: <config>
Sect-1	Element	NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-1	Stream	Output 0 W	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0 p	: pressure [Pa]	: <Float>	: <exec>
Sect-1	Stream	Output 0 i	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-1	Stream	Output 0 T	: temperature [oC]	: <Float>	: <exec>
Sect-1	Stream	Output 0 Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0 Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0 WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 0 WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-1	Stream	Output 1 value	: Analog Stream value	: <Float>	: <exec>
Sect-1	Stream	Output 2 value	: Analog Stream value	: <Float>	: <exec>
Sect-1	Stream	Output 3 value	: Analog Stream value	: <Float>	: <exec>
Sect-1	Stream	Output 4 value	: Analog Stream value	: <Float>	: <exec>
Sect-2	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-2	Element	d	: pipe diameter [m]	: <Float>	: <config>
Sect-2	Element	L	: pipe length [m]	: <Float>	: <config>
Sect-2	Element	Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-2	Element	Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-2	Element	G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-2	Element	dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-2	Element	NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-2	Element	Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-2	Element	q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-2	Element	NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-2	Element	EDType	: entrainment/deposition model option	: <Mode>	: <build>
Sect-2	Element	Node_Type	: annular node type option	: <Mode>	: <build>
Sect-2	Element	GLE frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
Sect-2	Element	L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-2	Element	x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-2	Element	K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
Sect-2	Element	K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Sect-2	Element	CG	: deposition enhancement constant	: <Float>	: <config>
Sect-2	Element	a	: deposition enhancement decay rate	: <Float>	: <config>
Sect-2	Element	NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-2	Stream	Output 0 W	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-2	Stream	Output 0 p	: pressure [Pa]	: <Float>	: <exec>
Sect-2	Stream	Output 0 i	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-2	Stream	Output 0 T	: temperature [oC]	: <Float>	: <exec>
Sect-2	Stream	Output 0 Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-2	Stream	Output 0 Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-2	Stream	Output 0 WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-2	Stream	Output 0 WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-2	Stream	Output 1 value	: Analog Stream value	: <Float>	: <exec>
Sect-2	Stream	Output 2 value	: Analog Stream value	: <Float>	: <exec>
Sect-2	Stream	Output 3 value	: Analog Stream value	: <Float>	: <exec>
Sect-2	Stream	Output 4 value	: Analog Stream value	: <Float>	: <exec>
Sect-3	Element	Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-3	Element	d	: pipe diameter [m]	: <Float>	: <config>
Sect-3	Element	L	: pipe length [m]	: <Float>	: <config>
Sect-3	Element	Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-3	Element	Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-3	Element	G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-3	Element	dp	: total pressure drop [Pa]	: <Float>	: <exec>

Sect-3	Element		NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-3	Element		Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-3	Element		q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-3	Element		NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-3	Element		EDType	: entrainment/deposition model option	: <Mode>	: <build>
Sect-3	Element		Node_Type	: annular node type option	: <Mode>	: <build>
Sect-3	Element		GLE_frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
Sect-3	Element		L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-3	Element		x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-3	Element		K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
Sect-3	Element		K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Sect-3	Element		Co	: deposition enhancement constant	: <Float>	: <config>
Sect-3	Element		a	: deposition enhancement decay rate	: <Float>	: <config>
Sect-3	Element		NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-3	Stream	Output 0	W	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-3	Stream	Output 0	p	: pressure [Pa]	: <Float>	: <exec>
Sect-3	Stream	Output 0	i	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-3	Stream	Output 0	T	: temperature [oC]	: <Float>	: <exec>
Sect-3	Stream	Output 0	Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-3	Stream	Output 0	Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-3	Stream	Output 0	WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-3	Stream	Output 0	WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-3	Stream	Output 1	value	: Analog Stream value	: <Float>	: <exec>
Sect-3	Stream	Output 2	value	: Analog Stream value	: <Float>	: <exec>
Sect-3	Stream	Output 3	value	: Analog Stream value	: <Float>	: <exec>
Sect-3	Stream	Output 4	value	: Analog Stream value	: <Float>	: <exec>
Sect-4	Element		Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-4	Element		d	: pipe diameter [m]	: <Float>	: <config>
Sect-4	Element		L	: pipe length [m]	: <Float>	: <config>
Sect-4	Element		Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-4	Element		Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-4	Element		G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-4	Element		dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-4	Element		NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-4	Element		Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-4	Element		q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-4	Element		NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-4	Element		EDType	: entrainment/deposition model option	: <Mode>	: <build>
Sect-4	Element		Node_Type	: annular node type option	: <Mode>	: <build>
Sect-4	Element		GLE_frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
Sect-4	Element		L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-4	Element		x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-4	Element		K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
Sect-4	Element		K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Sect-4	Element		Co	: deposition enhancement constant	: <Float>	: <config>
Sect-4	Element		a	: deposition enhancement decay rate	: <Float>	: <config>
Sect-4	Element		NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-4	Stream	Output 0	W	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-4	Stream	Output 0	p	: pressure [Pa]	: <Float>	: <exec>
Sect-4	Stream	Output 0	i	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-4	Stream	Output 0	T	: temperature [oC]	: <Float>	: <exec>
Sect-4	Stream	Output 0	Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-4	Stream	Output 0	Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-4	Stream	Output 0	WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-4	Stream	Output 0	WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-4	Stream	Output 1	value	: Analog Stream value	: <Float>	: <exec>
Sect-4	Stream	Output 2	value	: Analog Stream value	: <Float>	: <exec>
Sect-4	Stream	Output 3	value	: Analog Stream value	: <Float>	: <exec>
Sect-4	Stream	Output 4	value	: Analog Stream value	: <Float>	: <exec>
Sect-5	Element		Fluid	: name of fluid (property)	: <Text>	: <build>
Sect-5	Element		d	: pipe diameter [m]	: <Float>	: <config>
Sect-5	Element		L	: pipe length [m]	: <Float>	: <config>
Sect-5	Element		Zi	: inlet elevation [m]	: <Float>	: <config>
Sect-5	Element		Zo	: outlet elevation [m]	: <Float>	: <config>
Sect-5	Element		G	: mass flow velocity [kg/m2-s]	: <Float>	: <exec>
Sect-5	Element		dp	: total pressure drop [Pa]	: <Float>	: <exec>
Sect-5	Element		NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Sect-5	Element		Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
Sect-5	Element		q0	: normalized heat flux input [W/m2]	: <Float>	: <exec>
Sect-5	Element		NodeFile	: File to store Nodal variable values	: <Text>	: <config>
Sect-5	Element		EDType	: entrainment/deposition model option	: <Mode>	: <build>
Sect-5	Element		Node_Type	: annular node type option	: <Mode>	: <build>
Sect-5	Element		GLE_frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
Sect-5	Element		L_CHF	: CHF location [m]	: <Float>	: <exec>
Sect-5	Element		x_CHF	: CHF quality [m]	: <Float>	: <exec>
Sect-5	Element		K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
Sect-5	Element		K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Sect-5	Element		Co	: deposition enhancement constant	: <Float>	: <config>
Sect-5	Element		a	: deposition enhancement decay rate	: <Float>	: <config>
Sect-5	Element		NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>
Sect-5	Stream	Output 0	W	: total flow rate [kg/s]	: <Float>	: <exec>
Sect-5	Stream	Output 0	p	: pressure [Pa]	: <Float>	: <exec>
Sect-5	Stream	Output 0	i	: enthalpy [J/kg]	: <Float>	: <exec>
Sect-5	Stream	Output 0	T	: temperature [oC]	: <Float>	: <exec>
Sect-5	Stream	Output 0	Wl	: total liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-5	Stream	Output 0	Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
Sect-5	Stream	Output 0	WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
Sect-5	Stream	Output 0	WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
Sect-5	Stream	Output 1	value	: Analog Stream value	: <Float>	: <exec>
Sect-5	Stream	Output 2	value	: Analog Stream value	: <Float>	: <exec>
Sect-5	Stream	Output 3	value	: Analog Stream value	: <Float>	: <exec>
Sect-5	Stream	Output 4	value	: Analog Stream value	: <Float>	: <exec>
trans2	Element		Stream	: Type of Stream connection	: <Mode>	: <build>
trans2	Element		p	: pressure [Pa]	: <Float>	: <exec>
trans2	Element		W	: total flow rate [kg/s]	: <Float>	: <exec>
trans2	Element		i	: enthalpy [J/kg]	: <Float>	: <exec>
trans2	Element		T	: temperature [oC]	: <Float>	: <exec>

trans2	Stream	Output	0	W	: total flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0	p	: pressure [Pa]	: <Float>	: <exec>
trans2	Stream	Output	0	i	: enthalpy [J/kg]	: <Float>	: <exec>
trans2	Stream	Output	0	T	: temperature [°C]	: <Float>	: <exec>
trans2	Stream	Output	0	WL	: total liquid flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0	Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0	WLF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	0	WLE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>
trans2	Stream	Output	1	value	: Analog Stream value	: <Float>	: <exec>
Jct-1	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Jct-1	Stream	Output	1	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Input	5	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Input	6	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Input	7	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Input	8	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Input	9	value	: Analog Stream value	: <Float>	: <exec>
High	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Input	5	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Input	6	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Input	7	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Input	8	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Input	9	value	: Analog Stream value	: <Float>	: <exec>
Low	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Jct-2	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Jct-2	Stream	Output	1	value	: Analog Stream value	: <Float>	: <exec>
q-min	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
q-max	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Err-1	Stream	Input	0	value	: Analog Stream value	: <Float>	: <exec>
Err-1	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Err-2	Stream	Input	0	value	: Analog Stream value	: <Float>	: <exec>
Err-2	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Err-3	Stream	Input	0	value	: Analog Stream value	: <Float>	: <exec>
Err-3	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Err-4	Stream	Input	0	value	: Analog Stream value	: <Float>	: <exec>
Err-4	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
Err-5	Stream	Input	0	value	: Analog Stream value	: <Float>	: <exec>
Err-5	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Input	5	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Input	6	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Input	7	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Input	8	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Input	9	value	: Analog Stream value	: <Float>	: <exec>
High-e	Stream	Output	0	value	: Analog Stream value	: <Float>	: <exec>

C.3 OSM Object Data Sheets

C.3.1 Component Objects

Object: Pipe
Type: Element
Related: <none>

Icon:



Purpose: calculate the friction and total pressure drop inside a pipe for a constant-property fluid at steady-state.

Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
Fric_Mode	: turbulent friction formula option	: <Mode>	: <build>
d	: pipe diameter [m]	: <Float>	: <config>
L	: pipe length [m]	: <Float>	: <config>
Zi	: inlet elevation [m]	: <Float>	: <config>
Zo	: outlet elevation [m]	: <Float>	: <config>
G	: mass flow velocity [kg/m ² -s]	: <Float>	: <exec>
dp	: total pressure drop [Pa]	: <Float>	: <exec>
u	: average fluid velocity [m/s]	: <Float>	: <exec>
Re	: Reynolds number	: <Float>	: <exec>
f	: Fanning friction factor	: <Float>	: <exec>
tau_w	: wall shear stress [Pa]	: <Float>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	pin	PStream	inlet flow stream
Output	0	pout	PStream	outlet flow stream

Details

Fluid the name of a text-file (Fluid.dat) containing the constant fluid properties (see CPProp data object)

Fric_Mode: various formulations of the single-phase friction factor inside tubes:

- = Blasius: Blasius formula
- = Prandtl: Prandtl formula
- = Overlap: Prandtl logarithmic-overlap

=	Spalding:	Spalding formula
=	PrPipe:	Prandtl-Reichardt relation

Default Configuration

Steady-state constant property pipe			
Fluid	: name of fluid (property)	: water	: <Text> : <build>
d	: pipe diameter [m]	: 0.0100	: <Float> : <config>
L	: pipe length [m]	: 1.0000	: <Float> : <config>
Zi	: inlet elevation [m]	: 0.000	: <Float> : <config>
Zo	: outlet elevation [m]	: 0.000	: <Float> : <config>
Fric_Mode	: turbulent friction formula option	: Prandtl	: <Mode> : <build>

Object: TPPipe
Type: Element
Related: Pipe

Icon:



Purpose: steady-state single-phase and two-phase flow and pressure drop inside a pipe with uniform heat-flux on the wall.

Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
d	: pipe diameter [m]	: <Float>	: <config>
L	: pipe length [m]	: <Float>	: <config>
Zi	: inlet elevation [m]	: <Float>	: <config>
Zo	: outlet elevation [m]	: <Float>	: <config>
G	: mass flow velocity [kg/m ² -s]	: <Float>	: <exec>
dp	: total pressure drop [Pa]	: <Float>	: <exec>
NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
q0	: normalized heat flux input [W/m ²]	: <Float>	: <exec>
NodeFile	: File to store Nodal variable values	: <Text>	: <config>
NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	pin	TPStream	inlet two-phase flow stream
Input	1	q0	AStream	nominal heat flux input
Output	0	pout	TPStream	outlet two-phase flow stream

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Solve_Type: various formulations for the finite-difference governing equations:

= Step1: 1st-order predictor
 = RK-4: 4th-order Runge-Kutta

NodeFile: filename to store the nodal solution variables when NodeArray is included in the network trend variable list

NodeArray: nodal solution variables:

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
p	: pressure [Pa]	: Float	: exec
i	: enthalpy [J/kg]	: Float	: exec
T	: temperature [oC]	: Float	: exec
G	: mass velocity [kg/m ² -s]	: Float	: exec
G _l	: liquid mass velocity [kg/m ² -s]	: Float	: exec
G _g	: vapour mass velocity [kg/m ² -s]	: Float	: exec
u	: mass-average velocity [m/s]	: Float	: exec
u _l	: liquid mass-average velocity [m/s]	: Float	: exec
u _g	: vapour mass-average velocity [m/s]	: Float	: exec
uu	: momentum-average velocity [m/s]	: Float	: exec
dp_by_ds	: total pressure gradient [Pa/m]	: Float	: exec
dGg_by_ds	: vapour mass velocity gradient [kg/m ³ -s]	: Float	: exec
duu_by_ds	: mixture mom. velocity gradient [1/s]	: Float	: exec
dil_by_dp	: liq. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
dig_by_dp	: vap. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
x _T	: thermodynamic quality	: Float	: exec
x	: flowing quality	: Float	: exec
alpha	: void fraction	: Float	: exec
rho	: density [kg/m ³]	: Float	: exec
slip	: gas-to-liquid slip ratio	: Float	: exec
f _{tp}	: two-phase friction factor	: Float	: exec
tau_w	: wall shear stress [Pa]	: Float	: exec
q	: heat flux [W/m ²]	: Float	: exec
Gamma_vap	: evaporation rate [kg/m ³ -s]	: Float	: exec
Gamma_lg	: liquid flash rate [kg/m ³ -s]	: Float	: exec
Gamma_gl	: vapour condense rate [kg/m ³ -s]	: Float	: exec

Default Configuration

```

Steady-state two-phase pipe
Fluid      : name of fluid (property)           : water           : <Text>       : <build>

d          : pipe diameter [m]                  : 0.0100          : <Float>      : <config>

L          : pipe length [m]                    : 1.0000          : <Float>      : <config>

Zi         : inlet elevation [m]                : 0.000           : <Float>      : <config>

Zo         : outlet elevation [m]               : 0.000           : <Float>      : <config>

NNodes     : no. of fluid nodes [2-500]        : 25              : <Integer>    : <build>

Solve_Type : FD numerical sol'n method         : Step1           : <Mode>       : <config>

NodeFile   : File to store Nodal variable values : Node            : <Text>       : <config>
  
```

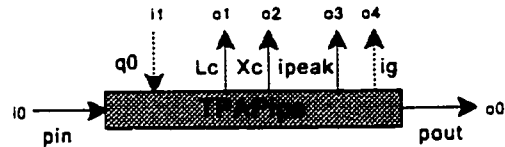
ject: TPAPipe

Icon:

Type: Element

Related: TPPipe
Pipe

Purpose: steady-state single-phase and two-phase annular flow and pressure drop inside a pipe with uniform heat-flux on the wall.



Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
d	: pipe diameter [m]	: <Float>	: <config>
L	: pipe length [m]	: <Float>	: <config>
Zi	: inlet elevation [m]	: <Float>	: <config>
Zo	: outlet elevation [m]	: <Float>	: <config>
G	: mass flow velocity [kg/m ² -s]	: <Float>	: <exec>
dp	: total pressure drop [Pa]	: <Float>	: <exec>
NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
q0	: normalized heat flux input [W/m ²]	: <Float>	: <exec>
NodeFile	: File to store Nodal variable values	: <Text>	: <config>
EDType	: entrainment/deposition model option	: <Mode>	: <build>
Node_Type	: annular node type option	: <Mode>	: <build>
GIE_frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
x_onaf	: flowing quality at ONAF (0-1)	: <Float>	: <config>
L_CHF	: CHF location [m]	: <Float>	: <exec>
x_CHF	: CHF quality [m]	: <Float>	: <exec>
NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	pin	TPAStream	inlet two-phase flow stream
Input	1	q0	AStream	nominal heat flux input
Output	0	pout	TPAStream	outlet two-phase flow stream
Output	1	Lc	AStream	critical length
Output	2	Xc	AStream	critical quality
Output	3	ipeak	AStream	enthalpy at peak film thickness
Output	4	ig	AStream	enthalpy of dry vapour

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport fluid properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Solve_Type: various finite-difference formulations of the governing equations:

```
=      Step1:      1st-order predictor
=      RK-4:       4th-order Runge-Kutta
```

NodeFile: filename to store the nodal solution variables when NodeArray included in the network trend variable list

EDType: various entrainment/deposition options:

```
=      Whalley:    Whalley et al. (1974)
=      Hewitt:     Whalley and Hewitt (1978)
=      ASSERT:     Tahir et al. (1987)
=      Govan:      Hewitt and Govan (1990)
=      Saito:      Saito et al. (1978)
=      Sugawara:   Sugawara (1990)
```

Node_Type: various triangular solution options, used to solve the interfacial shear stress, liquid film thickness, and film flow:

```
=      Universal:  universal velocity
=      Empirical:  approximate thick-film
=      Integral:   shear stress integration
```

NodeArray: nodal solution variables:

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
p	: pressure [Pa]	: Float	: exec
i	: enthalpy [J/kg]	: Float	: exec
T	: temperature [oC]	: Float	: exec
G	: mass velocity [kg/m2-s]	: Float	: exec
G _l	: liquid mass velocity [kg/m2-s]	: Float	: exec
G _g	: vapour mass velocity [kg/m2-s]	: Float	: exec
u	: mass-average velocity [m/s]	: Float	: exec
u _l	: liquid mass-average velocity [m/s]	: Float	: exec
u _g	: vapour mass-average velocity [m/s]	: Float	: exec
u _u	: momentum-average velocity [m/s]	: Float	: exec
dp_by_ds	: total pressure gradient [Pa/m]	: Float	: exec
dG _g _by_ds	: vapour mass velocity gradient [kg/m3-s]	: Float	: exec
duu_by_ds	: mixture mom. velocity gradient [1/s]	: Float	: exec
dil_by_dp	: liq. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
dig_by_dp	: vap. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
x _T	: thermodynamic quality	: Float	: exec

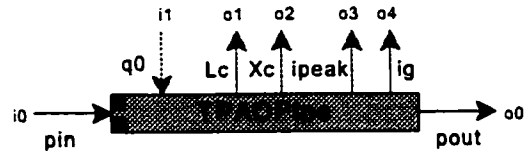
x	: flowing quality	: Float	: exec
alpha	: void fraction	: Float	: exec
rho	: density [kg/m3]	: Float	: exec
slip	: gas-to-liquid slip ratio	: Float	: exec
f_tp	: two-phase friction factor	: Float	: exec
tau_w	: wall shear stress [Pa]	: Float	: exec
q	: heat flux [W/m2]	: Float	: exec
Gamma_vap	: evaporation rate [kg/m3-s]	: Float	: exec
Gamma_lg	: liquid flash rate [kg/m3-s]	: Float	: exec
Gamma_gl	: vapour condense rate [kg/m3-s]	: Float	: exec
GlF	: liquid film mass velocity [kg/m2-s]	: Float	: exec
GlE	: entrained liquid mass velocity [kg/m2-s]	: Float	: exec
u_c	: core mass-average velocity [m/s]	: Float	: exec
ulF	: liquid film mass-average velocity [m/s]	: Float	: exec
ulE	: droplet mass-average velocity [m/s]	: Float	: exec
Gamma_D	: volumetric deposition rate [kg/m3-s]	: Float	: exec
Gamma_E	: volumetric entrainment rate [kg/m3-s]	: Float	: exec
Gamma_Fg	: volumetric film flash rate [kg/m3-s]	: Float	: exec
Gamma_Eg	: volumetric droplet flash rate [kg/m3-s]	: Float	: exec
dGlE_by_ds	: entrained liquid gradient [kg/m3-s]	: Float	: exec
dGuc_by_ds	: core momentum gradient [N/m3]	: Float	: exec
x_c	: core flowing quality	: Float	: exec
alpha_gc	: core gas void fraction	: Float	: exec
alpha_c	: core void fraction	: Float	: exec
rho_c	: core density [kg/m3]	: Float	: exec
C	: core droplet concentration [kg/m3]	: Float	: exec
k	: droplet mass transfer coefficient [m/s]	: Float	: exec
delta	: liquid film thickness	: Float	: exec
tau_i	: interfacial shear stress [Pa]	: Float	: exec

Default Configuration

steady-state two-phase annular pipe			
Fluid	: name of fluid (property)	: water	: <Text> : <build>
d	: pipe diameter [m]	: 0.0100	: <Float> : <config>
L	: pipe length [m]	: 1.0000	: <Float> : <config>
Zi	: inlet elevation [m]	: 0.000	: <Float> : <config>
Zo	: outlet elevation [m]	: 0.000	: <Float> : <config>
NNodes	: no. of fluid nodes [2-500]	: 25	: <Integer> : <build>
Solve_Type	: FD numerical sol'n method	: Step1	: <Mode> : <config>
NodeFile	: File to store Nodal variable values	: Node	: <Text> : <config>
EDType	: entrainment/deposition model option	: Whalley	: <Mode> : <build>
Node_Type	: annular node type option	: Empirical	: <Mode> : <build>
GlE_frac	: entrainment fraction at ONAF (0-1)	: 0.9900	: <Float> : <config>
x_onaf	: flowing quality at ONAF (0-1)	: 0.0100	: <Float> : <config>

Object: TPAOPipe
Type: Element
Related: TPAPipe
 TPPipe
 Pipe

Icon:



Purpose: steady-state single-phase and two-phase annular flow pipe with flow obstruction at the inlet – pressure drop and flow inside the pipe with uniform heat-flux on the wall.

Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
d	: pipe diameter [m]	: <Float>	: <config>
L	: pipe length [m]	: <Float>	: <config>
Zi	: inlet elevation [m]	: <Float>	: <config>
Zo	: outlet elevation [m]	: <Float>	: <config>
G	: mass flow velocity [kg/m ² -s]	: <Float>	: <exec>
dp	: total pressure drop [Pa]	: <Float>	: <exec>
NNodes	: no. of fluid nodes [2-500]	: <Integer>	: <build>
Solve_Type	: FD numerical sol'n method	: <Mode>	: <config>
q0	: normalized heat flux input [W/m ²]	: <Float>	: <exec>
NodeFile	: File to store Nodal variable values	: <Text>	: <config>
EDType	: entrainment/deposition model option	: <Mode>	: <build>
Node_Type	: annular node type option	: <Mode>	: <build>
GLE_frac	: entrainment fraction at ONAF (0-1)	: <Float>	: <config>
x_onaf	: flowing quality at ONAF (0-1)	: <Float>	: <config>
L_CHF	: CHF location [m]	: <Float>	: <exec>
x_CHF	: CHF quality [m]	: <Float>	: <exec>
K_strip	: liquid-film stripping coeff (0-1)	: <Float>	: <config>
K_depos	: liquid-droplet impingement coeff (0-1)	: <Float>	: <config>
Co	: deposition enhancement constant	: <Float>	: <config>
a	: deposition enhancement decay rate	: <Float>	: <config>
NodeArray	: Array to store Nodal variable values	: <Array>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	pin	TPAStream	inlet two-phase flow stream
Input	1	q0	AStream	nominal heat flux input
Output	0	pout	TPAStream	outlet two-phase flow stream
Output	1	Lc	AStream	critical length
Output	2	Xc	AStream	critical quality
Output	3	ipeak	AStream	enthalpy at peak film thickness
Output	4	ig	AStream	enthalpy of dry vapour

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport fluid properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Solve_Type: various finite-difference formulations of the governing equations:

```
= Step1:      1st-order predictor
= RK-4:      4th-order Runge-Kutta
```

NodeFile: filename to store the nodal solution variables when NodeArray included in the network trend variable list

EDType: various entrainment/deposition options:

```
= Whalley:    Whalley et al. (1974)
= Hewitt:    Whalley and Hewitt (1978)
= ASSERT:    Tahir et al. (1987)
= Govan:     Hewitt and Govan (1990)
= Saito:     Saito et al. (1978)
= Sugawara:  Sugawara (1990)
```

Node_Type: various triangular solution options, used to solve the interfacial shear stress, liquid film thickness, and film flow:

```
= Universal:  universal velocity
= Empirical:  approximate thick-film
= Integral:   shear stress integration
```

NodeArray: nodal solution variables:

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
p	: pressure [Pa]	: Float	: exec
h	: enthalpy [J/kg]	: Float	: exec
T	: temperature [oC]	: Float	: exec
G	: mass velocity [kg/m2-s]	: Float	: exec
G1	: liquid mass velocity [kg/m2-s]	: Float	: exec
Gg	: vapour mass velocity [kg/m2-s]	: Float	: exec
u	: mass-average velocity [m/s]	: Float	: exec
u1	: liquid mass-average velocity [m/s]	: Float	: exec
ug	: vapour mass-average velocity [m/s]	: Float	: exec
uu	: momentum-average velocity [m/s]	: Float	: exec
dp_by_ds	: total pressure gradient [Pa/m]	: Float	: exec
dGg_by_ds	: vapour mass velocity gradient [kg/m3-s]	: Float	: exec
duu_by_ds	: mixture mom. velocity gradient [1/s]	: Float	: exec
dil_by_dp	: liq. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
dig_by_dp	: vap. enthalpy-press. gradient [J/kg-Pa]	: Float	: exec
x_T	: thermodynamic quality	: Float	: exec

x	: flowing quality	: Float	: exec
alpha	: void fraction	: Float	: exec
rho	: density [kg/m3]	: Float	: exec
slip	: gas-to-liquid slip ratio	: Float	: exec
f_tp	: two-phase friction factor	: Float	: exec
tau_w	: wall shear stress [Pa]	: Float	: exec
q	: heat flux [W/m2]	: Float	: exec
Gamma_vap	: evaporation rate [kg/m3-s]	: Float	: exec
Gamma_lg	: liquid flash rate [kg/m3-s]	: Float	: exec
Gamma_gl	: vapour condense rate [kg/m3-s]	: Float	: exec
GLF	: liquid film mass velocity [kg/m2-s]	: Float	: exec
GLE	: entrained liquid mass velocity [kg/m2-s]	: Float	: exec
u_c	: core mass-average velocity [m/s]	: Float	: exec
ulF	: liquid film mass-average velocity [m/s]	: Float	: exec
ulE	: droplet mass-average velocity [m/s]	: Float	: exec
Gamma_D	: volumetric deposition rate [kg/m3-s]	: Float	: exec
Gamma_E	: volumetric entrainment rate [kg/m3-s]	: Float	: exec
Gamma_Fg	: volumetric film flash rate [kg/m3-s]	: Float	: exec
Gamma_Eg	: volumetric droplet flash rate [kg/m3-s]	: Float	: exec
dGLE_by_ds	: entrained liquid gradient [kg/m3-s]	: Float	: exec
dGuc_by_ds	: core momentum gradient [N/m3]	: Float	: exec
x_c	: core flowing quality	: Float	: exec
alpha_gc	: core gas void fraction	: Float	: exec
alpha_c	: core void fraction	: Float	: exec
rho_c	: core density [kg/m3]	: Float	: exec
C	: core droplet concentration [kg/m3]	: Float	: exec
k	: droplet mass transfer coefficient [m/s]	: Float	: exec
delta	: liquid film thickness	: Float	: exec
tau_i	: interfacial shear stress [Pa]	: Float	: exec

Default Configuration

steady-state two-phase annular pipe			
Fluid	: name of fluid (property)	: water	: <Text> : <build>
d	: pipe diameter [m]	: 0.0100	: <Float> : <config>
L	: pipe length [m]	: 1.0000	: <Float> : <config>
Zi	: inlet elevation [m]	: 0.000	: <Float> : <config>
Zo	: outlet elevation [m]	: 0.000	: <Float> : <config>
NNodes	: no. of fluid nodes [2-500]	: 25	: <Integer> : <build>
Solve_Type	: FD numerical sol'n method	: Step1	: <Mode> : <config>
NodeFile	: File to store Nodal variable values	: Node	: <Text> : <config>
EDType	: entrainment/deposition model option	: Whalley	: <Mode> : <build>
Node_Type	: annular node type option	: Empirical	: <Mode> : <build>
GLE_frac	: entrainment fraction at ONAF (0-1)	: 0.9900	: <Float> : <config>
x_onaf	: flowing quality at ONAF (0-1)	: 0.0100	: <Float> : <config>
K_strip	: liquid-film stripping coeff (0-1)	: 0.0000	: <Float> : <config>
K_depos	: liquid-droplet impingement coeff (0-1)	: 0.0000	: <Float> : <config>
Co	: deposition enhancement constant	: 0.0000e0	: <Float> : <config>
a	: deposition enhancement decay rate	: 0.0000e0	: <Float> : <config>

Object: TPInput
Type: Element
Related: <none>

Icon:



Purpose: two-phase flow input specifier

Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
Mode	: inlet specification	: <Mode>	: <build>
p	: thermodynamic pressure [Pa]	: <Float>	: <input>
W	: total flow rate [kg/s]	: <Float>	: <input>
x	: flowing quality	: <Float>	: <input>
T	: fluid temperature [oC]	: <Float>	: <input>
Hin	: fluid enthalpy [J/kg]	: <Float>	: <input>
Hsub	: fluid subcooling [J/kg]	: <Float>	: <input>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Output	0	pout	TPStream	outlet two-phase flow stream

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport fluid properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Mode: various methods of specifying the fluid enthalpy:

=	temperature:	fluid temperature, including subcooled temperatures
=	quality:	thermodynamic or flow quality, including subcooling
=	enthalpy:	fluid enthalpy
=	subcooling:	amount of enthalpy subcooling

The associated input variable (T, x, Hin, Hsub) is used in both the input and trend variable list

Default Configuration

Homogeneous Two-Phase Flow Input			
Fluid	: name of fluid (property)	: steam	: <Text> : <build>
Mode	: inlet specification	: quality	: <Mode> : <build>

Object: TPAInput
Type: Element
Related: TPIInput

Icon:



Purpose: two-phase annular flow input specifier

Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Fluid	: name of fluid (property)	: <Text>	: <build>
Mode	: inlet specification	: <Mode>	: <build>
p	: thermodynamic pressure [Pa]	: <Float>	: <input>
W	: total flow rate [kg/s]	: <Float>	: <input>
x	: flowing quality	: <Float>	: <input>
T	: fluid temperature [oC]	: <Float>	: <input>
Hin	: fluid enthalpy [J/kg]	: <Float>	: <input>
Hsub	: fluid subcooling [J/kg]	: <Float>	: <input>
WLF	: liquid film flow rate [kg/s]	: <Float>	: <input>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Output	0	pout	TPAStream	outlet annular flow two-phase stream

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport fluid properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Mode: various methods of specifying the fluid enthalpy:

=	temperature:	fluid temperature, including subcooled temperatures
=	quality:	thermodynamic or flow quality, including subcooling
=	enthalpy:	fluid enthalpy
=	subcooling:	amount of enthalpy subcooling

The associated input variable (T, x, Hin, Hsub) is used in both the input and trend variable list. For all cases of subcooled inlet, the liquid-film flow rate (WLF) is reset to zero.

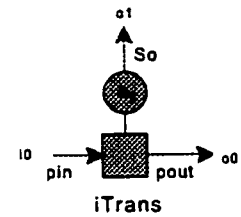
Default Configuration

Annular Two-Phase Flow Input			
Fluid	: name of fluid (property)	: steam	: <Text> : <build>
Mode	: inlet specification	: quality	: <Mode> : <build>

Object: iTrans
Type: Element
Related: <none>

Purpose: enthalpy flow transmitter

Icon:



Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	<u>Status</u>
Stream	: Type of Stream connection	: <Mode>	: <build>
p	: pressure [Pa]	: <Float>	: <exec>
W	: total flow rate [kg/s]	: <Float>	: <exec>
h	: enthalpy [J/kg]	: <Float>	: <exec>
T	: temperature [oC]	: <Float>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	pin	<user-defined>	inlet process stream
Output	0	pout	<user-defined>	outlet process stream
Output	1	So	AStream	enthalpy output signal

Details

Stream the name of the stream to which the enthalpy transmitter is to be attached to:

= PStream: single-phase process stream
 = TPStream: two-phase (two-fluid) stream
 = TPASStream: two-phase (three-fluid stream)

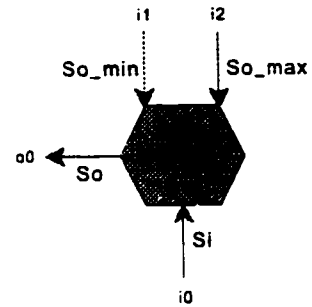
Default Configuration

enthalpy flow transmitter
 Stream : Type of Stream connection : PStream : <Mode> : <build>

Object: Iterator
Type: Element
Related: <none>

Purpose: Secant solution iteration block

Icon:



Variables

<u>Name</u>	<u>Desc</u>	<u>Type</u>	
<u>Status</u>			
iniOut	: initial output signal	: <Float>	: <config>
Sp	: controller set point	: <Float>	: <input>
minOut	: minimum output signal	: <Float>	: <exec>
maxOut	: maximum output signal	: <Float>	: <exec>

Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si	AStream	input signal
Input	1	So_min	AStream	minimum output signal
Input	2	So_max	AStream	maximum output signal
Output	0	So	AStream	output signal

Details

Secant solution:

$$e = S_p - S_i$$

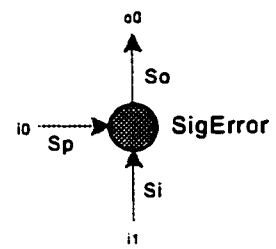
$$S_o^{(n)} = \frac{S_o^{(n-1)} e^{(n-2)} - S_o^{(n-2)} e^{(n-1)}}{e^{(n-2)} - e^{(n-1)}}$$

Default Configuration

Secant Solution Iterator
 iniOut : initial output signal : 100.0000e0 : <Float> : <config>

Object: SigError
Type: Element
Related: <none>
Purpose: Error signal generator

Icon:



Variables <none>

Streams

<u>I/C</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Sp	AStream	set-point signal
Input	1	Si	AStream	input signal
Output	0	So	AStream	output signal

Details

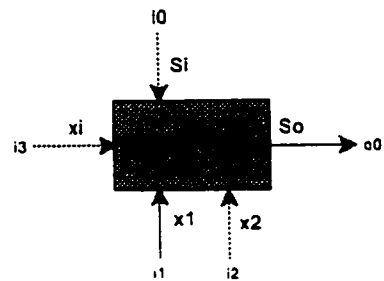
Output signal:

$$S_o = S_p - S_i$$

Object: SigRatio
Type: Element
Related: <none>

Icon:

Purpose: Condition the output signal using the ratio of three external signals and an input signal



Variables <none>

Streams

<u>I/C</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si	AStream	input signal
Input	1	x1	AStream	reference signal #1
Input	2	x2	AStream	reference signal #2
Input	3	xi	AStream	reference signal #3
Output	0	So	AStream	output signal

Details

Output signal:

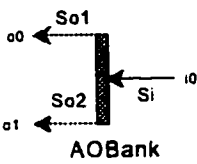
$$S_o = \frac{(x_i - x_1)}{(x_2 - x_1)} S_i$$

Object: AOBank
Type: Element
Related: <none>

Purpose: distribute an input signal to two output signals of the the same value

Variables <none>

Icon:



Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	S_i	AStream	input signal
Output	0	S_{o1}	AStream	output signal #1
Output	1	S_{o2}	AStream	output signal #2

Details

Output signal:

$$S_{o1} = S_{o2} = S_i$$

Object: SigJctx10
Type: Element
Related: AOBank

Purpose: distribute an input signal to a number of connected output signals of the the same value

Variables <none>

Streams

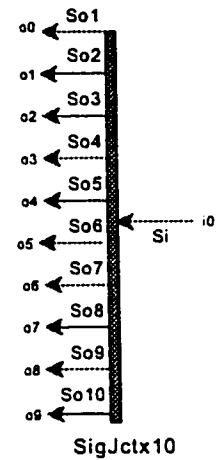
<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si	AStream	input signal
Output	0	So1	AStream	output signal #1
Output	1	So2	AStream	output signal #2
Output	2	So3	AStream	output signal #3
	.			.
Output	9	So10	AStream	output signal #10

Details

Output signal:

$$S_{o1} = S_{o2} = S_{o3} \dots = S_{o10} = S_i$$

Icon:



Object: LowSig
Type: Element
Related: <none>

Purpose: select the lower of two analog signals

Variables <none>

Streams

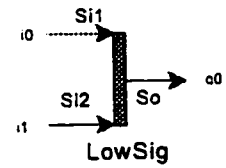
<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si1	ASStream	input signal #1
Input	1	Si2	ASStream	input signal #2
Output	0	So1	ASStream	output signal

Details

Output signal:

$$S_o = \min(S_{i1}, S_{i2})$$

Icon:



Object: LowSig10
Type: Element
Related: LowSig

Purpose: select the lower of 10 analog signals

Variables <none>

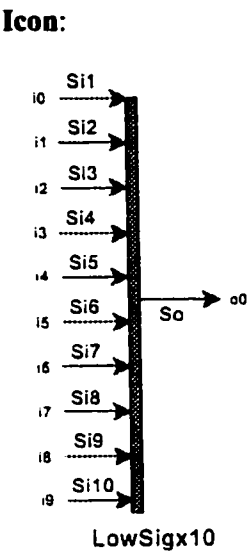
Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si1	AStream	input signal #1
Input	1	Si2	AStream	input signal #2
Input	2	Si3	AStream	input signal #3
Input	9	Si10	AStream	input signal #10
Output	0	So	AStream	output signal

Details

Output signal:

$$S_o = \min(S_{i1}, S_{i2}, \dots, S_{i10})$$

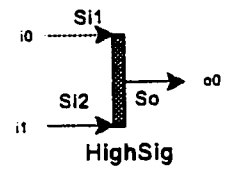


Object: HighSig
Type: Element
Related: <none>

Purpose: select the higher of two analog signals

Variables <none>

Icon:



Streams

<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si1	AStream	input signal #1
Input	1	Si2	AStream	input signal #2
Output	0	So1	AStream	output signal

Details

Output signal:

$$S_o = \max(S_{i1}, S_{i2})$$

Object: HighSig10
Type: Element
Related: HighSig

Purpose: select the higher of 10 analog signals

Variables <none>

Streams

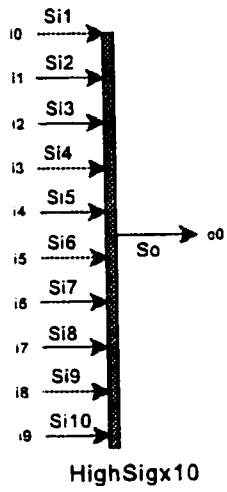
<u>I/O</u>	<u>Num</u>	<u>Label</u>	<u>Name</u>	<u>Desc</u>
Input	0	Si1	ASStream	input signal #1
Input	1	Si2	ASStream	input signal #2
Input	2	Si3	ASStream	input signal #3
				.
Input	9	Si10	ASStream	input signal #10
Output	0	So	ASStream	output signal

Details

Output signal:

$$S_o = \max(S_{i1}, S_{i2}, ..., S_{i10})$$

Icon:



Object: CHFBowring
Type: Element
Related: <none>

Purpose: CHF correlation by Bowring (1972), formulated to compute CHF based on inlet conditions and heated length (steam only)

Variables

Name	Desc	Type	Status
p	: pressure [Pa]	: <Float>	: <input>
G	: mass flux [kg/m ² -s]	: <Float>	: <input>
d	: pipe diameter [m]	: <Float>	: <input>
L	: verical pipe length [m]	: <Float>	: <input>
Hsub	: inlet subcooling [J/kg]	: <Float>	: <input>
Qc	: critical Heat Flux [W/m ²]	: <Float>	: <exec>
Xc	: critical quality [0-1]	: <Float>	: <exec>

Streams <none>

Object: CHFKatto
Type: Element
Related: <none>

Purpose: CHF correlation by Katto and Ohne (1984), formulated to compute CHF based on inlet conditions and heated length (any fluid)

Variables

Name	Desc	Type	Status
P	: pressure [Pa]	: <Float>	: <input>
G	: mass flux [kg/m ² -s]	: <Float>	: <input>
d	: pipe diameter [m]	: <Float>	: <input>
L	: vertical pipe length [m]	: <Float>	: <input>
Hsub	: inlet subcooling [J/kg]	: <Float>	: <input>
Qc	: critical Heat Flux [W/m ²]	: <Float>	: <exec>
Xc	: critical quality [0-1]	: <Float>	: <exec>
Fluid	: name of Operating Fluid	: <Text>	: <build>

Streams <none>

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Object: CHFAeclUo
Type: Element
Related: <none>

Purpose: 1994 AECL-UO CHF look-up table, formulated to compute CHF based on inlet conditions and heated length

Variables

Name	Desc	Type	Status
p	: pressure [Pa]	: <Float>	: <input>
G	: mass flux [kg/m ² -s]	: <Float>	: <input>
d	: pipe diameter [m]	: <Float>	: <input>
L	: vertical pipe length [m]	: <Float>	: <input>
Hsub	: inlet subcooling [J/kg]	: <Float>	: <input>
Qc	: critical Heat Flux [W/m ²]	: <Float>	: <exec>
Xc	: critical quality [0-1]	: <Float>	: <exec>
Fluid	: name of Operating Fluid	: <Text>	: <build>

Streams <none>

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport properties (Fluid-2.dat)—see the TPSatTable1 and TPSatTable2 data objects

Also requires the presence of the CHF look-up table (CHFtable.dat) input as a text file for the Table3D data object.

Object: CHFPoly
Type: Element
Related: <none>

Purpose: Generalized CHF correlation, formulated to compute CHF based on inlet conditions and heated length

Variables

Name	Desc	Type	Status
p	: pressure [Pa]	: <Float>	: <input>
G	: mass flux [kg/m2-s]	: <Float>	: <input>
d	: pipe diameter [m]	: <Float>	: <input>
L	: vertical pipe length [m]	: <Float>	: <input>
Hsub	: inlet subcooling [J/kg]	: <Float>	: <input>
Qc	: critical Heat Flux [W/m2]	: <Float>	: <exec>
Xc	: critical quality [0-1]	: <Float>	: <exec>
Fluid	: name of Operating Fluid	: <Text>	: <build>
p1	: correlation constant #1	: <Float>	: <config>
p2	: correlation constant #2	: <Float>	: <config>
p3	: correlation constant #3	: <Float>	: <config>
p4	: correlation constant #4	: <Float>	: <config>
p5	: correlation constant #5	: <Float>	: <config>
p6	: correlation constant #6	: <Float>	: <config>
p7	: correlation constant #7	: <Float>	: <config>
Tin	: inlet fluid temp. (oC)	: <Float>	: <exec>

Streams <none>

Details

Fluid the name of two text-files: one containing the thermodynamic fluid properties (Fluid-1.dat), the other containing the transport properties (Fluid-2.dat) (see the TPSatTable1 and TPSatTable2 data objects)

Correlation:

$$q_c = p_1 P^{p_2} G^{p_3} + p_4 P^{p_4} G^{p_5} X_c^{p_7}$$

- Notes:**
1. units of (P, G) are MPa and Mg/m²-s, respectively, for the correlation so that a unit conversion precedes the use of the correlation by CHFPoly,
 3. make sure (P, G) are in the correlation units when deriving your own constants (p₁-p₇).

C.3.2 Stream Objects

Object: PStream
Type: Stream
Related: <none>

Purpose: transfer single-phase flow parameters between elements

Variables

Name	Desc	Type	Status
W	: flow rate [kg/s]	: <Float>	: <exec>
p	: pressure [Pa]	: <Float>	: <exec>
i	: enthalpy [J/kg]	: <Float>	: <exec>
T	: temperature [oC]	: <Float>	: <exec>

Object: TPStream
Type: Stream
Related: PStream

Purpose: transfer two-phase flow parameters between elements

Variables

Name	Desc	Type	Status
W	: total flow rate [kg/s]	: <Float>	: <exec>
p	: pressure [Pa]	: <Float>	: <exec>
i	: enthalpy [J/kg]	: <Float>	: <exec>
T	: temperature [oC]	: <Float>	: <exec>
Wl	: liquid flow rate [kg/s]	: <Float>	: <exec>
Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>

Object: TPAStream
Type: Stream
Related: PStream
 TPStream

Purpose: transfer two-phase annular flow parameters between elements

Variables

Name	Desc	Type	Status
W	: total flow rate [kg/s]	: <Float>	: <exec>
p	: pressure [Pa]	: <Float>	: <exec>
i	: enthalpy [J/kg]	: <Float>	: <exec>
T	: temperature [oC]	: <Float>	: <exec>
Wl	: liquid flow rate [kg/s]	: <Float>	: <exec>
Wg	: vapour flow rate [kg/s]	: <Float>	: <exec>
WlF	: liquid film flow rate [kg/s]	: <Float>	: <exec>
WlE	: entrained liquid flow rate [kg/s]	: <Float>	: <exec>

Object: AStream
Type: Stream
Related: <none>

Purpose: transfer a single-value (analog) between elements

Variables

Name	Desc	Type	Status
value	: Analog Stream value	: <Float>	: <exec>

C.3.3 Data Objects

Object: CPPProp
Type: Data
Related: <none>

Purpose: contains a standard set of constant-property fluid parameters

Variables

Name	Desc	Type	Status
rho	: density [kg/m3]	: <Float>	: <build>
mu	: dynamic viscosity [kg/m-s]	: <Float>	: <build>
Cp	: specific heat [J/kg-oC]	: <Float>	: <build>
K	: thermal conductivity [W/m-oC]	: <Float>	: <build>

Example

```
constant properties of water at T = 10oC
rho      : density [kg/m3]           : 999.2000e0
mu       : dynamic viscosity [kg/m-s] : 1.3100e-3
Cp       : specific heat [J/kg-oC]    : 4.1950e3
K        : thermal conductivity [W/m-oC] : 0.5850e0
```


Object: TPSatTable1
Type: Data
Related: Table1D

Purpose: 1-D multi-variable look-up table containing saturated thermodynamic fluid properties

Example: R-134a-1.dat

Thermodynamic Properties of Saturated Freon R-134A

P	Tsat	v_f	v_g	h_f	h_fg	h_g	s_f	s_fg	s_g
50699.75	-40.0	7.057617E-04	3.586259E-01	0.00E+00	223286.1	223286.1	0.00E+00	957.6931	957.6931
67068.60	-35.0	7.169280E-04	2.827749E-01	5821.551	220632.1	226453.7	24.44489	926.4419	950.8868
85703.23	-30.0	7.217917E-04	2.252942E-01	11840.20	217748.0	229588.2	48.69506	895.5297	944.2247
107519.6	-25.0	7.301217E-04	1.812512E-01	17785.97	214906.9	232692.9	71.67426	866.0364	937.7106
133366.2	-20.0	7.369887E-04	1.471509E-01	23748.60	212020.5	235769.2	93.81236	837.5294	931.3417
164032.9	-15.0	7.447021E-04	1.204844E-01	29794.96	209022.0	238817.0	115.4172	809.6921	925.1093
200261.7	-10.0	7.533119E-04	9.943394E-02	35971.66	205863.0	241834.7	136.6964	782.3030	918.9994
242756.5	-5.0	7.627606E-04	8.246616E-02	42307.77	202511.3	244819.0	157.7765	755.2164	912.9929
292193.5	0.0	7.729513E-04	6.919488E-02	48817.40	198947.8	247765.2	178.7201	728.3464	907.0665
349231.4	5.0	7.837780E-04	5.828315E-02	55502.44	195164.3	250666.7	199.5414	701.6512	901.1926
414521.6	10.0	7.951426E-04	4.937480E-02	62355.14	191160.5	253515.6	220.2195	675.1208	895.3403
2630054.0	80.0	1.073261E-03	6.458320E-03	171460.3	106567.4	278027.6	485.5168	301.7623	787.2792
2923605.0	85.0	1.126974E-03	5.513917E-03	181495.5	95562.53	277058.0	506.7584	266.8226	773.5810
3243176.0	90.0	1.196377E-03	4.644097E-03	192435.8	82027.86	274463.7	529.9073	225.8787	755.7860
3590858.0	95.0	1.288538E-03	3.808609E-03	204516.5	64787.65	269304.2	555.5251	175.9816	731.5067
3968919.0	100.0	1.415151E-03	2.826390E-03	218011.3	42392.28	260403.6	584.2458	113.6065	697.8524
4064043.0	101.1	2.012783E-03	2.012783E-03	251469.7	0.00E+00	251469.7	800.4443	0.00E+00	800.4443

Object: TPSatTable2
Type: Data
Related: Table1D

Purpose: 1-D multi-variable look-up table containing saturated transport fluid properties

Example: R134a-2.dat

```

Transport Properties of Saturated Freon R-134A
p      Tsat   mu_f      Cp_f      K_f      mu_g      Cp_g      K_g      sigma
50698.75 -40.0 4.729021E-04 1129.369 1.089680E-01 7.971560E-06 743.0391 7.555834E-03 1.760851E-02
67068.60 -35.0 4.384850E-04 1153.564 1.068516E-01 8.639793E-06 757.2891 8.053966E-03 1.683023E-02
85703.23 -30.0 4.076264E-04 1177.975 1.047350E-01 9.205883E-06 773.2234 8.547775E-03 1.606672E-02
107519.6 -25.0 3.798463E-04 1202.374 1.026185E-01 9.680862E-06 790.4764 9.039141E-03 1.531624E-02
133366.2 -20.0 3.547418E-04 1226.590 1.005025E-01 1.007576E-05 808.7717 9.528990E-03 1.457728E-02
164032.9 -15.0 3.319734E-04 1250.505 9.838714E-02 1.040162E-05 827.9220 1.001778E-02 1.384855E-02
200261.7 -10.0 3.112528E-04 1274.056 9.627287E-02 1.066947E-05 847.8296 1.050593E-02 1.312896E-02
242756.5 -5.00 2.923348E-04 1297.236 9.416000E-02 1.089034E-05 868.4860 1.099415E-02 1.241766E-02
292193.5 0.00 2.750095E-04 1320.090 9.204891E-02 1.107527E-05 889.9720 1.148367E-02 1.171400E-02
349231.4 5.00 2.590969E-04 1342.719 8.994004E-02 1.123528E-05 912.4576 1.197638E-02 1.101755E-02
414521.6 10.00 2.444416E-04 1365.277 8.783384E-02 1.138142E-05 936.2022 1.247470E-02 1.032811E-02

2630054. 80.00 1.193829E-04 2009.427 5.902712E-02 1.814896E-05 2024.568 2.280091E-02 1.648895E-03
2923605. 85.00 1.139590E-04 2198.392 5.706127E-02 1.941094E-05 2399.403 2.604149E-02 1.152384E-03
3243176. 90.00 1.088267E-04 2558.451 5.511603E-02 2.083559E-05 3062.931 3.152907E-02 6.998272E-04
3590858. 95.00 1.039660E-04 3423.144 5.319358E-02 2.243392E-05 4481.439 4.077645E-02 3.086484E-04
4064043. 101.1 5.600073E-05 30569.84 3.549817E-02 3.401540E-05 30569.84 3.549817E-02 8.977900E-09
  
```

Object: Table3D
Type: Data
Related: Table1D
Table2D

Purpose: 3-D single-variable look-up table

Example: Chftable.dat

```
1994 ARRL-UE 1-D CHF look-up table
3 xc p qc
- .50 - .40 - .30 - .20 - .10 - .05 .00 .05 .10 .15 .20 .25 .30 .35 .40 .45 .50 .60 .70 .80 .90 1.00
100 0 6606 5931 5779 5230 4593 3419 2247 1066 421 298 207 158 142 110 120 111 103 99 84 74 68 67 0
100 50 7125 6618 6468 5729 4940 3881 2618 1526 787 754 681 615 620 609 600 591 582 470 513 401 288 253 0
100 100 7920 7291 7039 6140 5204 4124 2942 1747 1159 1137 1123 1107 1093 1084 1078 1070 1060 1017 961 747 550 416 0
100 150 8359 7581 7195 6216 5232 4204 3475 2792 1691 1465 1451 1598 1534 1502 1475 1378 1243 1151 979 751 626 550 0
100 200 8504 7663 7455 6223 5261 4305 3768 3204 2040 1887 1881 1875 1798 1725 1714 1615 1486 1463 1188 752 558 415 0
100 250 8850 7809 7442 6261 5307 4426 4129 3527 2528 2286 2280 2211 2129 2028 1870 1655 1612 1631 1434 850 428 206 0
100 300 8850 7809 7442 6261 5307 4426 4129 3527 2528 2286 2280 2211 2129 2028 1870 1655 1612 1631 1434 850 428 206 0
100 350 9417 8302 7561 6292 5432 4714 4216 3606 2652 2427 2405 2292 2195 2084 1905 1657 1656 1856 1597 819 148 109 0
100 400 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 450 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 500 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 550 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 600 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 650 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 700 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 750 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 800 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 850 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 900 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 950 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
100 1000 10635 9440 8014 6306 5434 4719 4218 3614 2693 2487 2466 2333 2215 2094 1950 1918 1889 1815 1466 474 181 62 0
```

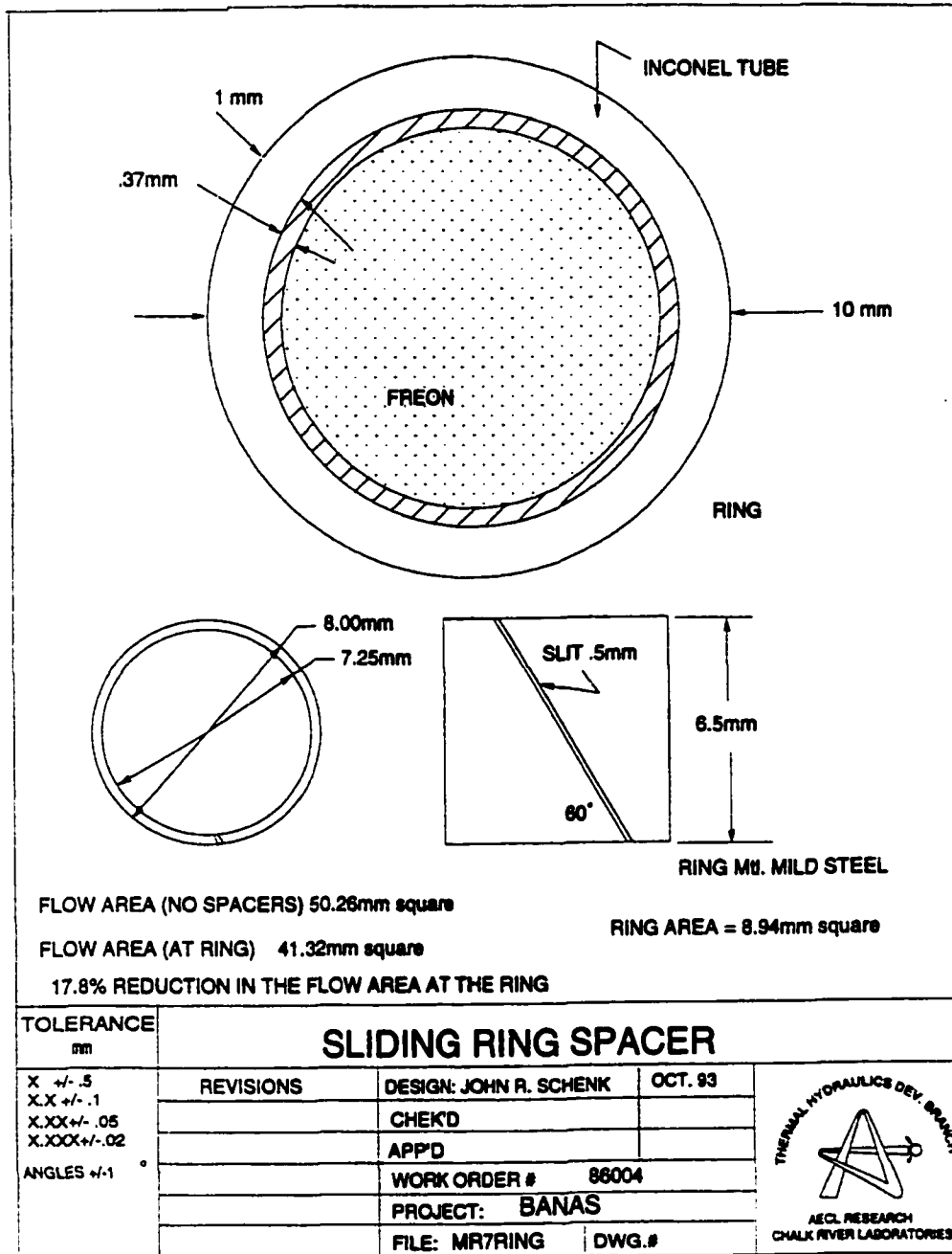
Appendix D: Flow Obstruction Specifications

D.1 18% Ring Flow Obstruction D-1

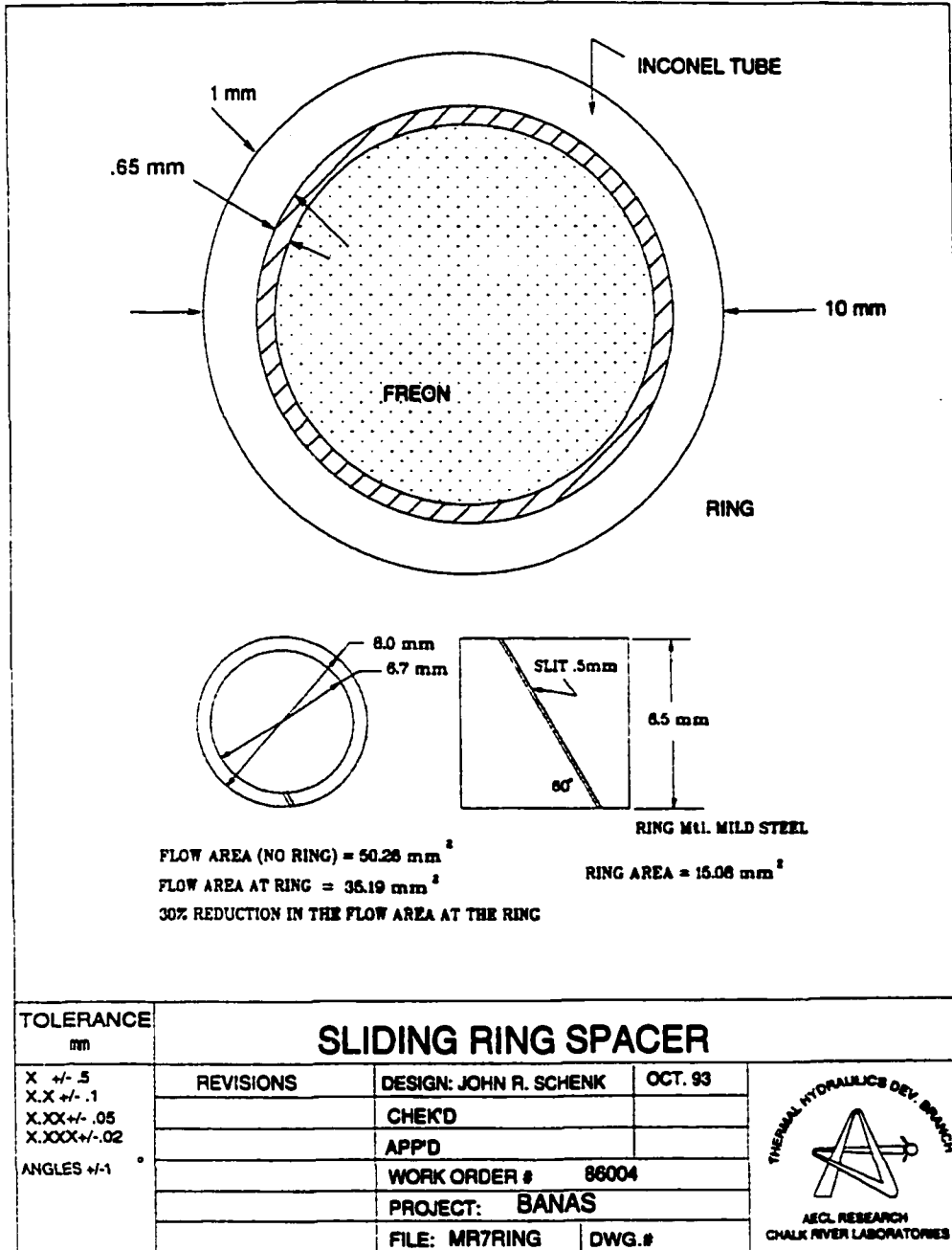
D.2 30% Ring-Type Flow Obstruction D-2

D.3 18% Block-Type Flow Obstruction D-3

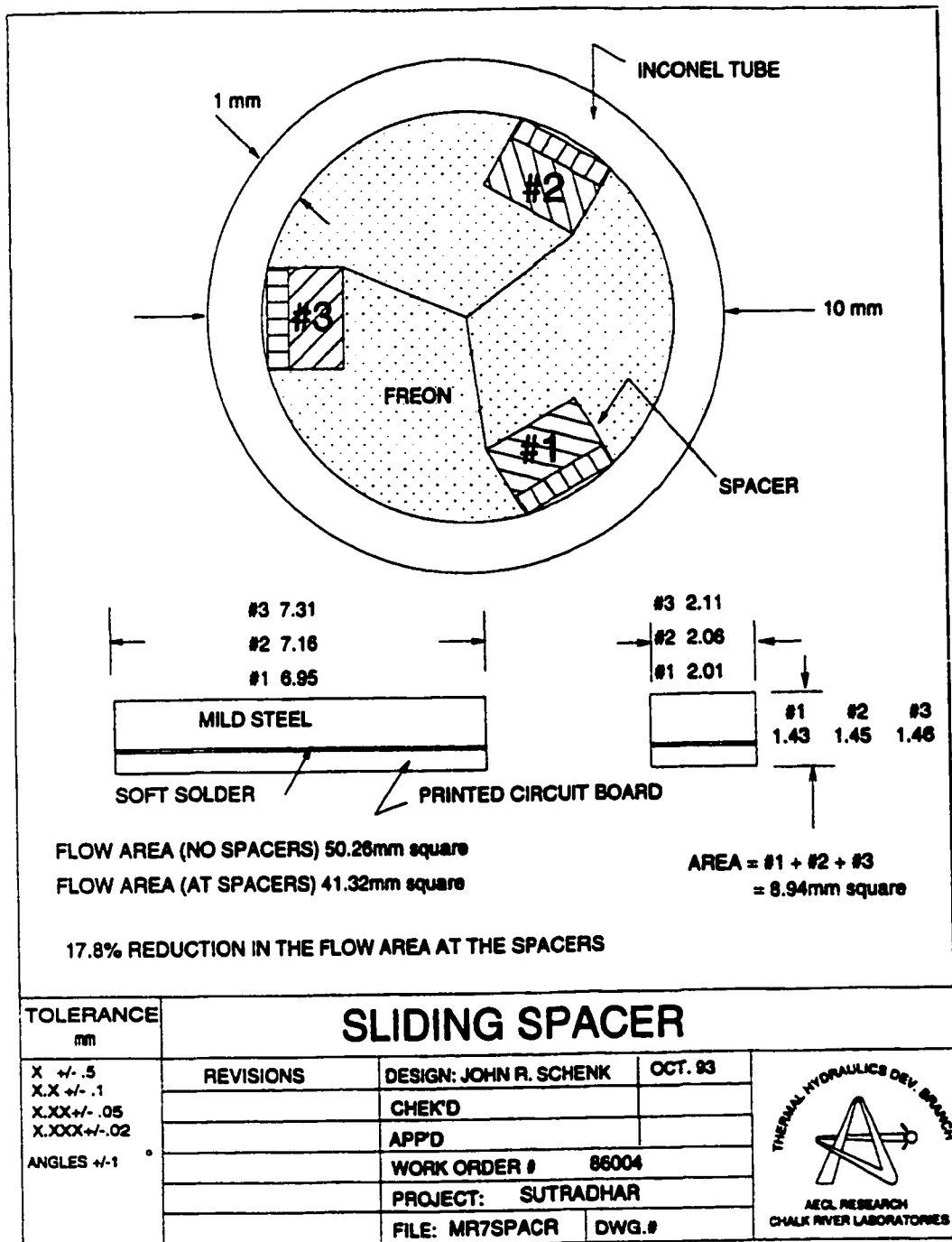
D.1 18% Ring Flow Obstruction



D.2 30% Ring-Type Flow Obstruction



D.3 18% Block-Type Flow Obstruction





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Note : office located at 'W.R. Davis Engineering Ltd.', not 'University of Ottawa'

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k-Type Roughness

Clauser (1956) proposed a downward shift parameter for modifying the logarithmic overlap velocity profile to account for the effect of a repeated roughness with an average height (k):

$$u^+ = \frac{1}{K} \ln y^+ + B - \Delta B(k^+) \quad (2.15)$$

$$k^+ = \frac{ku_\tau}{\nu}$$

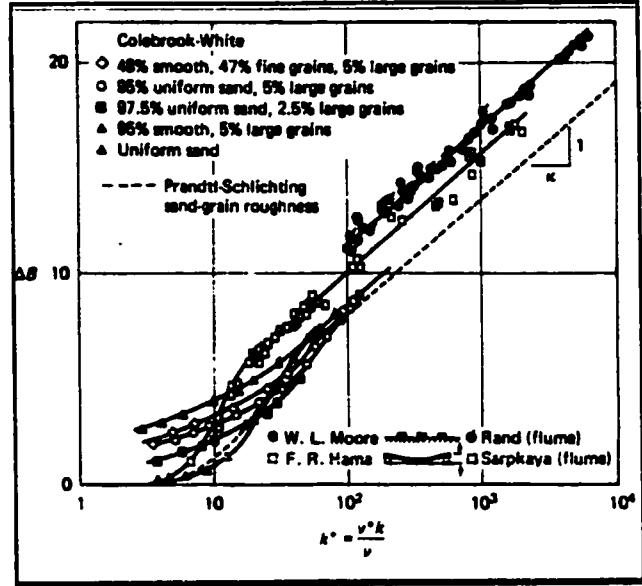


Figure 2.3: Clauser (1956) profile-shift parameter $B(k^+)$ (White, 1991).

Unfortunately, B is not a unique function of k^+ but varies with the roughness geometry, as illustrated in Figure 2.3. The curves indicate that for $k^+ > 60$, the relation is logarithmic (i.e., no viscosity effect) and this flow has been termed fully rough.

White (1991) curve-fitted the following relation to the sand-grain roughness data:

$$\Delta B_{\text{sand}} \approx \frac{1}{K} \ln(1 + 0.3 k^+) \quad (2.16)$$

When substituted into Equation (2.15), the following velocity profile for fully-rough k -type flow is obtained:

$$u^+ = \frac{1}{K} \ln y^+ + B - \frac{1}{K} \ln(1 + 0.3 k^+) \quad (2.17)$$

$$\approx \frac{1}{K} \ln \left(\frac{y}{k} \right) + 8.5, \quad k^+ > 60$$

17 September 1999

Our Ref: I/Whalley/AMIZ/sp

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CHEMICAL ENGINEERING SCIENCE, Vol 28, pp 974-975, 1973, Hutchinson, "A possible characterization..." 1 Figure only
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